Towards Using Advanced Analytics for Port Performance Management

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Abstract

Ports are important elements in the maritime transport system and thereby contribute in the development of the world's economy. They can be poles of growth if they are well managed and supervised. Their performance management approach can affect significantly their competitiveness. This paper tries to enlighten on the complexity of the port system and the difficulty to set a single performance management model. It presents port's definitions and classifications, discusses a selection of port performance approaches and their limits, and highlight the necessity to use full potential of advanced analytics for a better definition of port performance evaluation program.

Keywords
Port Performance, Port Management, Port System, Analytics, Optimization and Simulation.

1. Introduction

Today, interdependency between the maritime transport and the world economy is apparent, the large volume of the international trade (more than 80%) performed by sea being its most obvious illustration. Evidently, understanding and improving the maritime transport network will allow a better assessment of the world's economic situation.

One of the core elements in maritime transport system are ports. They are focal points handling intermodal transport connections, traditionally defined as sub-systems of the maritime industry or linking nodes in the sea network (Bichou (2014), Talley (2009)). However, the complexity of ports, which is a result of their several components and their interactions, can turn them into bottlenecks. In order to support a port in its mission to ensure social and economic growth, its performance strategy has to be carefully defined. Actually, port performance management is a challenge for its managers as well as a Government concern as efficient ports are key to economic development (Brooks 2006). Ports are facing many challenges whether associated to their complex structure or to the increasing traffic. According to the projections of the United Nations Conference on Trade and Development (UNCTAD/RMT/2018), world seaborne trade will expand at a compound annual growth of 3.8 per cent during the period 2018-2023, making ports more and more sophisticated.

There are many approaches to ports classification (Bichou 2014) and definition, consequently the literature on port performance management offers several diverging approaches and models, and presents a range of tools and methods (Bichou 2006). Brooks and Pallis (2008) reported that the performance of ports has been extensively evaluated using efficiency criteria with an increasing employment of Data Envelopment Analysis (DEA) in ports production analysis, also a particular focus is on studying container ports efficiency (Brooks 2006). Furthermore, benchmarking of ports performance should consider groups of similar ports (Brooks 2006). However, there is an issue to determine the benchmark elements in a convoluted port system, that is the reason behind addressing ports similarities from a geographical point of view only (Bichou 2006), which is an elementary dimension.

Despite the variety of port performance measurement models, many gaps have been detected providing some scopes for more development. The widely used approach to port performance assessment, i.e. internal and external performance evaluation mostly defined as efficiency and effectiveness, has to be revisited with more contribution in quality measurement. Also, the scope of studies should consider different classification facets of ports (e.g. bulk private port, liquid landlord port) instead of limiting the scale to the type of cargos handled by the port (or ports) of interest (e.g. container, bulk). Another point is that the performance assessment approach for a port should reflect its characteristics, given that ports have different objectives from each other (e.g. commercial profit, regional development).

When seeking the appropriate way to the port performance analysis, a necessary condition is to analyze the factors behind its positive and negative results. To this end, many simulation models have been developed for different purposes (Dragović et al. (2016), Crainic et al. (2017)). Furthermore, Ports are critical hubs within the trade network full of challenges and uncertainties that managers could overcome easily if they are equipped with predictive and prescriptive analytics to envision and manage unfavorable situations.

Our goal is to look into the performance management literature of ports and highlight the possible contribution of analytics to help building more suitable models. To that end, we started by describing ports as complex systems and identifying their main actors in section 2. Section 3 presents the main approaches and some of their limits. Section 4 is about the important role of analytics in the optimization of the port system. Finally, section 5 is a recap of the conclusions made through the paper.

2. Ports as complex systems

Ports are areas shared by many actors with multiple dimensions, the definition of which is not always consistent through the literature. The objective of this chapter is to show the complex character of ports by describing their various components. Then, it features the important role of the port authority to enhance port performance. Finally, it provides an overview of the port's actors through the definition of the Port Community System.

2.1 Ports description

There is no single definition of ports, yet it is agreed that they play an important role in international trade. A port can be commonly defined as (Talley 2009) "a place at which the transfer of cargo and passengers to and from waterways and shores occurs. The transfers are made to and from vessels. The port may be a cargo port (handling only the transfer of cargo), a passenger port (handling only the transfer of passengers), or a combination cargo/passenger port (handling the transfer of both cargo and passengers)". They are also considered as nodes in a transportation network linking the movement of cargo and passengers.

Ports are not stand-alone points handling ships but they are crucial links within the supply chain. Their complexity has been discussed in many works. For instance, in his proposed simulation model for port activity, Hassan (1993) considered ports "as a complex system containing several entities with interfering attributes". First, he defined three major categories of port's entities: physical, financial and other entities. Table 1 shows in detail the 29 identified entities. Furthermore, he developed the attributes (factors and parameters) for each entity and displayed an exhaustive network demonstrating the complex aspect of port system. Finally, he suggested a subdivision of port operations into four categories to cast light on the complicated interactions between port operations. The first category is Ship Operations including ship arrival, entering anchorage area, assigning pilot and tugboat, passing through the channel, berthing, ship servicing, cargo handling, assigning pilot and tugboat for unberthing, unberthing operation, leaving through the channel, departure. The second category is Cargo-Handling Operations, consisting of opening ship's holds, preparing the ship for unloading, assigning crane to ship, assigning gangs to ship, unloading ship (direct route to railroads, trucks, waterways and pipelines, semi-direct route to berths and indirect route to transfer system). Another category is Warehouse Operations composed of cargo arrival by transfer system to transit sheds, warehouses and yards, assigning unloading equipment, assigning gangs for unloading, assess cargo place, stowage of cargo, cargo dwell time, delivery system to direct route transportation. Inland Transportation is the last category including choosing transportation means type (railways, trucks or barges), assigning loading equipment to transportation means, assigning gangs to transportation means, loading transportation means, leaving the port, distribution to final destination.

Table 1. Major entities in the port system (Hassan 1993)

Physical entities	Financial entities	Other entities
Port space Berths Channels	Cost Revenue	Environments Control and inspection Planning

Warehouses Equipment Technical Ships Cargoes Passengers Manpower Transportation means Gates Companies Agencies Customs		Administration Research and development Manpower training Pollution Security Communications Regulations Operating methods Politics.

The elaborated port's subdivision offered by Hassan (1993), although comprehensive, is not the only approach to define ports. Talley (2009) from his side, proposes for example, a different cargo breakdown to general and bulk cargos, where general cargos are either packaged cargos (containers and breakbulk) or loose (unpackaged) cargos which are neo bulk cargos, and bulk cargos are dry or liquid. For Hassan (1993), cargos are classified into general cargos, bulk cargos, containers and special cargos. This classification is also used to categorize ships according to cargo type, however, vessel groupings used in (UNCTAD/RMT/2018) are oil tankers, bulk carriers, general cargo ships and other ships. A recent economic classification of port's actors is given by Talley (2009) where the entities are either users or service providers. The users are transportation carriers, shippers and passengers. Port service providers include terminal operators and other actors such as shipping agencies, customs, pilotage, towage, third-party logistics firms etc.

Robinson (1976) also considered the port as a system that can be modeled at different levels of complexity through a hierarchy of models for port analysis. He proposed a breakdown of the port system into many sub-systems, and underlined that they cannot operate independently. The System Inputs related to ship and cargo arrivals, is the first sub-system. The second one is Support Systems to the port inputs, composed of pilot, tug, navigation etc. Then comes the Berth Search and Interchange followed by Ship Servicing and Cargo Transfer sub-systems. Other Support Systems made of cargo transfer, storage retrieval and distribution, are placed before the final Ships and Cargos Leave System. Both Robinson (1976) and Hassan (1993) have defended simulation as a powerful tool that captures the high interactivity among the port system components, considering queuing models and analytical methods partial and restricted to simple problems.

Not only are there many ways to think of ports entities, but their classification also is submitted to many approaches. Bichou (2014) recognized the port as "complex and multi-faced" system and mentioned that ports are commonly classified according to the cargo or commodity type they are handling (e.g., dry bulk port, liquid bulk port). Additionally, he summarized the different approaches to port classification that can be performed following ship type (e.g., ferry port, multipurpose port), trade type (e.g., import port, export port), institutional model (e.g., landlord port, tool port), ownership model (e.g., private port, public port), management model (e.g., trust port, autonomous port), organizational model (e.g., centralized port, decentralized port), geographical scope (e.g., coastal port, inland port) and logistics status (e.g., feeder port, transhipment port).

The institutional model adopted by a port is decisive on setting the appropriate strategies for its development. The World Bank (2007) noted four main categories of ports administration models: public service port, tool port, the landlord port and private service port. The service and tool port models revolve around public interest, the landlord port model seeks a trade-off between public and private interests and the private port model focuses on private interests. In short, table 2 express the relation between ownership models (public, private or semi-public) and the above-mentioned institutional models, as reported by World Bank (2007).

Table 2. Basic Port Management Models (World Bank 2007)

Type	Infrastructure	Superstructure	Port labor	Other functions
Public service port	Public	Public	Public	Majority public
Tool port	Public	Public	Private	Public/private

Landlord port	Public	Private	Private	Public/private
Private service port	Private	Private	Private	Majority public

Obviously, ports are significantly complicated systems involving many stakeholders, thereby they require a specific coordination among the parties.

2.2 The important role of port authorities in a landlord port governance model

The landlord port is a public-private form of ports that offers a harmonious governance structure for all actors and are leading management model in larger and medium-sized ports (World Bank 2007). In this model, port authorities perform a regulator and landlord role. They are linked to private operators through leasing or concession contracts. Port operations are conducted by concessionaires that maintain the infrastructure, provide the required superstructure and equipment and manage dock labor. The model requires a "greater co-ordination of marketing and planning" (Brooks and Cullinane 2006) as a major risk of over-capacity can occur from an activity expansion of the private operators. From an interorganizational perspective to logistics innovation in ports, De Martino et al. (2013) considered the ports as "heterogeneous and dynamic networks" and highlighted the important role that port authorities should play as leaders to enhance performance.

2.3 Port community

Ports are places where numerous stakeholders work together to efficiently ensure a smooth flow of goods from an origin firm to a destination firm. Port members are presumed to help and cooperate with one another. For example, expanding the operational area of the port to overcome some problems like an increasing throughput is not the only possible way (Long 2009). Other alternatives may be of a particular relevance such as innovative solutions acting on processes and procedures causing delays. One of the greatest solutions is the Port Community System which is defined by the International Port Community Systems Association (IPCSA) (PCS / Port Community System – IPCSA International 2014) as a neutral and open electronic platform enabling intelligent and secure information exchange between public and private stakeholders in order to improve the competitive position of the seaport communities. It optimizes, manages and automates logistics-efficient processes through a single submission of data, connecting transport and logistics chains. The main actors within the Port Community System perimeter are: freight forwarders (exporters & importers), customs, administrations, shipping agencies, port authority, warehouses, banks, services providers, ocean carriers, inland carriers, terminal operators (foreland & hinterland). These actors can be classified into users (e.g., shippers) or service providers (e.g., terminal operators) (Talley 2009). It is understood that, in order to benefit from the information streams coming from different sources, the use of a Port Community System would require a redesign and harmonization of many processes and a high degree of coordination between the various stakeholders. The port is an area involving numerous players, who often have conflicting requirements and objectives. And taking into account the particularly complex character of the port, improving its performance becomes a hard task to achieve.

Given the numerous approaches to ports definition and classification, their performance assessment is important to ensure that they are conform with their objectives, values and strategies. For this reason, port performance management models should be carried out carefully reflecting all parties' interests.

3. Review of Port Performance Management

The difficulty to define ports is transposed to their performance management system. Given the complexity of ports and the multiple governance models (World Bank 2007), it's hardly possible to set an individual standard to assess the port performance. This chapter presents some approaches to port performance management as well as their limitations.

3.1 Reference points

The pioneer monograph of UNCTAD (UNCTAD 1976) on port performance is one of the first established models on port efficiency assessment suggesting the indicators in table 3. Many port performance measurement models have since been developed with different approaches and goals, still there is no systematic model for the whole port performance assessment. Traditionally, port performance studies focus on container terminals efficiency benchmarking (Brooks 2006) and frontier statistical models, especially DEA (Talley 2007). A substantial work has been produced by the UNCTAD TrainForTrade Programme which is supporting ports from developing countries in assessing their performance (UNCTAD 2016). This work consists in building a generic and practical framework to evaluate the performance internally and perform benchmarking. Hence, a rich port performance scorecard has been developed including many components which are operations, finance, human resources, customer/market, environment, linking strategy and performance, stakeholder assessment and port typologies. Here below, we present a selection of models from the port performance management literature.

