Integration of Berth Allocation and Crane Assignment to Improve the Resource Utilization at a Seaport Container Terminal *

Frank Meisel and Christian Bierwirth

Martin-Luther-University Halle-Wittenberg
frank.meisel@wiwi.uni-halle.de, christian.bierwirth@wiwi.uni-halle.de

Abstract. This paper deals with the combination of two decision problems, which occur consecutively while planning the charge and discharge operations of container ships in container terminals. The Berth Allocation Problem (BAP) considers the allocation of ships to berths in the course of time. The Crane Assignment Problem (CAP) addresses the assignment of quay cranes to ships. We provide a heuristic approach for the integrated solution of these problems and present computational results based on real world data.

1 Introduction

As seaport terminals are often a bottleneck in the transport chain, the organization and control of container handling processes receives increasing attention. Terminal operations planning involves several tasks on the tactical as well as on the operational level [7, 8]. In this paper we concentrate on the quay side tasks in a container terminal (CT) by an investigation of the integration of the BAP and the CAP. It is organized as follows. In Section 2 we introduce the optimization problems under consideration, their integration and the related objective function. Section 3 presents a solution method which has been adopted from heuristics for the resource constrained project scheduling problem (RCPSP). Finally, some computational results are presented.

2 Problem Description

2.1 Berth Allocation Problem

A berth plan determines the quay positions and the berthing times for all container vessels which have to be served within a certain period. The BAP

* published in Haasis, H.-D.; Kopfer, H.; Schönberger, J. (Eds.): Operations Research Proceedings 2005, Springer, Berlin et al., 2006, p.105-110

usually aims at finding a berth plan which minimizes the total stay or delay times of vessels at a port. If the quay is partitioned into several berths with predetermined lengths it is only allowed to moor one vessel per berth at one time. Otherwise, if no such partition is given, vessels can be moored wherever enough space (including clearance) is available. In the first case the problem is referred to as the discrete BAP and as the continuous BAP in the other case [3]. This paper deals with the continuous type of BAP which has been previously investigated, cf. [2, 4].

2.2 Crane Operations Planning

The charge and discharge operations at a container vessel are performed by so called quay cranes (QCs). Several optimization problems have to be solved while planning the operations of QCs. First, in the Crane Assignment Problem (CAP) cranes must be assigned to the vessels over time. Second, in the Crane Split bay areas are assigned to QCs and the sequences in which cranes process the bays must be determined. Finally, in the Crane Scheduling Problem a detailed schedule for the charge and discharge operations at each bay has to be built. We consider only the CAP, i.e. decide how many QCs must work on each vessel at a certain point in time. Again the port stay times or the delay times are minimized.

2.3 Integration of BAP and CAP

The BAP and the CAP strongly interact. The CAP determines the vessel's port stay time which, at the same time, is an input for the BAP. Moreover, the BAP determines the vessel's time to berth which again is an input for the CAP . Therefore, the integration of both problems, which we refer to as the Berth Allocation & Crane Assignment Problem (BACAP), is particularly focused in the literature, cf. [1, 6].

Fig. 1 shows a feasible solution of an exemplary BACAP instance on the left hand side. In the space time diagram vessels are represented by rectangles with horizontal dimension equal to their length and vertical dimension expressing their port stay time. A gray shaded box within a vessel's rectangle indicates a QC being assigned to the vessel at an associated time t. It can be seen that the crane assignment influences the port stay times and therefore may render the berth plan infeasible, e.g. V_1 is served three additional hours if only four QCs are assigned and thus conflicts with V_2.

2.4 A Resource Oriented Objective Function

The most widespread objectives of terminal service-providers aim at minimizing the port stay times or the delays of vessels. These goals are important to fulfill customer expectations but they do not take the cost of operations into

