MODELING AND ANALYSIS OF CONTAINER TERMINAL OPERATIONS INTRODUCTION TO CONTAINER TERMINAL PLANNING AND OPERATIONAL DECISIONS

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ABSTRACT: This paper introduces the different container terminal planning and operational decisions and the operations research methods used to solve them including terminal design, berth allocation, quay crane assignment, quay crane scheduling, container storage space allocation, container location assignment, retrieval, and pre-marshalling, as well as resource scheduling and terminal logistics in general. Solution methods including optimization using mixed integer linear programming, heuristic methods and discrete event simulation will be described.

Keywords: container Terminal, operations research, heuristics, discrete event simulation, berth allocation, quay crane assignment, container storage, container pre-marshaling.

INTRODUCTION

Container terminals have always been an important connection in the global supply chain. Most of goods are shipped in form of containers due to low transit time and cheap shipping costs. This in turn induced a dramatic increase in the containerized trade in the last few years as shown in Figure 1. This trend is expected to sustain and grow during the coming years, which will put more pressure on container terminal to improve their performance to be able to cope with rising demand.
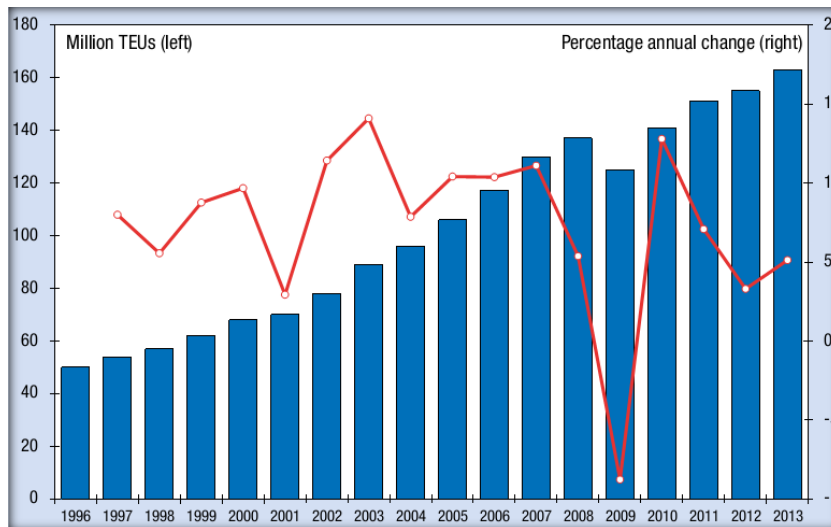
Figure (1) Development of Containerized Trade - Source: UNCTAD 2013

The need for optimization using methods of operations research in container terminal operation has become more and more important in recent years. This is because the logistics especially of large container terminals has already reached a degree of complexity that further improvements require scientific methods. The impact of concurrent methods of logistics and optimization can no longer be judged by operations experts alone. Objective methods are necessary to support decisions. Such decisions are nowadays unthinkable without the effective and efficient use of information technology as well as optimization and operations research methods (Steeken et al 2004[1]).

Different measures of performance can be used to gauge the success of a container terminal, a particular one is the vessel time in port. Therefore, a crucial competitive advantage is the rapid turnover of the containers,which corresponds to a reduction of the time in port of the container ships. One easy but expensive solution is to increase the logistics resources (quay cranes, trucks and gantry cranes), but, this is not typically available. The challenge in modern container terminal is how to optimize operations with the available resources, and they are usually scarce, especially, given the accelerating containerization of today's economy.

