

AN INTEGRATED SIMULATION AND OPTIMIZATION APPROACH FOR SEASIDE TERMINAL OPERATIONS

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KEYWORDS

Discrete Event Simulation, 0/1 MIP optimization model, container terminal, seaside operations planning, performance analysis.

ABSTRACT

In this paper we focus our attention on the operational decision problems related to the seaside area of maritime container terminals. In particular, we face the Quay Crane Assignment Problem (QCAP) and Quay Crane Scheduling Problem (QCSP) with an integrated simulation-optimization approach. A 0/1 MIP model is developed in order to determine the optimal assignment, on a shift basis, of QCs to bays of each ship served by the terminal during a given planning horizon, referred as *Bay_QCAP*. The optimization model solutions are used as input parameters for a Discrete Event Simulation (DES) model able to reproduce the system behaviour taking into account its stochastic nature and complexity. The framework can be used for evaluating the impact on the seaside terminal performance of the optimized solutions and the effects of different operative decisions related to the scheduling of QCs.

The framework is going to be applied to a real case study pertaining to the Southern European Container Hub (SECH), sited in the Port of Genoa, Italy.

INTRODUCTION

The competitiveness of a marine container terminal is based on different factors, such as transshipment time combined with low rates for loading and discharging and fast turnover of containers, which corresponds to a reduction of the berthing time and, consequently, of the cost of the whole transportation process. A marine terminal must be managed in such a way to optimise the flow of containers that arrive and leave it in various ways, as, for instance, by trucks, trains and vessels.

A terminal can be viewed as made up of many interrelated logistic processes as stressed in Vis and De Koster (2003) and Steenken et al. (2004). In these interesting overview papers the authors give a classification of the decision problems at marine container terminal in accordance with the following logistic processes: *i*) arrival of the ship, *ii*) discharging

and loading of the ship, *iii*) transport of containers from ship to stack and vice versa, *iv*) stacking of containers, and *v*) inter-terminal transport and other modes of transportation.

In this paper we focus our analysis on the discharging and loading of the ship process. In particular, we are interested in the tactical and operational decision problems related to the organization of the loading and unloading operations.

Gunther and Kim (2006) propose a classification of the problems arising in terminals following the planning level of decisions. In particular, the strategic level refers to long-term decisions pertaining to layout, connections, equipment, berthing and yard capacity, the tactical level regards mid-term decisions pertaining to berth and yard planning and policies, while the operational level refers to short-term decisions pertaining to quay side and land side operations. It is worth mentioning that there are strong relations among strategic, tactical and operations planning at the seaside area, as at the yard and the landside area.

Focusing on the seaside terminal management operations the main problems and their interrelations (see Figure 1) are described in details in a recent survey of Bierwirth and Meisel (2010).

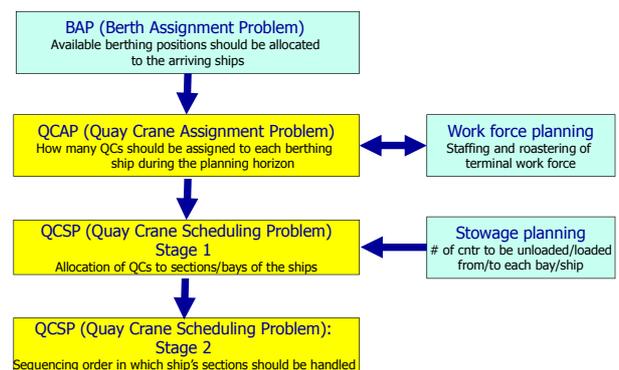


Figure 1: Seaside Decision Problems

The Berth Allocation Problem (BAP) concerns the assignment of quay space to vessels that have to be unload and loaded at the terminal. The Quay Crane Assignment Problem (QCAP) defines how many QCs assigning to each berthing ship, while the Quay Crane Scheduling Problem (QCSP) determines the allocation

of tasks to QCs (stage 1) and tasks schedule of each QC (stage 2). Note that tasks can be related to a bay area, a bay, stacks, or group of containers.

Generally, researchers decompose the seaside system into sub-systems and approach the above mentioned problems separately as single decision problem.

Anyway, as pointed out by the recent literature, the interrelations among the decision problems arising in the terminal seaside planning should not be ignored. In fact, only to give an example of these interrelations, we can note the QCSP has a direct connection with the QCAP that defines the exact number of quay cranes operating a vessel; in QCSP tasks must be split and scheduled among the assigned quay cranes.

