Chapter 5
Integration Concepts for Seaside Operations Planning

In this chapter different concepts for an integrated solution of seaside planning problems are discussed. Section 5.1 assesses a sequential solution process of the focused problems and provides a theoretical framework for an integrated solution of optimization problems. Following these ideas, a survey of published integration concepts for the seaside planning problems is provided in Sect. 5.2. The particular integration concept to investigate in the thesis is outlined in Sect. 5.3.

5.1 Sequential Solution

Seaside operations planning basically comprises a single optimization problem regarding the service of vessels under limited quay space and QC capacity where the objective is to maximize an appropriate quality measure for the provided service. However, in practice as well as in the scientific literature, the complexity of this overall problem is broken down into subproblems of manageable complexity, namely the BAP, the QCAP, and the QCSP. The separate consideration of these problems calls for a hierarchy, which defines an order for solving them. The sequential solution process enables a clear distinction of responsibilities among involved planners and an unambiguous chronology of decision making. It has to be noted that hierarchical planning is by no means unique to terminal operations planning. It is also a well known concept in production planning. In the basic model of hierarchical production planning of Hax and Meal (1975), product items are aggregated to product families, which, in turn, are aggregated to product types. A sequential solution process decides first on the production program for product types, then on the lot sizes for product families, and, finally, on the lot sizes for the product items of a family. As typical for hierarchical planning, each particular decision has to respect thereby the decisions made at previous levels of the hierarchy.

The sequential solution process of the three CT seaside planning problems is sketched in Fig. 5.1 together with the relevant input and output data of each

F. Meisel, *Seaside Operations Planning in Container Terminals*,
Contributions to Management Science,
DOI: 10.1007/978-3-7908-2191-8_5,

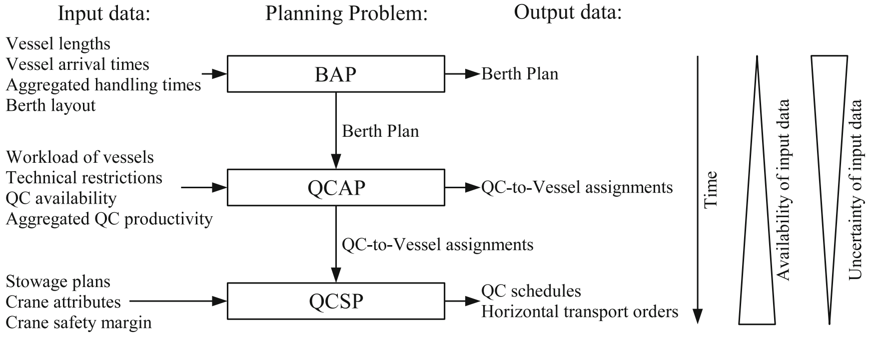

Fig. 5.1 Sequential planning of seaside operations

individual problem. As can be seen, the output (solution) of one problem may serve as a work plan for the terminal resources as well as an input for the subsequent planning problem.

Within the stated problem order the BAP is solved first. Vessel and quay data serve as a major input. Note that the handling time of a vessel represents aggregated data because the particular service process has not been planned yet. In the following QCAP, cranes are assigned to vessels with respect to the berthing times and berthing positions of vessels as derived within the BAP, i.e., the berth plan serves as an input for the crane assignment. Further input data is the workload of each vessel, e.g., the number of containers to charge and discharge, technical restrictions such as the maximum number of cranes to assign, and the availability of QCs within the planning horizon. Additionally, a QC productivity estimate can be used to decide on the crane capacity to assign to a vessel. At this stage, however, only empirical data, such as the number of moves per hour and crane observed at the terminal on average, can be used. Afterwards, the QCSP is solved, where the QC-to-Vessel assignments serve as an input. These assignments specify the availability of cranes at a vessel. Additionally, precise stowage plans are required for the detailed crane scheduling in order to derive the distribution of workload over the bays of a vessel.