CONTAINER TERMINAL PLANNING AND OPERATIONAL PROBLEMS

In container terminals three areas exist: the quay side, the land side, and the container yard. In order to check the performance of a container terminal, performance indicators are used. One of the most important indicators is the berthing time of vessels. It is desired to minimize the berthing time of a vessel which does not only depend on the performance of the Quay Cranes (QC), but also depends on the performance of Yard Cranes (YC) and the whole logistics system of the terminal as depicted in Figure (Steeken et al 20041[1]).
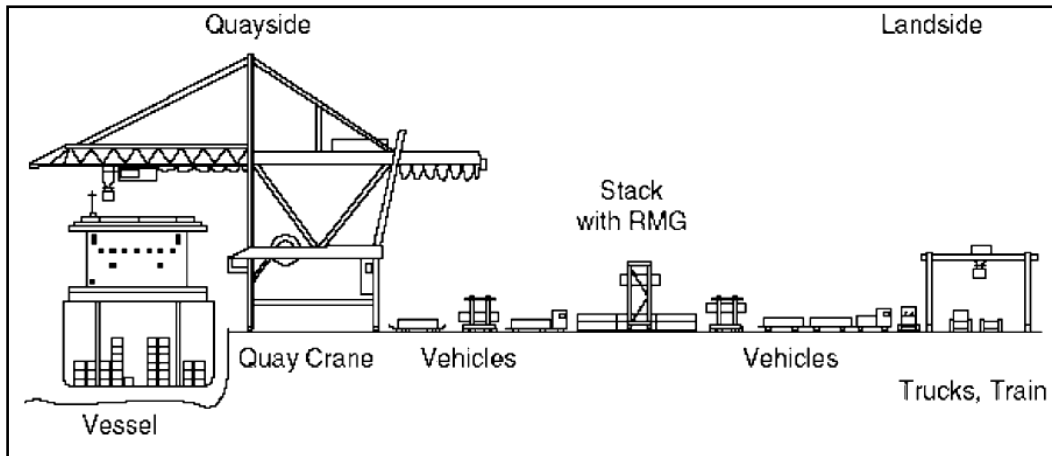
Figure (2) The different components of container terminal logistics system

CLASSIFICATION OF CONTAINER TERMINAL PROBLEMS

Container terminal decisions are classified in three levels: terminal planning decisions, operative planning decisions, and real-time control decisions. This paper will focus on terminal design and operative planning decisions as illustrated inFigure .
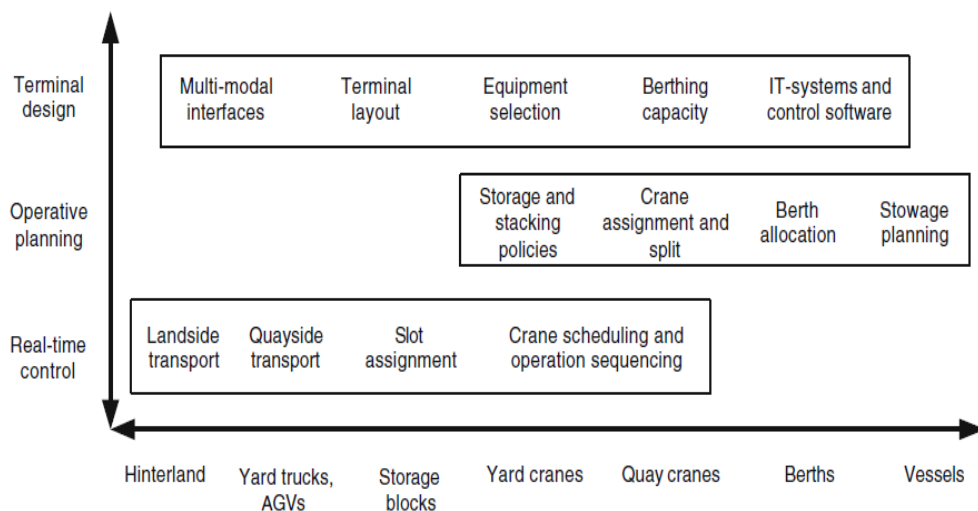

Figure (3) Logistics planning and control issues in seaport container terminals

Typical solution methods are mixed integer programming models, heuristic based methods, and in modeling full operation of the terminal simulation based methods are typically used.Steenken et al (2004)1[1] and Stahlbock, and Voß(2008)[2] provide comprehensive reviews of operations research methods used in solving the different classes of container terminal problems, while, Bierwirthand Meisel (2010)[3] present a focused review of berth allocation and quay crane scheduling problems.

There are many different decisions involved in operating container terminals and all these decisions affect each other. For example, decisions about the storage of containers in the yard directly affect the workloads of the yard cranes in the blocks and the traveling distances of the Internal Trucks (ITs) and indirectly affect the efficiency of QCs. All these decisions are also related to the berth allocation of vessels. Given the multi-criterion nature, the complexity of operations, and the size of the entire operations management problem, it is impossible to make the optimal decisions that will achieve the overall objectives. Logically, the hierarchical approach is adopted to break the whole problem into smaller sequential problems. The input to a problem is actually the output of its immediate predecessor, and is treated as a known quantity after the preceding problem is solved. Figure gives a typical hierarchical structure of operational decisions in a container terminal (Zhang et al. 2003)[4].
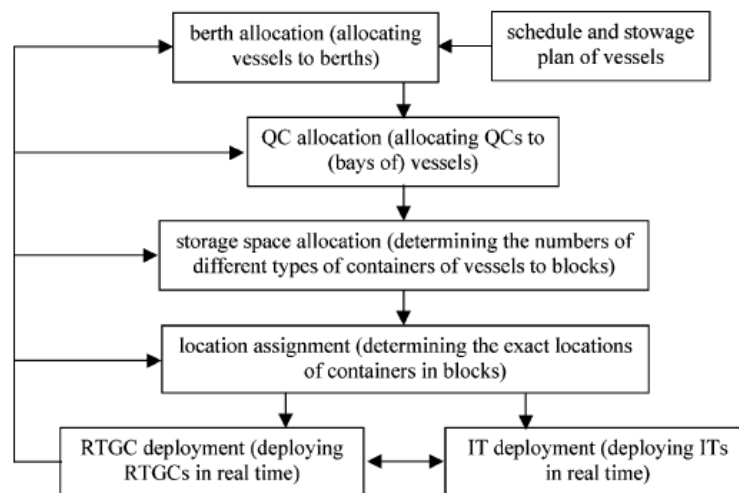

Figure (4) Decision Hirerchacy in The Container Terminal

THE BERTH ALLOCATION PROBLEM (BAP)

Problem Description: The entire quay in a Multi-User Terminal is partitioned into several berths, and the allocation of the ships to the proper quay locations is based on the berth. The problem of allocating ships to quay locations (or berths) is referred as the Berth Allocation Problem (BAP). The problem is to assign a berthing position and a berthing time to each vessel, such that a given objective function is optimized. An example for the graphical representation of a berth plan with five vessels is shown in Figure . Berth planninghas been shown to be an NP-hard problem.

A ship's handling time depends on the quay location where the particular ship is handled. More precisely, it is assumed that the handling time is defined by the physical relationship between ship's quay location and its container storage location in the yard.

The handling time may remain unaffected regardless of where a ship is moored and where its relevant container storage location is, if every ship employs a sufficient number of yard trailers resulting in no interruption or delay of the quay crane cycle. This is only possible if there is a very large fleet of yard trailers available to cover simultaneously all the ships in the terminal which turns out to be very costly as there is a considerable redundant fleet when the terminal is not so busy or when the ships are moored properly nearby their container storage location even when the terminal is at a busy state. Based on this consideration, it is assumed that due to the limited size of trailer fleet, every ship does not necessarily engage a trailer fleet large enough to keep seamless movement of cranes.
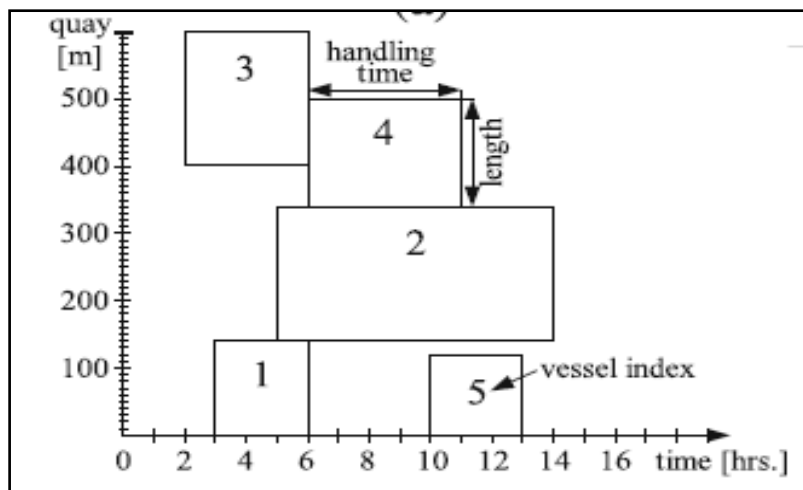

Figure (5) The Berth Allocation Problem

In practice, the handling time also depends on the number of quay cranes engaged in handling the ship. Usually the particular number of quay cranes that are assigned to a ship depends on the size of the ship and the container movements to be made. An exception to the rule is made in the occurrence of a late arrival of a ship requiring a quick turnaround, in which case many more cranes are assigned to it.