The main aim of QCSP usually regards the minimization of the makespan of the quay cranes schedule that represents the handling time of a vessel. This time is strictly connected with the number of assigned quay cranes, and finally the BAP depends on the handling time necessary for serving each vessel.

The number of available quay cranes to assign to vessels is directly affected by the quay crane deployment problem (i.e. see Legato et al. 2008) and by the ground crew planning problem (see Legato and Monaco 2004 for details on this problem). Moreover, the tasks to be scheduled in the QCSP are also affected by the stowage plans (see Ambrosino et al. 2004 for details on this problem).

Due to the impact of QCAP on the handling time, in the recent literature it is quite frequent to find integrated approaches for QCAP and BAP. In Bierwirth and Meisel (2010) a classification scheme for integrated seaside operations planning is reported. This scheme follows two different integration concepts proposed by Geoffrion (1999), i.e. deep and functional integration. In the deep integration a whole model includes interrelations among decisions, while in functional integration there is a sequence of solutions of sub-problems and a data exchange between base level and top level.

Approaches based on functional integration between the BAP and QCSP, between BAP and QCAP are reported i.e. in Lee et al (2006), Lokuge and Alahakoon (2007).

Approaches based on deep integration between BAP and QCAP are described, among others, in Giallombardo et al. (2008), Imai et al. (2008), Theofanis et al. (2007) and Park and Kim (2003). In Tavakkoli-Moghaddam et al. (2009) an approach based on deep integration between QCAP and QCSP is presented. Finally, some papers deal with integrated approaches among the three problems arising in the seaside planning (BAP-QCAP-QCSP), and sometimes deep and functional integration are jointly used. The interested readers can see for example Ak and Erera (2006), Liu et al. (2006) and Meisel (2009).

By more holistic point of view, simulation approaches have been quite often used to analyze the seaside terminal operations performance. Nam et al. (2002) examine the optimal number of berths and quay cranes for a terminal in Busan (Korea), while Legato and Mazza (2001) develop a simulation model for the

arrival-departure process of vessels at the container terminal of Gioia Tauro (Italy) that is used for optimisation scenario analysis of the berth planning problem. Kia et al. (2002) describe the role of simulation for evaluating the performance of a terminal's seaside equipment and capacity in Melbourne by using interesting performance criteria and model parameters.

In this paper, we start studying the challenging problem of integrating simulation and optimization (Fu 2002; Fu et al. 2005) in order to put together the capability of simulation to describe the dynamics of the system considered and perform scenarios analysis (what-if analysis), with the decisional advantage of optimization, i.e. what-best analysis.

The potentialities of an integrated simulation and optimization approach are herein exploited in order to analyse the performance of the seaside planning at an import/export container terminal.

In particular, we focus our attention on the QCAP and QCSP and propose an integrated simulation-optimization approach to solve in a concise framework the two problems (Figure 1). More precisely, we use a deep integration to solve the QCAP and QCSP (stage 1) by means of an ad hoc optimization model, called *Bay_QCAP*. Afterwards, applying a functional integration, the optimization model solution is used by a Discrete Event Simulation (DES) model designed to reproduce and evaluate alternative scheduling rules and solutions of the QCSP (stage 2) introducing in the analysis some stochastic elements (e.g. QCs' breakdowns).

The paper is organized as follows. Firstly the main characteristics of the modelling approach are described, with particular attention to the performance indexes to be computed. Afterwards, more details on both the optimization model *Bay_QCAP* and the DES model are reported. Finally, the main characteristics of the case study we are going to investigate are presented and some conclusions and further work are given.

PROBLEM ADRESSED AND MODELLING APPROACH

As described in the previous section our analysis is focused on the seaside area at container terminals with particular attention to the operational decisions problems related to the organization of the loading and unloading operations.

In particular, given:

- i) the expected time of arrival (ETA) and berthing position of the ships served by the terminal in a given planning horizon, i.e. the solution of the BAP;
 - ii) the number of import and export containers to be handled and their position on board, i.e. the solution of MBPP;
 - iii) the staffing and rostering of terminal work force;
- we are involved in the QCAP and QCSP, as described in previous section.