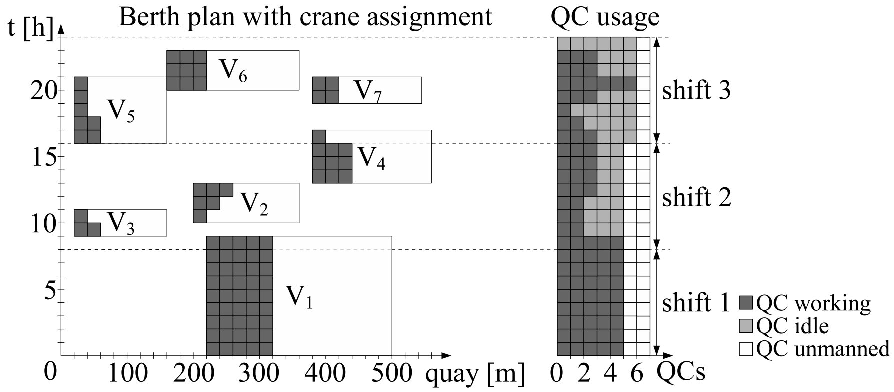

Abbildung 1. Berth plan with crane assignment and resulting QC usage

account. As the regional competition of terminal providers grows, however, cost orientation receives increasing importance. For this reason we introduce a new objective function that aims at a reduction of QC idle times. Idle times occur if a QC has been manned by a gang (seven or more workers) for a shift, but is not assigned to a vessel. This can e.g. happen due to the workload fluctuation. Especially difficult are large vessels which are served in parallel by many QCs at the beginning or at the end of a shift.

The occurrence of crane idle time is demonstrated for three consecutive working shifts (0-8, 8-16, 16-24) by the QC usage depicted at the right hand side of Fig. 1. We obtain a demand of five QCs for the first two shifts. However, in the shift 2 these QCs are only required from 8-9 to finish serving vessel V_1. Afterwards three and later two of the manned cranes get idle for the rest of the shift. A similar situation occurs in shift 3 where we observe a maximum demand of six QCs for only one hour.

To achieve a quantitative formulation of the objective function we introduce the following index variables:

t	working hours (enumerated), $t = 1, \dots T$
s	working shift $s = 1, \dots S$ with 8 hours per shift, $s(t) = \lceil \frac{t}{8} \rceil$
i	index of vessel V_i, $i = 1, \dots n$

Every solution of the BACAP provides the number of QCs assigned to V_i at time t denoted as r_{it}. The required number of manned QCs in shift s and the corresponding utilization rate are given by

$$c_s = \max \left\{ \sum_{i=1}^{n} r_{it} \mid t = 8(s-1)+1, 8(s-1)+2, \dots 8(s-1)+8 \right\} \quad (1)$$

$$u = \frac{\text{demanded QC capacity}}{\text{provided QC capacity}} = \frac{\sum_{t=1}^{T} \sum_{i=1}^{n} r_{it}}{\sum_{s=1}^{S} c_s \cdot 8} \quad (2)$$

Since the demanded capacity of QCs is preset, the utilization rate can only be improved by reducing the amount of capacity provided. This leads to the following objective function, which attempts to reduce the provided but unused QC capacity for a finite number of consecutive working shifts.

$$\min \rightarrow c = \sum_{s=1}^{S} \sum_{t=1}^{8} \left(c_s - \sum_{i=1}^{n} r_{i,8(s-1)+t} \right) \tag{3}$$

3 Scheduling Algorithm

This section outlines a heuristic scheduling algorithm for the BACAP which is based on priority-rule methods for the RCPSP. In our approach each vessel is represented by an activity. The required amount of the resource QC is allocated to the vessel activity over its duration. As there are several ways to allocate QCs, different modes of a vessel activity are created. An example is illustrated in Fig. 2 showing four modes of QC allocations for vessel V_4. This vessel requires a total of 11 QC-hours of service. The maximum number of parallel working QCs is three (*dashed line*). Using mode (a) the vessel is served from its berthing time b_4 by this maximum number of QCs which leads to $r_{4,b_4} = r_{4,b_4+1} = r_{4,b_4+2} = 3$ and $r_{4,b_4+3} = 2$. In mode (b) the vessel is served by at most two QCs and thus requires a single one during the last hour. Note that the vessel's port stay time increases from 4 to 6 hours if (b) is used instead of (a). Modes (c) and (d) show patterns with multiple changes of the crane assignment during a serving process. This can be a useful option if e.g. QCs become available during a shift or if a new vessel arrives which has to be served urgently. Many other modes are possible. However, modes with a lot of fluctuation are not welcome because they enforce frequent set-ups for the QCs.

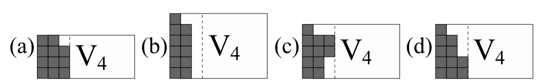

Abbildung 2. QC allocation modes for a vessel

In order to take the arrival times of vessels into consideration an additional activity must be included into the project for each vessel. Its processing time represents the lead time (head) for the arrival. This activity requires no resource and is a predecessor activity of the vessel's service activity. Predecessor relationships can also arise among the service activities of vessels, e.g. if a feeder vessel has to be delayed until a deep sea vessel discharged its containers.

To solve such problems heuristically, we apply a simple priority-rule based method. First, for every service activity we create eight QC allocation modes. Next, activities are introduced to ensure the arrival times. All these activities are inserted into the *open set*, which contains all so far unscheduled activities. Further required activity sets are the *active set* (actually processing activities), the *decision set* (activities with all predecessor activities already scheduled) and the *done set* (finished activities).

