Chapter 6
Berth Allocation and Quay Crane Assignment

The new concept for integrated seaside operations planning comprises a deep integration of the BAP and the QCAP. The resulting problem, namely the Berth Allocation and Crane Assignment Problem (BACAP), is studied within this chapter. The first mathematical formulation of the combined problem of berth allocation and crane assignment has been presented by Park and Kim (2003). A new problem formulation has been provided by Meisel and Bierwirth (2009), which incorporates QC productivity determining effects. This new model is presented in Sect. 6.1 and solution methods are described in Sect. 6.2. Computational tests follow in Sect. 6.3. Section 6.4 concludes the BACAP study.

6.1 Modeling the BACAP

6.1.1 Problem Description and Assumptions

The BACAP bases on the continuous dynamic variant of the BAP. It is formally described as follows. A terminal with a quay of length $L$, measured in segments of 10 m length, is considered. A number of $Q$ QCs is available to serve vessels. The planning horizon of the BACAP is $H$ hours, where $T$ is a corresponding set of 1-hour time periods, i.e., $T = \{0, 1, \ldots, H - 1\}$. Within the planning horizon a set of vessels $V = \{1, 2, \ldots, n\}$ is projected to be served, where $n$ is the total number of vessels.

For each vessel $i \in V$ its length $l_i$, measured in segments of 10 m length, is given. The crane capacity demand of vessel $i$ to fulfill all loading and unloading operations is $m_i$ QC-hours. The minimum and maximum number of QCs to assign to the vessel are denoted by $r_i^{\text{min}}$ and $r_i^{\text{max}}$, yielding the range $R_i = [r_i^{\text{min}}, r_i^{\text{max}}]$. Furthermore, an expected time of arrival $\text{ETA}_i$ is given. Berthing the vessel earlier than $\text{ETA}_i$ is possible by a speedup on its journey to the terminal. The realizable speedup, however, is bounded. To model this an earliest starting time $\text{EST}_i \leq \text{ETA}_i$ is given, i.e., the
vessel cannot be berthed earlier than \( EST_i \). Finally, an expected finishing time \( EFT_i \) and a latest finishing time \( LFT_i \) are given for the vessel. Import and export containers of a vessel are stored in dedicated yard areas. A desired berthing position \( b^0_i \) is specified for vessel \( i \) within the vicinity of these yard areas.

The following assumptions are made for the BACAP:

1. Each quay position shows sufficient water depth to berth arbitrary vessels.
2. It takes no time to berth and to unberth vessels.
3. It takes no time to move a QC from one vessel to another vessel.
4. Vessels are served without preemption, i.e., once started to serve a vessel the process is not interrupted until the service is completed.
5. Every crane has the technical capability to serve every vessel. Furthermore, the cranes are identical, i.e., they show the same maximum productivity.

The decisions of the BACAP are to determine a berthing time \( s_i \), a berthing position \( b_i \), and the number of QCs to assign to each vessel \( i \in V \) in its service periods such that a cost measure is minimized. The berthing time \( s_i \) of a vessel follows from the beginning of the first period with cranes assigned, whereas its departure time \( e_i \) is defined by the end of the last period with cranes assigned. The time span between \( s_i \) and \( e_i \) defines the handling time of vessel \( i \). The assignment of cranes to vessels is represented by a binary decision variable \( r_{itq} \). It is set to 1, if and only if exactly \( q \) QCs are assigned to vessel \( i \) at time \( t \). To evaluate a solution to the BACAP, the deviation from the desired berthing position \( \Delta b_i = |b^0_i - b_i| \), the necessary speedup \( \Delta ETA_i = (ETA_i - s_i)^+ \), and the tardiness \( \Delta EFT_i = (e_i - EFT_i)^+ \) are determined for each vessel \( i \). Figure 6.1 illustrates the interrelations of the so far introduced vessel data and variables. A description of the cost structure of a vessel follows in Sect. 6.1.3.

### 6.1.2 Resource Utilization

Different effects influence the productivity of a terminal and thus, the utilization of its resources. For seaside operations, two influencing factors are of importance and need to be incorporated in a BACAP formulation: