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A decision support system for quayside operations in a container terminal

Evrim Ursavas

Department of Operations, Faculty of Economics and Business, University of Groningen, The Netherlands

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ABSTRACT

This paper proposes a decision support system for optimizing operations on the quayside of a container terminal. Due to the existence of multiple parties involved in the decision making processes within port operations, it is essential to pay attention to each parties' concerns and demands which by nature are frequently conflicting with each other. This calls for a DSS that offers the flexibility of adjusting the balance within conflicting objectives, guiding the decision maker towards the final decision. Consequently, this study provides a DSS that determines the berthing and crane allocations simultaneously. To show the practical application of the DSS presented, a real life case study at a container terminal has been conducted. Implementation of the model shows that improvements ranging from 10% to 25% on service time and costs can be attained.

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1. Introduction

The prolonged economic recession together with weak economic growth is leading container terminals to follow a cautious approach when serving their customers. Before the economic crisis, where more optimistic figures were prospected, concentrating on satisfying these customers to the highest level has been the more focused approach to gain share in the market. Nowadays, the necessity for considering cost issues while providing quality service to the customers has increased.

The decisions for operations within the terminal depend on the balance of influence between terminal operators and shipping companies. From the terminal operator's perspective operating for high productivity and container throughput at low costs is a critical element to stay competitive. However, from the shipping companies' perspective low turnaround time and reliability regarding adherence to promised handling times are more critical elements. Hence, there are different views existing between the parties involved at the container terminals [24,29]. With shipping companies on one side and terminal operators on the other, each having its own concerns and demands and which by nature are frequently conflicting with each other, the decision makers call for supporting instruments that help them to attain a balance among those differing intentions. Yet, recent literature on quayside operations within a container terminal does not provide adequate support to resolve the issue via practical considerations. Subsequently, this study attempts to provide a decision support tool that determines the berthing and crane allocations simultaneously under multiple objectives.

At a container terminal, vessels are docked on a berth where containers are loaded/unloaded by cranes at the quayside. These containers are then transferred to a storage area called yard. The focus of this study is at the quayside operations. The first concern is the allocation of berths to the arriving vessels. Berth allocation (BAP) drives the port management process and the major objective for this process is to determine the optimal location and optimal berthing time for the vessels. The next problem, quay crane allocation (CAP) and crane scheduling (CSP) determine the assignment sequence of quay cranes to a container ship in fulfilling pre-specified objectives and satisfying various constraints. Without a doubt, outputs for these three decisions have enormous impact on port performance measures such as waiting times, service times and operating costs. The turnaround time of ships in ports, involving waiting times and service times, is a direct common concern to the shipping companies, whereas, on the supply side, operations should not be managed without recognizing the fact that the bottom line for terminal operations is cost. One of the two components of this cost linked with terminal assets such as quay length, cranes and land is fixed and can rarely be controlled within short run. Labor hours, on the other hand, may be seen as the key variable in the near-term. It should also be noted that, labor cost is rather important especially in Europe and the U.S., where man power is scarce and expensive. Managing operations so as to conserve this scarce resource is axiomatic where the share of port labor varies between 50 and 75% of total terminal operating costs [25]. It can be observed that different operating conditions in time can lead to different cost outcomes. For instance, most terminals will run a second shift as necessary to turn the vessel, but this comes with a cost. These late evening or second shifts are expensive and third or night shifts are still more expensive. It is then advisable for port operators to concentrate on costs controlled by minimizing labor, particularly on the second and third shifts.

In light of the above considerations, this study proposes a novel approach for the three problems, BAP, CAP and CSP, through a methodology based on multiple objectives. It should be noted that by the newly

E-mail address: e.ursavas@rug.nl.

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formulated integer linear programming formulation, optimal berthing times, berth allocations to vessels, berthing positions, crane assignments, crane schedules and their identities are calculated simultaneously, which puts the integration forward in this study, within the deepest ones in the literature. The literature on quayside operations is extended by better representing the real world implementation through embracing further facts linked with crane specifications. Quay cranes are usually of two types: rail-mounted quay cranes (RMQCs) and rubber-tired quay cranes (RTQCs). These two differ in terms of their crane-crossing restrictions and container handling rates. Another point that should be considered for the RMQCs is the crane reach distance restrictions that stem from the fact these cranes moving along the rail have physical restrictions due to their connecting devices such as cables. Further, container terminals may follow dynamic crane assignment policy where crane assignments may vary during the service time of vessel. That is, instead of assuming fixed handling time of the vessels, this study suggests an optimizing method that considers the handling time as a function of crane allocations in each time segment. Handling the practical realizations, a new bi-objective integer problem is proposed using a constraint handling method to obtain the non-dominated berth–crane assignments and schedules as Pareto optimal front via an interactive approach. Through the use of the decision support system the decision maker has the prospect to evaluate different planning solutions that simultaneously consider the shipping companies' and the terminal operators' interests with differing influences. For each different setting of balance between terminal operators and shipping companies, the decision maker will obtain different costs and service time outputs. The user is able to control the density of the alternative solutions and evaluate the trade-offs among them. So, the developed DSS employs an architecture to facilitate the generation and comparison of user intervened solutions. The DSS will also detect solutions where for instance, the same service time can be attained with lower costs. This is done through the designed cutting plane algorithm within the DSS where dominated solutions are eliminated and efficient solutions are presented. The decision maker will choose among these efficient solutions according to the present preferences or necessities. By offering the decision maker the flexibility of adjusting the balance within conflicting objectives, the port may continue to attract customers and also retain a recession-proof working environment.