The described sequential solution process reflects the increasing availability of input data and its decreasing uncertainty in the course of time. Nevertheless, the weakness of sequential planning becomes obvious in the light of the fact that the solution of a problem is based heavily on estimated input data. The BAP incorporates aggregated handling times while more precise handling times are obtained when the QCAP is solved afterwards. Similarly, the QCAP uses estimated QC productivity information although the realizable productivity of assigned cranes is revealed in the QCSP, specifying the QC capacity demand of a vessel. In the sequential solution process, decisions made at previous stages cannot be revised, even if the outcome of a subsequent planning problem does not fit the estimates previously used. In practice this leads to *ad-hoc modifications of plans* during their execution, whenever infeasibilities or poor performance are identified. If, for example, due to an insufficient assignment of crane capacity, the service of a vessel takes longer than expected, subsequently served vessels must be delayed or reassigned to other quay positions. Obviously, such modifications disturb the operations of the CT. In the best case, they cause idle times of quay space and cranes. More worse, ad-hoc modifications of berthing times and increased vessel handling times reduce the reliability of terminal services and thus, reduce the satisfaction of CT customers.

Enhanced seaside operations planning is based on *precise vessel handling times*, which are achieved through considering the QC resource within the berth planning. This requires a turn away from the problem hierarchy towards alternative integration concepts for seaside operations planning. To provide a framework for distinguishing different concepts, the first of two sequentially solved problems is referred to as the top-level problem in the following and the second is called the base-level problem, see Schneeweiss (2003). The base-level has to respect decisions made at the top-level. They are propagated in the form of instructions to the base-level. In seaside operations planning the BAP is a top-level problem for the QCAP which plays the role of a base-level problem. Moreover, the QCAP is the top-level problem to the QCSP.

According to Geoffrion (1999) integration of two problems can be done either by a *deep integration* or by a *functional integration*. Similar concepts are proposed by Muhanna and Pick (1988) and Dolk and Kottemann (1993) under different terms. Deep integration merges the top-level problem and the base-level problem into a single monolithic problem formulation, which makes a propagation of instructions obsolete. While solutions may be excluded from the search in a sequential solution process because of the incomplete consideration of the subproblem interrelations, deep integration enables to search the complete solution space of the overall problem. However, a deep integration causes in general a strong increase in the computational effort compared to a sequential solution process.

A functional integration is based on the original formulations of the problems. The integration is realized by a computational agenda that defines the sequence of the problems in the solution process and the data to exchange between the base-level and the top-level. Basically, functional integration of two problems can follow two possible ways. If the order given by the hierarchy is preserved, integration takes place by feeding back the output of the base-level as a further input for the top-level, see Fig. 5.2a. The top-level decisions are revised by solving the problem

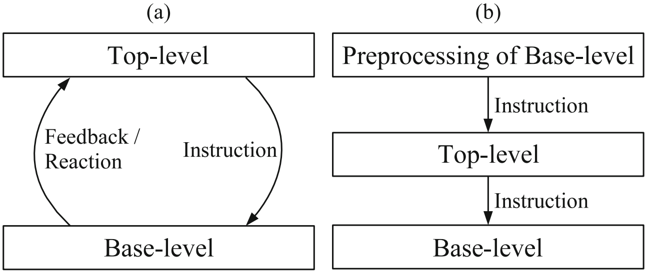

Fig. 5.2 Functional integration by a feedback loop (**a**) and by a preprocessing (**b**)

again using the feedback information. Such a *feedback loop* is performed iteratively until a certain termination criterion is met, e.g., a steady state is reached where no change in the solutions of the top-level problem is observed. The second way for a functional integration is to change the order of solving the problems, see Fig. 5.2b. Here, the original base-level problem is solved in a *preprocessing* phase to generate more detailed input data for the top-level problem. The success of this type of functional integration depends on the quality of base-level solutions. Note that these solutions have to be generated without knowing a top-level problem solution. The top-level problem incorporates information obtained in the preprocessing. Moreover, as shown in Fig. 5.2b, the base-level solutions of the preprocessing phase can be revised by finally solving the base-level problem again.