In more details, we have to define the assignment of quay cranes to the vessels served by the terminal, and,

more precisely, determine both the assignment of quay cranes to the bays of the vessels (QCAP) and the schedule of tasks of each quay crane (QCSP), in such a way to minimize the berthing time of the ship and the quay crane costs.

The problems herein addressed are solved with an integrated simulation-optimization approach, whose main characteristics are depicted in Figure 2. As optimization is referred, we focus our attention on the QCAP and QCSP (stage 1). A 0/1 MIP model has been developed in order to solve the *Bay_QCAP* and give the optimal number of QCs to be assigned to each ship as well as the assignment of QCs to the bays of the ships.

The optimization model solution is used as input parameter for a Discrete Event Simulation (DES) model designed to simulate the QCSP (stage 2). The DES model is able to manage the non-deterministic and dynamic behaviour of the system and its complexity and can be used to evaluate the impact on the seaside terminal performance of the optimized solutions.

The model can also be used to introduce many causes of variability in the system, such as breakdown and shift set-up times for the QCs and trucks, unplanned delays, meteorological adverse conditions, etc.

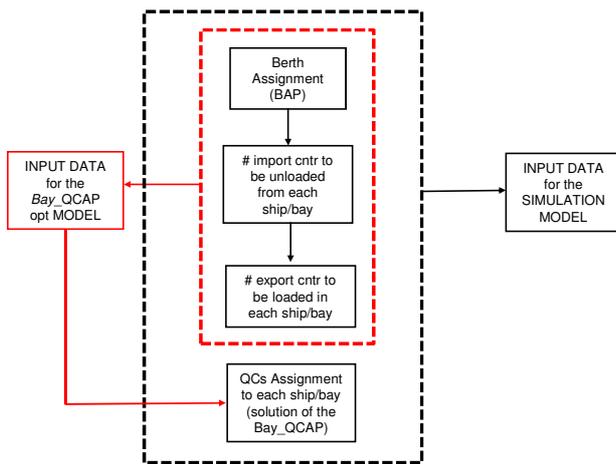


Figure 2: Integration between DES and QCAP opt model

Moreover, the major advantage of the integrated approach herein proposed is its ability to face in a concise and tractable framework both the QCAP and QCSP, using both deep and functional integration. More details on the *Bay_QCAP* and DES model are given in the following sections.

Performance Indexes

A major characteristic of the framework herein analysed is its ability to perform a very informative bottom-up performance analysis (Figure 3). In particular, we start by the assessment of the productivity of the resources involved in the seaside operations, i.e. gangs and QCs. Note that, a gang is defined as a team of human and

associated handling equipment, generally, composed of one quay crane driver, one deck man, one checker, one to three yard crane drivers, three track drivers, two twist handlers (for the entire ship) and three to eight lashing and unlash operators (for the entire ship). Note that each gang is assigned to one or more working periods (shifts); generally, a shift is 6 hours long.

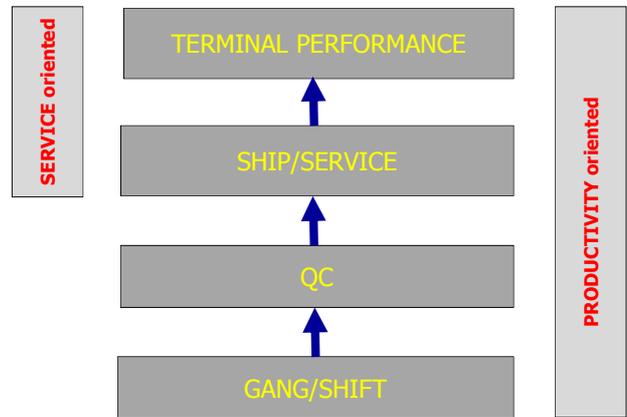


Figure 3: Bottom-up performance analysis

Afterwards, the indexes for each ship/service and for the whole terminal are computed as averages. Moreover, we focus our attention on the evaluation of two series of performance indexes. The first are the so-called productivity-oriented indexes (P) that measure the container traffic volume internal performance of the resources involved, while the second are the service-oriented indexes that measure the service levels (S) provided to clients and are computed for each service/ship and as a macro level terminal point of view. In Table 1 the whole set of indexes included in the performance analysis is reported.

With reference to the productivity oriented indexes, we decided to use: 1) the berth utilization level, expressed in terms of percentage time of berthing area utilization; 2) the QCs utilization, expressed in terms of percentage of utilization of the QCs involved in the seaside operations; 3) the QC and gang productivity computed as the ratio between the container moves and the berthing time and total shift time, respectively; 4) the “gang” utilisation rate expressed in terms of utilisation (in percentage), i.e. busy time, of the shifts, involved in the loading and unloading operations of each ship; 5) the gang used and related cost. The productivity level indexes should be computed for a macro level/terminal point of view, but more importantly they are also assessed for each ship/service, for each QC and for each gang (i.e. for each shift working period).

The service indexes are usually computed for each ship or service berthing the terminal. Among this group the most important are the berthing time and the so-called terminal performance index, expressed as the ratio between the total number of containers moved and the total berthing time. The above indexes can also be assessed as average, computing the above indexes for

the whole set of ships served by the terminal during a given planning horizon.

The proposed bottom-up performance analysis can allow the terminal to better understand bottlenecks in the seaside process, major costs and productivity gaps in the system.

Table 1. Performance indexes

<i>GANG/shift</i>	<i>Type</i>
Shift moves	P
Shift working time	P
Gang productivity=shift moves/shift length	P
Gang utilization= Gang working time/shift length	P
<i>QUAY CRANE</i>	
QC moves	P
Crane working time	P
# gangs (shifts) used	P
Crane productivity=QC moves/Crane working time	P
Crane utilization= Crane working time/Berthing time	P
Gang productivity=QC moves/(# gang used*shift length)	P
Gang utilization= Crane working times/(# gang used*shift length)	P
<i>SHIP/SERVICE</i>	
Ship moves	S
Berthing time	S
Vessel operation time (Gang on - ashore) (=loading time)	S
Terminal performance index=Total moves / Berthing time	S
% of berth utilization = Berthing time / Total time	P
Crane productivity = Ship moves / \sum Crane working times	P
Crane utilization = Avg crane working time/Berthing time	P
Gang productivity=Ship moves/(# gang used*shift length)	P
Gang utilization= \sum gang working times/(# gang used*shift length)	P
# gangs (shift) used	P
Ship gang cost	P
<i>TERMINAL</i>	
Total moves	S
Total Berthing time	S
Vessel operation time (Gang on - ashore) (=loading time)	S
Terminal performance index=Total moves / Berthing time	S
Berth utilization = Total Berthing time / Total time	P
Crane productivity = Total moves / \sum Crane working times	P
Crane utilization = Avg crane working time/Berthing time	P
Gang productivity=Total moves/(# gang used*shift length)	P
Gang utilization= \sum Gang working times/(# gang used*shift length)	P
# gangs (shift) used	P
Total terminal gang cost	P

Bay_QCAP MODEL

The model herein developed is designed to determine the amount of resources (gangs) needed to perform the loading and unloading operations of each ship entering the terminal in a given time horizon with the aim of minimizing a multi-objective function that takes into consideration both the overall gang cost (terminal point of view) and the ship cost related to the time the ships spend on berth (maritime company point of view).

As already said, each gang is assigned to one or more working periods (shifts); generally, a shift is 6 hours long. The cost of a gang is different in accordance with the working shift, i.e. shifts at night and on Sunday are more expensive. The assignment of a gang to a shift implies a fixed cost that is charged even if the shift is not completely used.

The maximum number of teams/gangs available in each shift is derived by the solution of the Ground Crew

Planning problem. Sometimes it is possible to obtain a higher number of gangs thanks to the possibility of activating some external contracts. In this case it is necessary to distinguish between the maximum number of internal gangs and the maximum number of external ones (i.e. more expensive gangs).

Often, also the minimum and maximum number of QCs to be used for each ship is known in advance. The first is determined by contractual agreement with each maritime company, while the latter is due to physical (i.e. length of the vessel) and logical constraints (interference between crane booms). It is generally required that there are not shifts unworked between the first and the last one (pairing constraints).

Cranes are lined up along the quay and can be moved to every vessel but cannot pass each other (spatial constraints).

More precisely, given: *i*) a planning horizon T, split into a given number of shift periods; *ii*) the solution of the BAP and MBPP; *iii*) the ETAs of each vessel; *iv*) the number of QCs available in the terminal for each shift; the *Bay_QCAP* herein addressed consists in determining the assignment of QCs to the bays of the vessels and the amount of work executed by each QC. The aim is to minimize the berthing time of the ships and the QCs costs, while satisfying the ships' demand, the QCs' capacity and other operative constraints.