The next section provides the related literature. In Section 3, the details of the model developed for the aforementioned problem are provided. Section 4 puts forward the decision support system. Section 5 reports the computational experiments via a case study. In the last section, the concluding remarks are presented.

2. Related work

Operations within a container terminal can be grouped into three main parts as quayside, yardside and transfer tasks within the terminal [32]. On the quayside, berth allocation (BAP), crane allocation (CAP) and crane scheduling problems (CSP) deal with the optimal assignment of berths and cranes together with optimal berthing and service times. The need for effective decision making strategies for managing these container terminal operations has become apparent and therefore has attracted many researchers into the subject [29,30]. Consequently, in the past, decision support systems that deal with the operations and planning of containers have been developed by researchers in the field. [1,22,23,28]. Bandeira et al. [1] proposed a decision support system that integrates the flow of full containers with the flow of empty containers. They have modeled the problem as a multiple-depot vehicle scheduling problem. The problem is tackled in two interconnected stages where first allocation and movement of containers are determined without considering transportation times and then unfolding this static solution in a time schedule. Murty et al. [22] developed a decision support system where a variety of interrelated daily decisions at a container terminal is analyzed. The aim of these decisions is to minimize the berthing time of vessels, the resources needed for handling the workload, the waiting time of customer trucks, and the congestion on the roads and at the storage blocks and docks inside the terminal as well as to make the best use of the storage space. Ngai et al. [23] discussed the development of a prototype system in a container depot with the use of radio frequency identification (RFID) features. The decision support system enables tracking of the locations of stackers and containers improving the visibility of operations data and control processes together with the support of mobile commerce activities. Shen and Khoong [28] proposed a decision support system using network optimization to model empty container repositioning. The system works on a rolling horizon approach where two algorithms are suggested to minimize the impact of changes in the demand and supply of empty containers on decisions taken in previous periods.

In the main, treatment of berth and cranes in isolation from each other leads to suboptimal results. Our focus in this review path will be on the studies on quayside operations that simultaneously tackle those problems. A detailed recent survey work provided by Bierwirth and Meisel [2] presents a state-of-art research on the topic. It may be seen that the level of integration for those problems may vary within studies. Mainly, integration of the CAP with either BAP or CSP models is commonly observed. The integration of the three problems together may be seen as the deepest level of integration. With the integration of BAP and CAP, the identities of specific cranes that are assigned to vessels are not determined but the number of crane assignments is. Works by Meisel and Bierwirth [19–21], Giallombardo et al. [7], Hendriks et al. [11], Liang et al. [14], Bierwirth and Meisel [2], Han et al. [10], and Blazewicz et al. [3] may generally be considered within this category. These papers present the optimization models to decide on the berthing time, the berthing position, and the number of cranes for each vessel. In practice, the specific cranes used for the service of vessels need to be determined additionally.

On a deeper integration level, Park and Kim [26] worked on BAP, CAP and CSP problems with a two-phase solution procedure. The first phase determines the berthing position and time of each vessel as well as the number of cranes assigned to each vessel at each time segment. Quay crane scheduling is then constructed in the second phase based on the solution found from the first phase. Following, study by Imai et al. [13] also considers BAP, CAP and CSP in the same manner, where the integration among the problem is weaker compared to a unified model. Functional integration among the stated problems is also adapted by Meier and Schumann [17] and Meisel [18]. Zhang et al. [31] use the sub-gradient optimization technique to solve the problem of BAP, CAP and CSP together. Related with this study, the newly formed model presented in this paper deals with the three problems in a unified modeling approach and extends the literature by considering different crane handling rates and crane movement restrictions.

The study presented in this work furthermore adapts a multi-objective approach. Accordingly, relevant recent works may be summarized as follows: for the BAP problem, a bi-objective approach that considers the minimization of delay of ships' departure and minimization of the total service time is implemented by Imai et al. [12]. To form the non-inferior solution set, they follow the weighting method where all objectives are combined into a single one by assigning weights and by changing the weights in a systematic fashion. Golias et al. [8] differentiate the service level given to customers with different priorities using the multi-objective approach via an evolutionary algorithm. Later, again for the BAP problem, they propose a non-numerical ranking preference method [9]. Cheong et al. [4] model the berth allocation problem tackling three objectives: makespan, waiting time, and degree of deviation from a predetermined priority schedule. Multi-objective evolutionary algorithm is used to find the Pareto efficient frontier. Studies discussed above do not deal with the crane allocation or the crane scheduling problem. It should also be remarked that the solution set provided by the above works is not guaranteed to be optimal.

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