5.2 Integration Concepts in the Literature

Recent integration approaches for seaside operations planning motivate a further classification scheme, based on the concepts briefly introduced in the previous section. To distinguish problem integration by monolithic models (deep integration), by problem preprocessing, and by feedback loops, the notation of Table 5.1 is used. In this table, capitals A and B stand proxy for a BAP, QCAP, or QCSP. If a planning problem involves multiple decision variables but not all of them are determined at once in the integration model, the addressed decisions appear in brackets. For example, $\boxed{\text{BAP, QCAP(number)}} \longrightarrow \text{QCAP(specific)}$ stands for an integration where a berthing time and position, and a number of cranes are assigned to every vessel in a monolithic model, while the used cranes are specified subsequently.

Table 5.2 gives an overview of approaches for integrated seaside operations planning. In the following the mentioned papers are reviewed with respect to the used integration models. Approaches that exclusively use functional integration are proposed by Lee et al. (2006) and Lokuge and Alahakoon (2007). Lee et al. (2006) consider a feedback loop integration between the discrete BAP and the QCSP. There is no QCAP involved because the berths possess dedicated cranes. The solution of the BAP delivers a sequence for serving the vessels at each berth. A resulting QCSP is solved for every vessel and the obtained handling times are returned to the berth planning level to revise the vessel sequences. This loop is executed for a preset number of iterations. In Lokuge and Alahakoon (2007) a MAS is used to integrate the hybrid BAP and the QCAP. Cranes are dedicated to berths which are

Table 5.1 A notation scheme for problem integration concepts

Notation	Description
$\boxed{\text{A, B}}$	Deep integration of problems A and B
$\text{A} \rightarrow \text{B}$	A is preprocessed to B
$\text{A} \rightleftarrows \text{B}$	Feedback loop integration of A and B

Table 5.2 Overview of integration concepts for seaside operations planning

Integration concept	Reference
BAP $\rightleftarrows$ QCSP	Lee et al. (2006)
BAP $\rightleftarrows$ QCAP	Lokuge and Alahakoon (2007)
$\boxed{\text{BAP, QCAP(number)}}$	Oğuz et al. (2004), Meisel and Bierwirth (2006), Hendriks et al. (2008), Giallombardo et al. (2008), Liang et al. (2009)
$\boxed{\text{BAP, QCAP(number)}} \rightarrow$ QCAP(specific)	Park and Kim (2003)
$\boxed{\text{BAP, QCAP(number)}} \rightleftarrows$ QCAP(specific)	Imai et al. (2008a)
$\boxed{\text{BAP, QCAP}}$	Rashidi (2006), Theofanis et al. (2007b)
BAP $\rightleftarrows \boxed{\text{QCSP, QCAP}}$	Meier and Schumann (2007)
$\boxed{\text{BAP, QCAP(number), QCSP}} \rightarrow$ QCAP(specific)	Ak and Erera (2006)
QCSP $\rightarrow \boxed{\text{BAP(berthing times), QCAP}}$	Liu et al. (2006)
$\boxed{\text{QCAP, QCSP}}$	Daganzo (1989), Peterkofsky and Daganzo (1990), Tavakkoli-Moghaddam et al. (2009)

shared by vessels served at the same time. The problem is solved by software agents responsible for berth planning and communicating with other agents responsible for the crane assignment. The architecture of the used MAS constitutes a feedback loop integration of the BAP and the QCAP.

A deep integration of the continuous BAP and the QCAP is investigated by Oğuz et al. (2004), Meisel and Bierwirth (2006), Hendriks et al. (2008), Park and Kim (2003), Rashidi (2006), and Theofanis et al. (2007b). These papers present optimization models to decide on the berthing time, the berthing position, and the number of cranes for each vessel. The same decisions are considered for the discrete BAP by Giallombardo et al. (2008), Liang et al. (2009), and Imai et al. (2008a). In four of these approaches, the specific cranes used for the service of vessels are additionally determined. For this purpose different integration concepts are applied. Park and Kim (2003) consider the specific crane assignment as an end-of-pipe optimization which is appropriately solved in a postprocessing phase. In contrast, Imai et al. (2008a) return the specific crane assignment to the berth planning level where the made berthing decisions are evaluated and possibly revised. In two papers, the number and the specific set of cranes assigned to vessels are decided within a monolithic model. Rashidi (2006) merges the top-level problem and the end-of-pipe problem of Park and Kim (2003) into a single optimization model. A deep integration is also proposed by Theofanis et al. (2007b) for simultaneously assigning QCs and allocating vessels along the quay.