Table 3. Summary of performance indicators (UNCTAD 1976)

Indicator type	Indicator
Financial	Tonnage worked Berth occupancy revenue per ton of cargo Cargo handling revenue per ton of cargo Labour expenditure Capital equipment expenditure per ton of cargo Contribution per ton of cargo Total contribution
Operational	Arrival rate Waiting time Service time Turn-around time Tonnage per ship Fraction of time berthed ships worked Number of gangs employed per ship per shift Tons per ship-hour in port Tons per ship hour at berth Tons per gang hours Fraction of time gangs idle

3.2 Efficiency versus Effectiveness

The literature corresponding to port performance measurement has traditionally been segregated into efficiency (quantitative) and effectiveness (qualitative) measures (Brooks 2006, Brooks and Pallis 2008, Talley et al. 2014). In the classification proposed by Brooks (2006) of various port performance measurement models, two main categories were presented: internal and external metrics. The former is split into system metrics (financial and non-financial) and functional activities metrics (vessel-handling, cargo-handling, ancillary services and marketing). The latter is about measures evaluating efficiency, effectiveness and satisfaction of external customers, stakeholders and suppliers. Internal metrics especially financial measures are reported to have been largely studied; accordingly, there is a room for port performance development by way of improved effectiveness.

3.3 The economic perspective

From an economic perspective, and according to Talley (2007), a common way for measuring port performance is the evaluation of port's throughput which is usually defined as the handled quantity of cargo. However, in a competitive environment, this is a meagre approach for not considering some important parameters such as costs generated from vessels waiting time. Based on the inter-port and intra-port competition concept, he provided first, the single-port approach to performance management, to evaluate the port performance over time, and second, the multi-port approach which is axed on comparing similar ports. For both approaches, the model defended by Talley (2007) is founded on an economic objective (e.g., profit target) that can be achieved either by setting an economic optimum throughput or by managing performance indicators. The economic objective could be technical efficiency (throughput as function of port's productive resources), cost efficiency (throughput as function of port's costs) or effectiveness (effectiveness operation objective such as maximizing profits). The proposed approach considers mixed-cargo port case (bulk and container), and a detailed model is described in Talley (2006).

3.4 A logistics and supply chain approach

Bichou (2006) adopted a supply chain point of view and provided a critical review of existing knowledge related to port performance models and approaches. He classified the literature into studies related to individual metrics and indices, port impact studies and works using frontier approaches. The first category of individual metrics and indices is widely represented by financial and utilization metrics and fall within financial productivity, physical productivity or multifactor productivity. Furthermore, the port impact studies are split into port economic impact and port trade efficiency. Finally, the frontier approaches used for port performance analysis are either parametric or non-parametric methods marked by a large use of DEA. This evaluation of port performance literature revealed many gaps. First, the high dimensional aspect of ports leads to diverging performance management approaches unable to capture both efficiency and effectiveness. Second, ports are complex networks holding many actors, thereby it becomes difficult to select the standpoint from which performance should be considered. A third gap is that studies on port performance benchmarking only focus on comparing group of similar ports, generally belonging to the same region, although benchmarking can be conducted internally (e.g., terminal comparison), on processes adopted by other ports (process benchmarking) or on the best methods used in different industries (generic benchmarking) such as the possibility to learn from airport industry (Brooks 2006). Finally, studies on port performance management have scarcely carried out the connection of port's components as a result of a multiplicity of port's dimension. Seeking a single model for port performance and benchmarking, Bichou (2006) proposed a logistics and supply chain approach. The suggested integrative approach aims to connect port's elements internally as well as externally, through a conceptualization of port system as three parallel channels: trade, supply chain and logistics. The conception makes operations more fluent and allows extending strategies over a long period. This multidimensional approach has also been indicated by Brooks and Pallis (2013) as a potential axe of research.

3.5 Further issues

Port performance objectives come under the disagreement between the different actors about what priorities should be put first, consequently uncomplicated models in line with port system goals should be adopted (Bichou 2006, Brooks 2006). In this regard, Talley (2007) highlighted the importance of setting performance indicators that match port's strategy, bearing in mind the singularity of a given port of study. With respect to this issue, fitted performance models seems to be a possible solution. The review of Ensslin et al. (2018) is an effort to determine the state-of-the-art of seaport performance evaluation. The review analyzed 31 relevant studies selected from 6053 identified papers published between 2000 and 2016. The major findings were that 18 papers focus on operational level, 10 on organizational strategy and only 3 on tactical level. Also, the most used technique is DEA with 18 papers followed by fuzzy theory and analytic hierarchy process with 3 papers each. In addition, the review proposed a classification of the relevant articles into realist (general models) and prescriptivist-constructivist (specific models), revealing that all studies are realist models. Therefore, the report shed light on the necessity to work on fitted models involving managers and to harness the power of strategic and tactical measures for a better management of port performance. However, the study didn't mention the high interest in container ports. Only one paper is actually addressing bulk ports issues, 12 deal with general ports and 18 concentrate on container ports. This only paper (De Oliveira and Cariou 2011) indicates that despite the important number of performance assessment models for ports, hardly any models spotlighted the performance in bulk sector. Also, a number of original and notable works on ports performance have not been cited by Ensslin et al. (2018). For example, approaches to identify similar ports using principal component analysis (Tongzon 1995) or cluster analysis (Tongzon and Ganesalingam 1994), lean ports model for assessing quantitative and qualitative performance indicators (Marlow and Casaca 2003), port service chain concept to evaluate effectiveness (Talley et al. 2014) and hybrid models such as combining balanced scorecard, analytic hierarchy process and fuzzy sets theory (Su et al. 2003).

The majority of existing attributes of port performance focus on the operational side only, limiting ports to terminals (Brooks and Pallis 2008). Nevertheless, effectiveness has been also considered in several recent works introducing new components. The diversity of indicators through port performance literature can be shown by the analysis conducted by Ha et al. (2017) on 259 relevant papers from 1970 to 2016, providing a hierarchy of 60 port performance indicators according to six dimensions (table 4). Admittedly, (Ha et al. 2017) is a valuable framework for assessing quantitative and qualitative performance integrating port stakeholders' interests in a single decision tool; even so, the study only capture container ports indicators and might not be adaptable to mixed-cargo ports which are even more complex.

Table 4. Classification of port performance indicators (Ha et al. 2017)

Dimensions	Principle Performance Indicators
Core activities	Output Productivity Lead time
Supporting activities	Human capital Organization capital Information capital
Financial strength	Profitability Liquidity and Solvency
Users satisfaction	Service fulfillment Service costs
Terminal supply chain integration	Intermodal transport systems Value-added services Information/communication integration
Sustainable growth	Safety and Security Environment Social engagement

In order for a port to be competitive, a strategy performance is a must. This strategy has to be well established in line with the port policy and objectives. The approach and the strategy set up could be based on ports data analysis, such data can be used to understand the ports environment interactions and to define the factors influencing its performance.

4. Potential of advanced analytics for port performance management

Improving the performance of complex systems like ports, especially when dealing with large amounts of data, needs some advanced analytics solutions to explore and understand how the system is influenced by different factors. This chapter is an indication of the variety of developed optimization models in the port context.

4.1 Port optimization

Port optimization is a long-standing area of research (Robinson 1976, UNCTAD 1976) that have been addressing many problems to develop the management of port system, such as resource allocation, equipment utilization and process scheduling. In port performance management models as in optimization models, studies have brought to the fore container terminals. For example, the papers (Carlo et al. (2013, 2014a, 2014b)) propose a set of surveys examining a container port operations issues, studies which are unavailable for other types of ports. Besides that, the most studied field in port optimization is berth allocation problem in container terminals (Bierwirth, and Meisel (2010,2015), Theofanis et al. 2009) with different objectives (e.g., makespan, cost generated by delays, quay crane time). Regarding bulk ports, the first studies on berth allocation problem were conducted by Barros et al. (2011) and Umang et al. (2013) but can be further developed (e.g., consider vessels with multiple cargo types or heterogeneous berths case).