The procedure repeats the following steps until either the vessels have been scheduled completely or the allowed project duration T is exceeded, where T is set to the latest allowed departure time of all vessels. The project time t is incremented by discrete time steps (e.g. hours). If it turns out that an activity in the *active set* is completed in step t, it is inserted into the *done set*. The *decision set* is updated by inserting those activities of the *open set* which are ready to be scheduled but not yet scheduled. For all modes of these activities the increase of the objective function value is computed by assuming that the vessel is scheduled at time t. Then the activity modes are sorted in ascending order of their contribution to the objective function value increase. The first activity in the sorted set for which appropriate QC capacity and quay space are available is scheduled. The vessel's berthing time is set to t and its crane allocation vector r_{it} is set to the corresponding activity mode. Finally, the activity is deleted from the *decision set* and added to the *active set* and the associated data is updated.

Notice that the above procedure makes decisions regarding the berthing times and positions of vessels as well as the particular service modes to be used. Of course, more sophisticated RCPSP-techniques can be involved, cf. [5], but this is beyond the scope of this paper.

4 Computational Results

We applied the solution method to a real world problem provided by a major CT operator in Germany. The data reflects a period of one week in which 52 vessels had to be served. From this data six instances are generated which respectively include all vessels to be served at two consecutive days. These instances are denoted as I_{d_1/d_2} with d_1 and d_2 as consecutive days.

The scheduling algorithm was implemented in Java. All tests were performed on a PC Pentium 4 with 3.06 GHz. Table 1 compares the schedules which have been manually generated in practice with the solutions found by the proposed algorithm. The results include the idle times of QCs c and the resulting utilization rate u, compare Equations (3) and (2). Furthermore, the average departure time d is listed to observe the impact of the used objective function on the port stay times. The computational time lies below one second for all six instances and therefore, it is not shown in the table.

It can be seen that for each instance c decreases and therewith u increases. For $I_{1/2}$ and $I_{6/7}$ even the average departure time is shortened. At first glance the proposed approach appears promising although a careful analysis is necessary to really understand the interaction of the potentially conflicting

Tabelle 1. Computational results

	n	Manually found solution			Scheduling algorithm			Relative deviation		
		c [QC-hrs.]	u [%]	d [hrs.]	c [QC-hrs.]	u [%]	d [hrs.]	c [%]	u [%]	d [%]
$I_{1/2}$	13	79	71	31.7	47	80	30.8	−41	+13	−3
$I_{2/3}$	12	49	69	28.8	41	73	29.0	−16	+ 6	+1
$I_{3/4}$	16	65	77	28.7	41	84	29.3	−37	+ 9	+2
$I_{4/5}$	14	103	75	29.4	39	87	30.8	−62	+16	+5
$I_{5/6}$	11	81	76	38.0	57	82	38.4	−30	+ 8	+1
$I_{6/7}$	18	96	68	32.7	49	81	32.5	−49	+19	−1

objectives. If successful, further research will concentrate on the incorporation of powerful improvement heuristics to solve larger problem instances.

5 Conclusions

The paper introduced a new objective function for the integrated BACAP occurring at seaport CTs. It considers the terminal operator's labor cost by minimizing the idle time of QCs. The problem was solved heuristically by a priority-rule based method. First computational tests came along with good results encouraging further research in the field.

Literatur

1. Daganzo C F (1989) The crane scheduling problem, Transportation Research B 23/3: 159–175
2. Guan Y, Cheung R K (2004) The berth allocation problem: models and solution methods, OR Spectrum 26: 75–92
3. Imai A, Sun X, Nishimura E, Papadimitriou S (2005) Berth allocation in a container port: using a continuous location space approach, Transportation Research B 39: 199–221
4. Kim K H, Moon K C (2003) Berth scheduling by simulated annealing, Transportation Research B 37: 541–560
5. Neumann K, Zimmermann J (2000) Procedures for resource leveling and net present value problems in project scheduling with general temporal and resource constraints, European Journal of Operational Research 127: 425–443
6. Park Y M, Kim K H (2003) A scheduling method for berth and quay cranes, OR Spectrum 25: 1–23
7. Steenken D, Voß S, Stahlbock R (2004) Container terminal operation and operations research - a classification and literature review, OR Spectrum 26: 3–49
8. Vis I F A, de Koster R (2003) Transshipment of containers at a container terminal: an overview, European Journal of Operational Research 147: 1–16