Several authors study integration models that involve all of the three seaside planning problems. A feedback loop integration of the BAP and the QCSP is described by Meier and Schumann (2007). The loop propagates a berth plan to the crane scheduling level. Detailed vessel handling times are obtained and returned to the top-level for an adjustment of the berth plan. The approach comprises a deep integration of QCAP and QCSP, because the crane schedules are collectively built for vessels served at the same time. Ak and Erera (2006) present an integration model that jointly decides on berth allocation, crane assignment, and crane scheduling. Merely the specific crane assignment is determined in a postprocessing, as has been proposed by Park and Kim (2003). The integration model of Liu et al. (2006) targets on the revision of a tentative berth plan. First, crane schedules are preprocessed to generate possible vessel handling times for each vessel and each assignable number of cranes. Next, specific cranes are assigned to vessels, where the tentative handling times are replaced by selecting values provided in the preprocessing phase. In order to minimize the maximum vessel tardiness, the tentative berthing times are revised in this model. The berthing positions are taken from the tentative berth plan.

Further integration models are formulated by Daganzo (1989) and Peterkofsky and Daganzo (1990). They combine the QCAP and the QCSP by simultaneously scheduling multiple cranes for a set of vessels. The authors remark that berthing decisions should be integrated with crane operations planning and illustrate this issue by examples under the assumption of identical sized vessels. Also Tavakkoli-Moghaddam et al. (2009) deal with the integration of crane assignment and scheduling. In this work the QCSP model of Kim and Park (2004) is extended such that multiple vessels are considered in parallel.

5.3 Designing a Comprehensive Integration Concept

As shown in the previous section, concepts for the integration of BAP, QCAP, and QCSP within the overall problem of seaside operations planning have seldom been investigated in scientific literature. Merely Liu et al. (2006), Ak and Erera (2006), and Meier and Schumann (2007) provide studies concerning this matter. In the following a new integration concept is presented in order to contribute to this field of research. The overall objective is to derive a concept that enables to determine berthing positions, berthing times, crane assignments, and crane schedules for the vessels with respect to the interrelations of the decisions fields. The following questions must be answered for the design of an integration concept:

1. Which variant of the BAP, the QCAP, and the QCSP is involved as subproblem in the overall problem of seaside operations planning?
2. How are the considered subproblems integrated within the overall problem?

The first question is answered by identifying problem characteristics that call for an integration. In CTs where the quay is not partitioned into berths, the assignment of cranes to vessels is most flexible and thus, the interrelations between BAP and QCAP are of particular importance. Hence, the continuous type of BAP is the most relevant problem variant for integrated seaside operations planning.

Moreover, respecting arrival times of vessels is indispensable for providing a satisfying service quality to vessel operators, calling for the consideration of the continuous dynamic BAP. A best possible assignment of cranes to vessels is enabled by considering variable-in-time QC-to-Vessel assignments. The important practical relevance of such assignments is revealed by the empirical investigation of Chu and Huang (2002). Hence, the crane assignment problem has to be formulated such that variable-in-time assignments are in its scope. The crane scheduling problem must be formulated at a reasonable level of detail in order to uncover the productivity loss caused by crane interference. A useful aggregation level for the QCSP is to define tasks by container groups. It allows cranes to share the workload of bays to a certain extent, while the computational effort is still moderate compared with scheduling single containers. The container group strategy preserves furthermore the grouping information of containers, which eases the planning of horizontal transport operations.

The question how to integrate the considered subproblems in the overall problem cannot be answered consistently. A deep integration of BAP and QCAP has been studied in diverse papers, proving that the resulting problem is still computationally tractable. Unfortunately, a deep integration of the QCSP into the BAP and/or the QCAP fails for practical reasons. In practice vessel operators have often not transmitted the stowage plans for vessels once the seaside operations are to be planned. Consequently, the required input data for the crane scheduling is not available. A functional integration is more flexible because it can be bypassed for vessels without available stowage plans. Hence, functional integration is useful for the integration of crane scheduling into berth planning and crane assignment.