In the age of intelligent transportation system and industry 4.0, it is a must to take full advantage from the propounded solutions by technological developments (Brooks and Pallis 2013, UNCTAD/RTM/2018). The application of some technologies like automation, robotics, artificial intelligence, blockchain or Internet of things will absolutely boost all port's performance aspects (planning and development, design, operations, etc.). What is more, bringing analytics techniques to port system will be undoubtedly a strong driver for the successful change.

4.2 Simulation models

Several works are founded on simulation for improving port activities. The paper (Dragović et al. 2016) is a detailed literature review on the simulation models applied in ports development, through an important number of published works over the period (1961-2015). The paper extends the previous work of 10 reviews that cover a total number of 65 simulation models, to build a database of 209 models (including the 65 works already covered). The analysis by application area of the considered models revealed the high coverage of the container sector by 166 papers, followed by ports in general with 24 papers, 15 papers for port traffic and only 14 papers for bulk cargo terminals. Simulation models have been widely used to solve port related problems and have proven to be a popular decision support tool. Even so, the models presented in the literature concentrates on container terminals with a focus on performance evaluation, while the bulk cargo terminals are unattractive and this is a gap to be fulfilled.

Crainic et al. (2017) offers a taxonomy of simulation models of intermodal freight transportation systems. The paper clusters 150 studies into: network description, planning, simulation methods and simulation scope. Simulation methods are distinguished between numerical and optimization methods, both approaches can be static or dynamic and stochastic or deterministic. From a scope viewpoint, the models can differ depending on the study object (behavior and interactions, flow or event) or according to the simulation objectives (what-if analysis, forecasting, validation and enhancement). Once again, the multifaceted nature of ports arises in literature on simulation methods, even though simulation remains a great decision support tool.

4.3 Machine learning

The significant increase of the maritime traffic flow has led to a remarkable production of data, making the maritime transport system a topic of interest to researchers. The wealthy literature related to the application of machine learning techniques for maritime transportation system reveal an important contribution in highlighting the drivers of maritime performance. Some of the identified area of machine learning applications are port throughput forecasting (Geng et al. 2014, Mo et al. 2018), port productivity (Wasesa et al. 2017), prediction of vessel estimated time of arrival (Yu et al. 2018), vessels behavior and anomaly detection (Mascaro et al. 2014), shipping accidents (Bye and Aalberg 2018), piracy (Dabrowski and De Villiers 2015), document fraud detection (Triepels et al. 2018), ship emission (Yan et al. 2018), vessels trajectories (Zhang et al. 2018), vessel detection (Kanjir et al. 2018) and e-navigation (Im and Nguyen 2019).

In addition to the information exchanged and stored by different port actors, the Automatic Identification System (AIS) data has become available, and this has triggered the development of new applications and services. AIS is a vessel tracking system that provides regular updates on a vessel's movement and other relevant ship voyage data to other parties (e.g., ports and vessels). AIS data has proven to provide a particular support to develop ports analytics mainly short-term decisions (Grida and Lee 2018, Kruse et al. 2018, Zhang et al. 2018, Bye and Aalberg 2018, Mascaro et al. 2014, Yu et al. 2018).

Altogether, the mentioned studies in this chapter are only some of the various works on ports optimization models. However, some areas of research such as bulk or mixed-cargo ports deserve more attention from scholars. In this regard, advanced analytics can help building strategies to ensure smooth running of the entire port system.

5. Conclusion

From their review of 20 articles to identify the advancement in port management, Brooks and Pallis (2013) noticed the necessity to further work on port performance management in terms of goals, indicators and tools from both scholars and managers. Moreover, it is crucial to point out that port complexity hinders the adoption of a single performance model taking into account all port's activities and processes. The detected gaps in performance management models for ports are a chance to investigate new ways to the optimization of port system management.

In the light of the above presented elements, it is clear that many improvements are needed. We mention here the necessity to work on other types of ports than container ports, to explore new alternative solutions to port efficiency widely studied using DEA, to adopt a multidimensional perspective of the management of port performance deriving benefit from the Port Community System, and finally, to propose new benchmark methodologies.

The operational and spatial complexity of ports seem to be liable for misleading port performance and benchmarking. Here comes the role of advanced analytics as a powerful tool to delve into the port performance drivers. The factors influencing port performance are of prime concern and should be scrutinized to come up with an appropriate performance management model. However, further work in this area is still necessary to try to solve some difficulties faced by the port system.

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