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Invited Review

A follow-up survey of berth allocation and quay crane scheduling problems in container terminals

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ABSTRACT

This paper surveys recent publications on berth allocation, quay crane assignment, and quay crane scheduling problems in seaport container terminals. It continues the survey of Bierwirth and Meisel (2010) that covered the research up to 2009. Since then, there was a strong increase of activity observed in this research field resulting in more than 120 new publications. In this paper, we classify this new literature according to the features of models considered for berth allocation, quay crane scheduling and integrated approaches by using the classification schemes proposed in the preceding survey. Moreover, we identify trends in the field, we take a look at the methods that have been developed for solving new models, we discuss ways for evaluating models and algorithms, and, finally, we light up potential directions for future research.

1. Introduction

This contribution presents an update of our article ‘A survey of berth allocation and quay crane scheduling problems in container terminals’ which has been published in Bierwirth and Meisel (2010). The literature dealing with seaside operations planning in container terminals was connectedly reviewed in that paper for the first time, delivering an overview and classification of existing optimization models and solution methods. With the paper at hand, we carry on this project in order to reflect the bulk of new research published in the field throughout the last five years.

The rapid improvement of management techniques for the seaside operations in container terminals does definitely not stand alone. Important developments are also observed in related areas of port logistics and maritime transportation. A broad overview of port-related research including topics like port policies, port competition, and port development is provided by Woo, Pettit, Beresford, and Kwak (2012). An overview of the various operational planning issues faced by the management of container ports is provided by Goodchild, Zhao, and Wygonik (2010) and Rashidi and Tsang (2013). In a series of survey papers Carlo, Vis, and Roodbergen (2013, 2014a, 2014b) review the literature on seaside operations, transport operations and storage yard operations in container terminals. They also describe current trends driven by technological advancements as well as possible avenues for future research. An overview of modern equipment and performance figures of numerous container terminals in the world is given by Wiese, Kliewer, and Suhl (2009). Another overview of Lehnfeld and Knust (2014) considers the problem of loading and unloading container stacks as is faced in yard operations and stowage planning. Simulation studies that investigate the impact of management decisions on the performance of container terminals are reviewed by Angeloudis and Bell (2011) and Rashidi and Tsang (2013). Recent surveys on the design of liner shipping networks and the tactical management of a fleet of container vessels are given by Christiansen, Fagerholt, Nygreen, and Ronen (2013), Pantuso, Fagerholt, and Hvattum (2014), and Tran and Haasis (2013). Also some recent special issues of scientific journals like *Flexible Services and Manufacturing Journal* 23(4), 24(3), 25(4), *European Journal of Operational Research* 235(2), and *Transportation Science* (in press) provide good insight into the broad scope of topics currently considered in the area of maritime logistics.

Seaside operations planning in container terminals basically comprises the *berth allocation problem* (BAP), the *quay crane assignment problem* (QCAP), and the *quay crane scheduling problem* (QCSP). The decisions made when solving these problems are highly interrelated. Together they determine the port stay times of container vessels, which basically reflect the service quality promised to shipping companies and thus the competitiveness of a terminal as a whole. Consequently, the optimization problems involved in seaside operations planning are paid increasing attention in the operations research and transportation research literature. We have reviewed the reached state of this literature up to 2009 in Bierwirth and Meisel (2010). The paper

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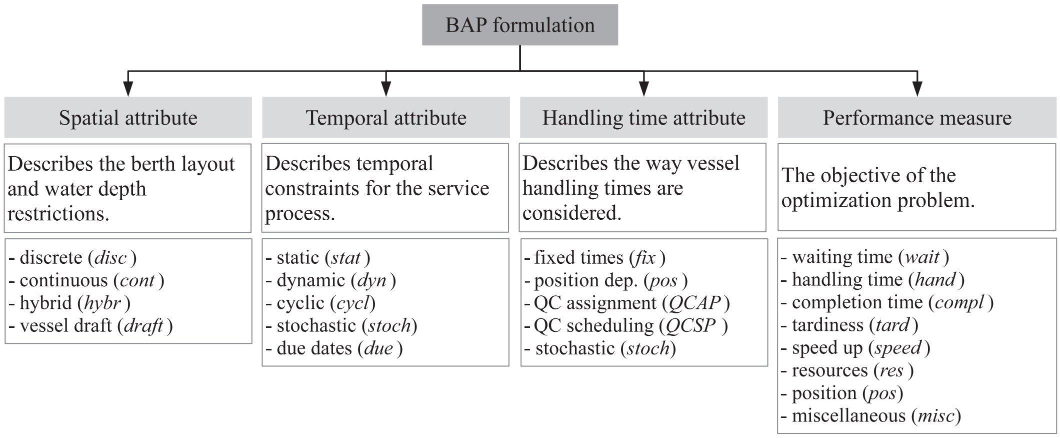

Fig. 1. BAP classification scheme.

provides classification schemes for BAP models and QCSP models. The QCAP hardly receives attention by its own, which is why there is no classification scheme for this problem. Nevertheless, integrated models connecting BAP and QCAP, QCAP and QCSP, or all three problems together are classified in Bierwirth and Meisel (2010) as well.

