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Evaluation of the floaterm concept at marine container terminals via simulation

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ABSTRACT

International seaborne trade rose significantly during the past decades. This created the need to increase capacity of existing marine container terminals to meet the growing demand. The major objective of this paper is to evaluate the floaterm concept using simulation modeling and determine if it can improve terminal productivity. The main difference between floaterm and conventional marine container terminals is that, in the former case, transshipment containers are handled by off-shore quay cranes and stored on container barges. Two terminal configurations performance is compared (vessel handling times and equipment utilization) under normal and disruptive conditions. Computational experiments confirm preliminary expectations that the floaterm concept can enhance efficiency of marine container terminal operations under normal and disruptive conditions.
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1. Introduction

The amount of cargo, transported by vessels, substantially increased over the last thirty years. According to United Nations Conference on Trade and Development (UNCTAD) overall seaborne trade, inlcuding containerized cargo, major bulk cargo, other dry cargo, and liquid bulk cargo, increased by roughly 3.6 billion tons from 2000 to 2013 and reached 9.6 billion tons [1]. International seaborne trade rose by more than 120% by weight from 1980 to 2008 primarily from increasing standards of living, fast industrialization, population growth, and competitive markets [2]. Containerized cargo increased by 6.6% in tonnage from 2012 to 2013, and the future growth was also projected for 2014 [1]. The Journal of Commerce [3] indicates that "*seeking efficiency and economies of scale, the world's container carriers are increasingly ordering megaships capable of handling more than 8000 20-foot-equivalent container units*". To meet this growing demand, while facing capacity expansion limitations (e.g., lack of land, high cost of expansion, etc.), it is necessary to provide proper planning and

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management of terminal operations. Deployment of larger vessels with higher capacity can further add constraints to seaport operations [4]. The port capacity can be increased by upgrading existing ports or constructing new facilities [5]. There are additional alternatives that do not involve construction, such as improvement of conventional equipment and productivity by introducing new forms of technology [6], information systems [7], and work organization [8].

Container terminal operations can be divided into quayside, storage yard, and landside operations. Quayside operations deal with berthing of vessels, stowage planning, quay crane (QC) assignment, and QC scheduling for (un)loading containers. Note that stowage planning is the only function not solely controlled by the terminal operator and receives significant input from the captain of the vessel. Storage yard operations include stacking and retrieval of inbound, outbound, and transshipment containers by gantry cranes (GCs) at yard blocks. Internal transport vehicles (ITVs) provide container transfer between the quayside and the storage yard. Landside operations consist of receiving or delivering containers by drayage trucks (DTs). There are three main quayside transfer processes at marine container terminals (MCTs): (a) vessel-to-yard (i.e., import), (b) yard-to-vessel (i.e., export), (c) and vessel-to-vessel (i.e., transshipment). Marine terminals operate as follows: once a vessel has entered the port, it is berthed at its assigned berth, and once moored, ship-to-shore QCs start (un)loading containers. ITVs (yard trucks, straddle carriers, automated guided vehicles, automated lifting vehicles, etc.) transfer containers between the quayside and pre-assigned blocks of the storage yard, where GCs arrange them either parallel or perpendicular to the berth. Import containers are delivered to the port by vessels, while export containers are drayed to the port by DTs through the gates (usually at least 24 h before the vessel calls at the port) or by rail (if on-dock rail access exists). Once a DT enters a terminal, it either travels to the assigned blocks in the storage area or to a receiving area where the container is (un)loaded. Transshipment occurs, when cargo, delivered by one vessel (usually called as mother vessel), is moved to another vessel (usually called as feeder vessel). Transshipment containers can be transported from vessel to vessel with or without temporary storage at the storage yard.

Realizing efficient operations at MCTs remains a difficult task (most operations are formulated as mathematical programing models belonging to the NP class). Handling equipment and containers should be properly allocated for quayside, landside and storage areas. QCs should be assigned to particular berths, and their numbers depend on several factors (i.e., total number of QCs available; total number of vessels assigned to each berth; total number of containers to be handled for each vessel, etc.). Particular dispatching strategies of ITVs should be chosen to decrease or eliminate idle time of QCs and GCs (although the former always receive priority). Available GCs should be properly allocated between yard blocks and if more than one GC serves a yard block, particular safety policies should be taken into account to avoid clashing. There are also traffic congestion issues for large container terminals due to longer travel distances travelled by ITVs. The allocated equipment should be utilized in the most efficient manner (e.g., dual cycling of QCs and ITVs).

To improve performance of MCTs by increasing quayside capacity with minimal capital investment a new concept (named floaterm) was proposed in early 2000 [9,10]. The floaterm concept includes two-sided operations (when a vessel is moored between the terminal berth and the crane barge as shown in Fig. 1A) and midstream operations (when a vessel is moored to the crane barge in the sea as shown in Fig. 1B). The floaterm concept was originally applied at the Ceres Terminal (Amsterdam, the Netherlands) in 2002 with throughput increasing by 24.6% from 2000 to 2005 [11,12]. No information was made available as to the role the floaterm concept played in the throughput increase. According to Ashar [9] and Liftech, Inc. [10] though the floaterm concept could significantly improve performance of seaports, decrease the size of the storage yard, reduce the number of handling equipment, reduce congestion, etc. To the best of the authors' knowledge, no computational study exists (to date), describing and modeling the impact of the floaterm concept on MCT operations. In this paper we use simulation to compare operations (under normal and disruptive conditions) of a conventional MCT to a terminal with the floaterm concept and quantify (any) productivity gains, that may be realized by the latter.

The rest of the paper is organized as follows. The next section presents a review of the literature on simulation modeling at MCTs. The third section describes the developed simulation models, and the fourth section presents a number of numerical experiments, conducted as part of this study. The fifth section discusses results from the study, and the last section provides conclusions and future research directions.

2. Literature review

Operational, tactical, and planning level decision problems at MCTs have been the focus of interest of numerous researches and practitioners, especially during the last fifteen years [13–17]. In this paper the reviewed literature focuses on simulation modeling applications at MCTs (i.e., berth allocation, stowage planning, QC assignment and scheduling, storage and stacking, landside and quayside transport, vulnerability/resiliency of marine terminals, etc.). For reviews of the general literature on MCTs we refer to Steenken et al. [13], Stahlbock and Vos [14], Theofanis et al. [15], Bierwirth and Meisel [16], and Carlo et al. [17]. These articles include historical overviews of world seaborne trade, description of MCT structure and handling equipment, and classification of published literature by different topics, which is out of the scope of this paper.

2.1. Quayside operations

Several simulation studies have been published on quayside operations (i.e., berth allocation/scheduling, stowage planning, QC allocation/scheduling, ITV scheduling and routing). Han et al. [18] addressed the problem of simultaneous berth and

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