The studies of Liu et al. (2006), Ak and Erera (2006), and Meier and Schumann (2007) consider the three seaside planning problems not on the level of abstraction described above. Liu et al. (2006) decide on the berthing times of the vessels, but assume that the berthing positions are given. Furthermore, variable-in-time QC-to-Vessel assignments are not in the scope of the approach. Also the approaches of Ak and Erera (2006) and Meier and Schumann (2007) show apparent weaknesses. For the proposed deep integration of the QCSP into the BAP or the QCAP, the relevant input data may not be available in practice. Furthermore, both studies define tasks on the basis of complete bays and ignore safety margins, which is inadequate for the integration of crane scheduling within the overall problem of seaside operations planning.

The new concept, which builds the basis for the integration of seaside planning problems in the thesis, is outlined in Fig. 5.3. It comprises a deep integration of BAP and QCAP within the *berth planning phase* and functional integrations of the QCSP in a *preprocessing phase* and a *feedback loop phase*. For the berth planning phase the concept of Park and Kim (2003) is taken up. It enables variable-in-time QC-to-Vessel assignments, and it decides also on the specific cranes that serve a vessel.

In the preprocessing phase, individual crane productivities for each vessel are generated in terms of crane utilization rates. This data is involved in the berth planning phase to generate appropriately dimensioned variable-in-time QC-to-Vessel assignments. To obtain precise crane productivities, a rich QCSP formulation has to

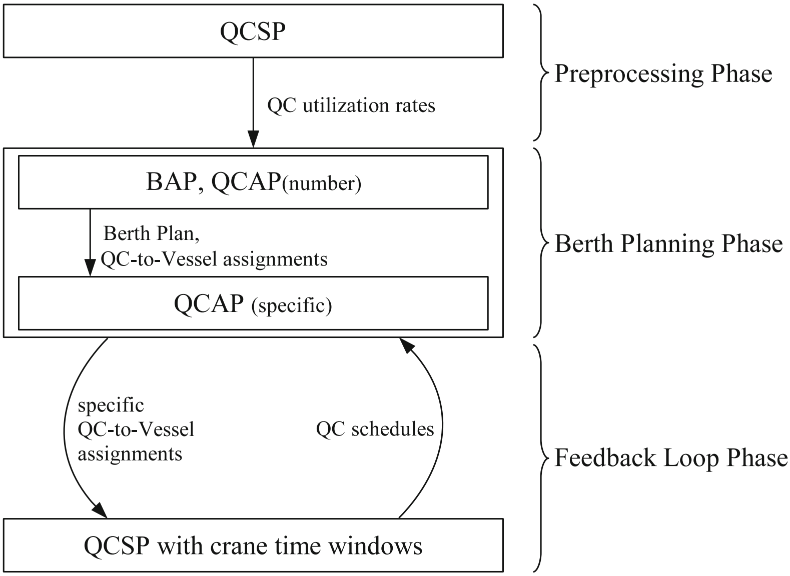

Fig. 5.3 A new concept for integrating seaside planning problems

be employed where tasks are defined by container groups and where safety margins, the non-crossing condition, and movement time of cranes are respected. Such a formulation is provided in the stream of research of Kim and Park (2004), Moccia et al. (2006), and Sammarra et al. (2007).

The feedback loop phase generates crane schedules for the QC-to-Vessel assignments derived in the berth planning phase. This requires an extension of the QCSP with respect to time windows for the cranes. Feeding back these crane schedules into the berth planning phase is necessary in order to adjust inappropriate crane assignments, berthing positions, and berthing times.

To summarize, the new integration concept represents the decisive interrelations between berth planning and crane operations planning. The subsequent chapters of the thesis provide studies that are concerned with modeling, solving, and linking of the optimization problems contained in the integration approach. Chapter 6 provides a study on the berth planning phase. In Chap. 7 crane scheduling is investigated as an isolated problem. Finally, in Chap. 8 the integration of crane scheduling into the berth planning phase is considered by investigating the preprocessing phase and the feedback loop phase in detail.