The *Bay_QCAP* differs from the classical QCAP (that defines how many QCs should be assigned to each berthing ship during a given planning horizon) because it also defines which bays must be operated by each QC and the assignment of QCs to the ships in each shift of the berthing period; moreover, QC's costs are also included in *Bay_QCAP* model.

In this first attempt to face this problem, the following assumptions are considered:

- there is a fixed maximum number of gangs available for each shift;
- there is no minimum number of QCs to use for each ship, even if it is required that there are no shifts unworked between the first and the last one (pairing constraints);
- the maximum number of QCs working a ship derives from operational constraints that, in accordance with the type of QCs, require a one-bay or a two-bays distance between QCs working;
- QCs assignment assumptions:
 - a1. a QC should be assigned to more than one ship for each shift;
 - a2. a QC should be assigned to more than one bay for each shift;
 - a3. a bay should not be served by more than one crane in each shift;

A mathematical formulation for the *Bay_QCAP* described above is now introduced.

Let:

$S = \{1,2,\dots,l\}$ the set of shifts of the given planning horizon T;

$V = \{1,2,\dots,m\}$ the set of vessels of the given BAP;

$B = \{1, 2, \dots, n\}$ the set of bays;
 $QC = \{1, 2, \dots, o\}$ the set of quay cranes/gangs;
 $d_{v,b}$ the demand, i.e. time necessary for loading/unloading containers in bay b of vessel v , $\forall b \in B, \forall v \in V$ (in minutes);
 d_v the total demand of vessel v , $\forall v \in V$ (in minutes);
 Q_s maximum number of QCs available in shift s ;
 K_q Shift capacity of QC q , $\forall q \in QC$ (in minutes);
 $cf_{q,s}$ gang fixed cost for using quay crane q in shift s , $\forall q \in QC, \forall s \in S$;
 $cv_{q,b}$ cost for serving bay b by QC q , $\forall q \in QC, \forall b \in B$;
 $cb_{v,s}$ ship berthing cost for vessel v in shift s , $\forall v \in V, \forall s \in S$.

Let us introduce the following decision variables:

$$z_{q,v,b,s} = \begin{cases} 1 & \text{if bay } b \text{ of vessel } v \text{ is assigned to crane } q \text{ in shift } s \\ 0 & \text{otherwise} \end{cases}$$

$$x_{q,v,b,s} \geq 0 \text{ quantity of work executed by crane } q \text{ in bay } b \text{ of vessel } v \text{ in shift } s$$

$$y_{q,s} = \begin{cases} 1 & \text{if crane } q \text{ is used in shift } s \\ 0 & \text{otherwise} \end{cases}$$

$$w_{v,s} = \begin{cases} 1 & \text{if vessel } v \text{ is berthed in shift } s \\ 0 & \text{otherwise} \end{cases}$$

The resulting 0/1 MIP model is the following:

Min

$$\sum_{v \in V} \sum_{s \in S} cb_{v,s} w_{v,s} + \sum_{q \in QC} \sum_{s \in S} cf_{q,s} y_{q,s} + \sum_{q \in QC} \sum_{v \in V} \sum_{b \in B} \sum_{s \in S} cv_{q,b} z_{q,v,b,s} \quad (1)$$

Subject to

$$\sum_{v \in V} \sum_{b \in B} x_{q,v,b,s} \leq K_q y_{q,s} \quad \forall q \in QC, \forall s \in S \quad (2)$$

$$\sum_{q \in QC} \sum_{s \in S} x_{q,v,b,s} = d_{v,b} \quad \forall b \in B, \forall v \in V \quad (3)$$

$$x_{q,v,b,s} - M z_{q,v,b,s} \leq 0 \quad \forall q \in QC, \forall b \in B, \forall v \in V, \forall s \in S \quad (4)$$

$$\sum_{q \in QC} y_{q,s} \leq Q_s \quad \forall s \in S \quad (5)$$

$$\sum_{v \in V} z_{q,v,b,s} + \sum_{v \in V} \sum_{q': q' \neq q} z_{q',v,b+1,s} + \sum_{v \in V} \sum_{q': q' \neq q} z_{q',v,b+2,s} \leq 1 \quad \forall q \in QC, \forall b \in B, \forall s \in S \quad (6)$$

$$d_v - \sum_{q \in QC} \sum_{b \in B} \sum_{s \in S: s' < s} x_{q,v,b,s} \leq M w_{v,s} \quad \forall v \in V, \forall s \in S \quad (7)$$

$$\sum_{q \in QC} \sum_{b \in B} z_{q,v,b,s} \geq w_{v,s} \quad \forall v \in V, \forall s \in S \quad (8)$$

$$\sum_{q \in QC} \sum_{v \in V} z_{q,v,b,s} \leq 1 \quad \forall b \in B, \forall s \in S \quad (9)$$

$$\sum_{v \in V} b z_{q,v,b,s} < \sum_{v \in V} (b+i) z_{q+1,v,b+i,s} \quad \forall s \in S, \forall b \in B, \forall i=1, \dots, |B|-b, \forall q=1, \dots, o-1. \quad (10)$$

The objective function minimises berthing costs and QCs costs; moreover, it includes a third term aimed at reducing the movements of QCs in the quay. The last term also reduce the possibility of obtaining solutions in which QCs pass other ones, even if for avoiding crossing of cranes spatial constraints are necessary (10). Berthing costs are computed in accordance with the number of shift vessels are berthed; anyway the minimization of berthing time does not grant that there are no shifts unworked between the first and the last one. For this aim pairing constraints (8) are necessary.

The capacity constraints (2) ensure that the total amount of work executed by a QC in a shift must be less than the maximum shift capacity of the QC. The demand of each vessel, and more precisely of each bay of each vessel, must be satisfied as required by constraints (3).

Constraints (4) are related to the definition of the assignment variables of QC and link variables $z_{q,v,b,s}$ and $x_{q,v,b,s}$. Constraints (5) guarantee not to exceed the maximum number of QCs available for serving vessels in each shift.

Constraints (6) guarantee to have two bays' distance between two quay cranes working a vessel.

Thanks to constraints (7) variables $w_{v,s}$ are fixed to one when the global demand of a vessel is not yet completely satisfied, thus vessel v remains in the port during shift s , while thanks to constraints (8) vessel is worked in shift s . In fact, pairing constraints (8) assign at most one QC to vessel v until the vessel is completely served.

Constraints (9) ensure that in each shift a bay is worked at most by one crane.

If a QC can be assigned to at most one ship in each shift, i.e. the QC assignment assumption a1) does not yet hold, the following constraints should be also included in the model:

$$\sum_{v \in V} a_{q,v,s} \leq 1 \quad \forall q \in QC, \forall s \in S \quad (11)$$

where:

$$a_{q,v,s} = \begin{cases} 1 & \text{if crane } q \text{ is assigned vessel } v \text{ in shift } s \\ 0 & \text{otherwise} \end{cases}$$

and the new set of variables is defined by:

$$\sum_{b \in B} z_{q,v,b,s} \leq |B| a_{q,v,s} \quad \forall q \in QC, \forall v \in V, \forall s \quad (12)$$

If a bay can be served by more than one crane in each shift, i.e. the QC assignment assumption a3) does not yet hold, the following constraints must be included in the model to check that the total amount of work in a bay is less than the length of a shift:

$$\sum_{q \in QC} x_{q,v,b,s} \leq l_s \quad \forall b \in B, \forall v \in V, \forall s \in S \quad (13)$$

where l_s represents the length of shifts.

Finally, the model can be easily extended to include external gangs.

This mathematical model has been implemented in MPL and has been solved with the commercial solver Cplex 11.0.

DES MODEL

The DES model is designed to represent the flow of containers related to the unloading and loading operations of the terminal for a given planning horizon.

In Figure 4 the model overview related to the set of operations to be performed for a given ship is reported.

In the operative scenarios herein considered, containers are unloaded (import cntr) and loaded (export cntr) by QCs and internal non-lifting vehicles (trucks) transport containers from the quay to the yard and vice versa.

Note that we assume that QCs move bay to bay in the same direction along the ship (i.e. unidirectional schedule) and after finishing unloading all the bays assigned a QC starts loading bay by bay working the other way round. This means that the unloading and loading processes of each ship are managed in a sequential logic, even if mixed handling techniques can also be analysed.

The model starts at the beginning of the planning horizon (usually a week). As discussed above, the model reads the solution of the BAP that gives the time of arrival and berth position of the set of ship expected to arrive during the period. The number of bays in each ship is known in advance. The number of import and export containers for each ship is generated together with their distribution over the bays of the ship.

Afterwards, the number of QCs assigned to each ship, as well as the set of bays to be handled by each QC, are read by the solution of the *Bay_QCAP* optimization model. The numbers of trucks assigned to each QC/gang are simulation parameters known in advance.

When a ship arrives, the QCs assigned to it start to unload the containers from the first assigned bay following a given sequencing (could be right to left, left to right or other handling techniques).

After unloading a container from its bay position on board the QC drops it to a truck ready on quay. If no trucks are available to transport the unloaded container the QC is blocked and must await a truck to deliver the container and to start another job. These delays must be obviously reduced in order to improve the seaside performance by deciding the right number of trucks to assign to each QC/gang. The trucks transport the containers to the storage area where they will then be stacked by the yard equipment. The trucks' service times include the time needed to transport a container to its yard position and the time needed to RMG or RTG cranes to pick up the container and release the truck to start a new transportation job. This means that we are not interested in what happens to import containers after the internal vehicles have transported them to the yard positions.

After unloading all containers in a given bay the QC must move to the next bay but delays can occur if there is not the security distance of two bays, needed to avoid interference among QCs working.

The QCs unload import containers bay by bay and when they finish unloading start the loading process working the other way round bay by bay. Note that the same pool of internal transport vehicles are devoted to firstly

transport import containers to the yard and, afterwards, to deliver the export containers to be loaded under the assigned QC.

The terminating simulation run stops at the end of the planning period (usually a week), when all operations have been performed to the set of ships planned to arrive and all the statistics and performance indexes introduced above are recorded.

APPLICATION TO A REAL CASE STUDY

The proposed framework is going to be applied to a real case study referred as the Southern European Container Hub (SECH) terminal container sited in the Port of Genoa, Italy. The terminal SECH is a medium-sized import export container terminal which covers a 206.000 sqm total surface ground and has a quay length of 526 m. The terminal is based upon the Indirect Transfer System (ITS) in which a fleet of shuttle vehicles (Reach stackers, Fork lifts and Internal trucks) transports the containers from a vessel to the stack area while dedicated cranes (i.e. rail mounted gantry cranes (RMG) or rubber-tired gantry cranes (RTG)) stack containers in the yard slots. In the same way, export containers arriving by road or railway at the terminal are handled within the truck and train operation areas, picked up by the internal transportation equipment and distributed to the respective stacks in the yard by using dedicated equipment. 5 QCs are available for the loading and unloading operations and 27 internal trucks are used to transport the containers from quay to yard and vice versa. Interested readers can refer to the web site <http://www.sech.it> for getting more information about the terminal SECH.

The DES model presented has been already implemented for the SECH case study using the simulation software environment Witness (Witness, 2010).

At present the main efforts are concentrated on getting the information related to the system parameters to be used in the DES model, with a particular attention to the ship berthing time and number of container movements and to the quay crane and internal transport service times.

As far as the optimization model is considered, preliminary tests for solving real instances of terminal SECH are characterized by a planning horizon of 7 days split into 28 shifts, 5 QCs and a berth 35 bays long. A deeper analysis on the model is under investigation.

Note that, the proposed approach can be easily adapted for being applied to other terminals characterized by different equipment and facilities.

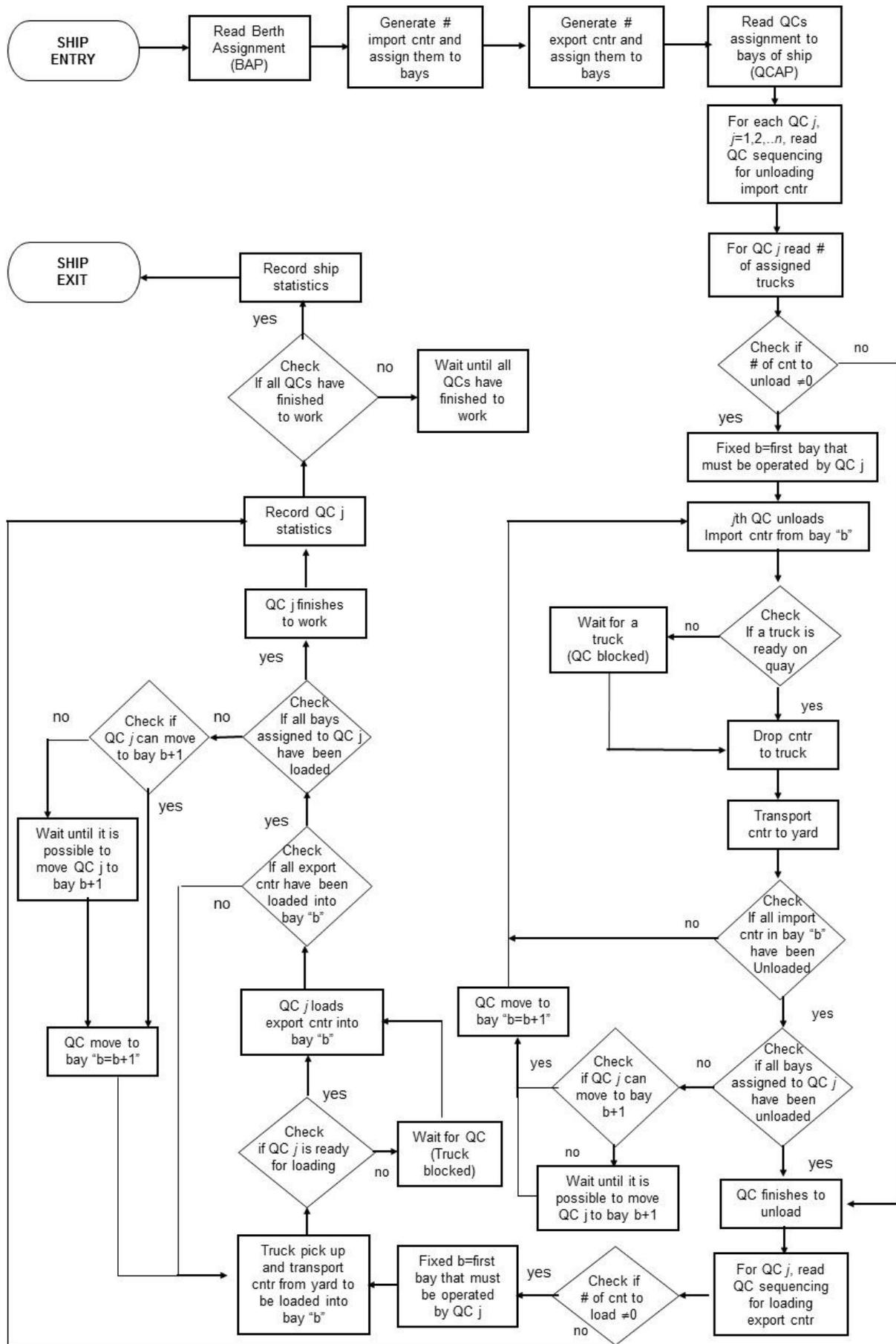


Figure 4. Simulation model overview

CONCLUSIONS AND FURTHER RESEARCH

In this paper we propose an integrated use of optimisation and simulation to study the seaside operations at terminal containers.

In particular, we introduce the *Bay_QCAP* optimization model that generates cranes and gangs allocation plans to be used as input data for a DES model. Afterwards, a simulation model, based on a more realistic representation of the terminal than the one assumed in the *Bay_QCAP* model, is implemented to solve the resource allocation problem and assess the validity of the generated solution.

At present, the main efforts are aimed at collecting the main data, debugging and tuning the model for a real case study. Afterwards, particular attention will be given to the validation of the model comparing the model's output with historical data (parametric tests) and verifying the results together with the terminal operators involved in the data collection (face validity).

We expect to give the first findings of the application of the framework to the SECH terminal during the conference.

Note that, the proposed approach can be easily adapted for being applied to other terminals characterized by different equipment and facilities.

The main expected results regard the possibility to constrain the resources (in particular trucks vehicles and gangs) and compute various performance statistics including: berth and quay utilization, average ship berthing time, QCs delays time, trucks' utilization rate, etc.

The validated model could be used to identify the critical components of the system that represent the process bottlenecks, and perform a scenario analyses aimed at evaluating the impact of organizational changes or alternative operative rules for the quay area, alternative gang work plans for each ship entering the terminal and work sequences on each QC with relevant cost savings.

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