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Review Article

State-of-the-art of port simulation models for risk and capacity assessment based on the vessel navigational behaviour through the nautical infrastructure

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HIGHLIGHTS

- State-of-the-art of the current port simulation models for risk and capacity assessment.
- Identification of the main navigational processes related to the port nautical infrastructure.
- Assessment focused on how operations are covered by each model and how they represent realistic vessel navigation.
- Future port simulation models should consider detailed infrastructure, explicit tug and pilot assistance, and traffic rules.
- Existing research should be used for a more realistic port traffic modelling for risk and capacity assessment.

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ABSTRACT

Ports play an increasingly important role in the freight transportation chain due to containerization. High vessel flows and higher densities increase the relevance of the non-terminal related processes. Several simulation models have been developed in the recent decades with different goals, but their abilities to represent realistic vessel traffic in ports differ. In this paper, we identify the main navigational processes and operations related to the port nautical infrastructure, and review and assess the current port simulation models. This survey represents an exhaustive review of the state-of-the-art of simulation models for port assessment purposes focussing on safety and capacity. The model assessment focuses on the identification of the relevant criteria to represent vessel navigation, based on which processes are covered by each model and how they have been considered in each model. The assessment covers the nautical infrastructure representation and the navigational behaviour. The outcome of this review will be used for the development of a simulation based port assessment methodology. Future port simulation models should include the suitable criteria for a more realistic traffic representation that allows a proper safety and capacity port analysis and assessment.

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1. Introduction

Globalization is leading to a rapid growth in maritime transport, both in size and number of vessels. The world seaborne trade has increased substantially in the past two decades (UNCTAD, 2013). As shown by Ducruet and Notteboom (2012), the total port throughput has exponentially increased during the last 50 years, and it has been more than doubled just in the last 20 years. The increase in throughput is linked to more vessel movements. Since ports are quite inflexible infrastructures and difficult to expand, the situation has led to higher traffic densities and eventual congestions in some areas. Ports accommodate a higher traffic demand without a waterway infrastructure expansion that implies, in many cases, longer waiting times for vessels, which reduces the efficiency of the system. Because of this increasing demand and the limited nautical infrastructure (berths and sailing areas), vessel navigation related processes in the port become decisive for port performance. Existing ports might need be optimized or expanded and new ports have to be planned considering these limitations. In both cases, their safety and capacity, among other factors, should be guaranteed and tools to assess them in different designs are required.

Maritime transportation simulation models have been proven to be useful tools to represent port operations and processes to assess port performance. Several models have been developed during the last decades with many different purposes, such as strait or waterway performance or maritime risk assessment. Regarding traffic simulation in straits, several models represent navigation systems as queueing systems, with first in first out (FIFO) sequences (Golkar et al., 1998; Köse et al., 2003). Waterway traffic representation has been another subject of interest (Almaz and Altiok, 2012; Hasegawa et al., 2001; Xiao et al., 2012, 2013; Xu et al., 2015). In relation to risk assessment, a risk index-based model for vessels was developed, the safety assessment model for shipping and offshore on the North Sea (SAMSON) model, by Maritime Research Institute Netherlands (MARIN, 2015). Furthermore, a simulation model for vessel traffic based on ship collision probability has been developed (Goerlandt and Kujala, 2011). Moreover, there are models for detailed port representation and performance analysis (Bellsolà Olba et al., 2017; Groenveld, 1983; Scott et al., 2016; Thiers and Gerrit, 1998).

As described in the previous paragraph, there is a wide range of maritime simulation models with different purposes. In this paper, we present a state-of-the-art of port models and we assess their applicability to port risk and capacity assessment, as a base for the future development of a port assessment methodology based on a suitable simulation model. This research includes some models recently reviewed (Bellsolà Olba et al., 2015) and models that have been developed since then. It includes, to the best of our knowledge, all the current non commercial port simulation models, which features are described in detail in scientific publications. The commercial models are excluded because their details and features are not available. In previous work, the most relevant processes involved in port navigation were identified a more comprehensive description is presented in Section 2. Moreover, this paper reviews and assesses the models already developed on these processes in a more detailed level. The calibration of the models is an important step to ensure that they properly simulate real traffic. Hence, all the models have been assessed based on if they have been calibrated or not.

The outline of this paper is as follows. Section 2 describes the nautical processes in a port. Section 3 identifies all the required criteria for port traffic simulation. Section 4 describes the characteristics of the criteria identified. Based on these, the assessment of simulation models will be discussed in two parts, layout and navigational behaviour, in Section 5. This paper concludes with a discussion of the results with an overall model assessment in Section 6, and conclusions and remarks for future model development in Section 7.

2. Port nautical processes

Ports are complex networks, both from an infrastructure and navigation point of view. This section describes the main processes linked to the nautical infrastructure necessary to represent the vessel traffic in a port and its evaluation (Fig. 1).

Traffic processes in a port start when a vessel arrives and requests access. The vessel traffic service (VTS) provides information about the berth availability and other conditions, such as weather or tide. If it is feasible to enter the port, the traffic situation is checked. Vessels with permission from the port authorities can enter the port and sail towards their destination. Otherwise, they wait outside the port in the anchorage until permission is given. Vessels with specific navigation requirements or limitations will need pilot and/or tug assistance.

Once a vessel is allowed to enter the port, it sails to a specific berth through the approach channel or entrance waterway. Until its arrival at the berthing area, each vessel will sail through different parts of the port, such as turning basins, crossings or inner basins. Each of these areas has specific requirements in sailing and manoeuvring, also depending on the vessel characteristics. Vessels can usually sail in any position inside each section of the port, but, to avoid groundings, there are some fixed corridors or paths for vessels with the deepest draughts.

After the vessel has performed all these steps, the berthing process is performed and loading/unloading operations start.

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