In the preparation of this follow-up paper, we followed some guidelines. First, in order to reduce redundancy with the preceding survey, only the relevant new literature published after 2009 is taken into consideration. Second, our problem classification schemes are taken up from the preceding survey and just slightly adapted to capture newly treated problem features. Third, the main outline of the previous survey paper is kept, structuring it into three sections that deal with the BAP, the QCSP and integrated approaches thereof. In the section on integrated planning we also review recent approaches of further integrating seaside operations planning with liner scheduling and with yard operations planning. An integration with liner scheduling aims for aligning the sailing times of vessels with the berthing times at the visited ports. Such integration promises reduced vessel waiting times at congested terminals. The integration with yard planning is motivated by the observation that fast seaside operations not just require efficient berth plans and quay crane operations but also an efficient usage of other resources like yard trucks, yard cranes, and storage locations. Therefore, recent studies strive for a combined solution of seaside problems and yardside problems in order to minimize yard congestions as well as the travel effort of transport vehicles while planning berth and quay crane operations.

In order to identify and collect all new relevant publications on berth allocation and crane operations planning, we have conducted a comprehensive literature search. At first we have scanned online search engines for papers that contain the key words ‘Berth allocation’, ‘Berth scheduling’, ‘Berth assignment’ or ‘Quay Crane’. The searched media include the online-resources of the publishers *Elsevier, Informs, Interscience, Palgrave, Springer, Taylor&Francis*, and the scientific search engine *Google Scholar*. At second we have used the citation indices of *ISI Web of Knowledge* and *Scopus* to identify further journal papers citing one of the previous surveys of Stahlbock and Voß (2008), Steenken, Voß, and Stahlbock (2004), Vis and de Koster (2003), and Bierwirth and Meisel (2010). The literature references of these papers were searched for further relevant publications. In this follow-up survey, we collect all papers that appeared in reviewed international journals or compilations and are not already surveyed in Bierwirth and Meisel (2010). With the exception of nine papers, all papers included in this survey appeared in 2010 or later. Papers that are published in proceedings, collections, extended abstracts, and technical reports are only taken up in this survey if the modeling approach or methodology is original and not published elsewhere. Altogether, this survey collects and classifies 131 new approaches for the BAP and the QCSP, described in more than 120 papers, of which 111 have been published in international scientific journals and 20 elsewhere.

The outline of the paper is as follows. In Sections 2 and 3, we classify the collected papers on berth allocation and quay crane scheduling, respectively. In both fields, we discuss recent developments to highlight promising topics for future research. In Section 4, we review those studies that investigate integrated approaches for seaside operations planning. Section 5 concludes the survey by highlighting topics that we consider particularly important in future research.

2. Berth allocation problems

2.1. Scope and classification scheme

In berth allocation problems, we are given a berth layout together with a set of vessels that have to be served within a planning horizon. The vessels must be moored within the boundaries of the quay and cannot occupy the same quay space at a time. In the basic optimization problem, berthing positions and berthing times have to be assigned to all vessels, such that a given objective function is optimized. A variety of optimization models for berth allocation have been proposed in the literature to capture real features of practical problems. In Bierwirth and Meisel (2010), we have proposed a scheme for classifying such models according to four attributes, namely a *spatial attribute*, a *temporal attribute*, a *handling time attribute*, and the *performance measure* addressed in the optimization. The values each attribute can take are listed in Fig. 1.

2.1.1. Spatial attribute

This attribute concerns the berth layout, which is either a discrete layout (*disc*), a continuous layout (*cont*), or a hybrid layout (*hybr*). In case of *disc*, the quay is partitioned into berths and only one vessel can be served at each single berth at a time. In case of *cont*, vessels can berth at arbitrary positions within the boundaries of the quay. Finally, in case *hybr*, the quay is partitioned into berths, but vessels may share a berth or one vessel may occupy more than one berth. A particular form of a hybrid berth is an indented berth where large vessels can be served from two oppositely located berths. The spatial attribute is extended by item *draft*, if the BAP-approach additionally considers a vessel’s draft when deciding on its berthing position.

2.1.2. Temporal attribute

This attribute describes the arrival process of vessels. The attribute reflects static arrivals (*stat*), dynamic arrivals (*dyn*), cyclic arrivals (*cycl*), and stochastic arrival times (*stoch*). In case of *stat*, we assume that all vessels have arrived at the port and wait for being served. In contrast, in case of *dyn*, the vessels arrive at individual but deterministic arrival times imposing a constraint for the berth allocation.