Imaiet al. (2005)[5]classify the bap into the following cases:(a) discrete layout: the quay is partitioned into a number ofsections, called berths. Only one vessel can be served ateach single berth at a time. The partitioning can eitherfollow the construction of the quay (Figure a) or is organizationallyprescribed to ease the planning problem(Figure b).(b) continuous layout: there is no partitioning of the quay, i.e.vessels can berth at arbitrary positions within the boundariesof the quay (Figure c). For a continuous layout, berthplanning is more complicated than for a discrete layout atthe advantage of better utilizing quay space.(c) hybrid layout: like in the discrete case, the quay is partitionedinto berths, but large vessels may occupy more thanone berth (Figure d) while small vessels may share a berth(Figure e). An indented berth results if two opposing berths exist, which can be used to serve a large vessel from both sides (Figure f).
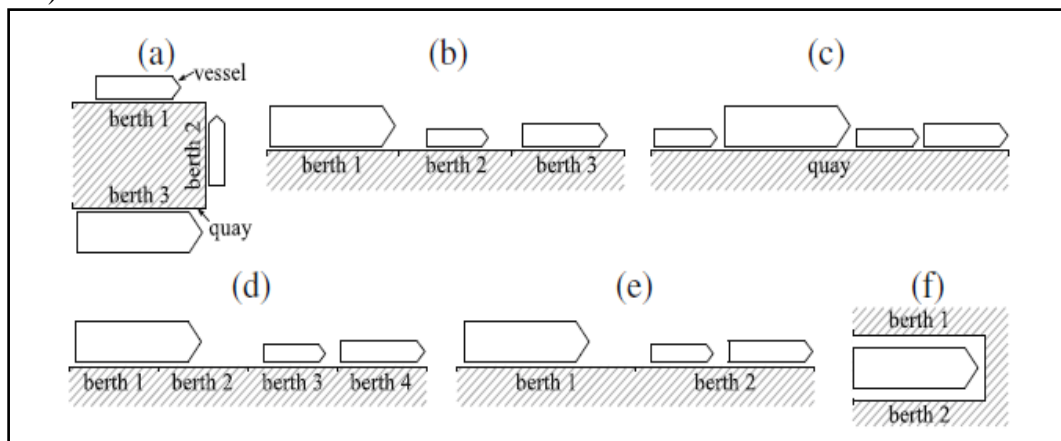

Figure (6) Spatial Classification of Berth Allocation Problem (Bierwirth and Miesel 2010)

The performance of a berth plan is often measured in terms of costs which allows to combine different goals in an overall cost function. Typical solution methods include mathematical programming and heuristic methods. The typical outputs are: the quay location of each ship; the start time of handling for each ship; and the completion time of handling for each ship.

THE QUAY CRANE ASSIGNMENT PROBLEM (QCAP)

In the QCAP a feasible berth plan and a set of identical QCs, which are available for service are given. For all the vessels included in the berth plan, the volume of containers to be loaded and/or unloaded is known as well as the maximum number of cranes allowed to serve it simultaneously. The cranes are supposed to be lined up alongside the quay. They can be moved to every vessel but they are not able to pass each other. The problem is to assign cranes to vessels such that all required transshipments of containers can be fulfilled. In Figure , QCs numbers 2,3 and 4 are assigned to vessel 3. In time period 5, two cranes are shifted from vessel 3 to start serving vessel 2. The QCAP and BAP are basically interrelated, because solving the QCAP can have a strong impact on the vessels' handling times. Only in case of a

discrete berth layout, where each berth holds a set of dedicated cranes, an explicit assignment of cranes to vessels is not necessary.

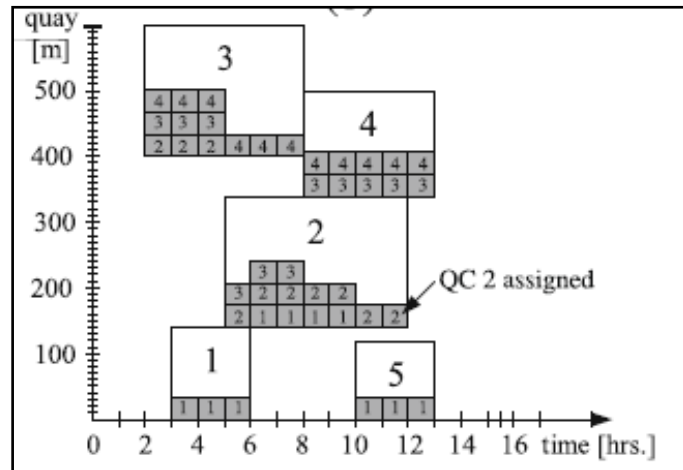**Figure (7) The Quay Crane Assignment Problem**

The QCAP problem is typically not addressed individually but in an integrated manner with the BAP.

THE QUAY CRANE SCHEDULING PROBLEM (QCSP)

In the QCSP we consider a set of tasks, representing transshipmentoperations for a vessel, and a set of assigned QCs. Precedencerelations among tasks can be given to ensure thatunloading precedes loading and to represent the stacking of containersas defined by a stowage plan. Every task must be processed(usually without preemption) once by a QC while a QCcan process at most one task at a time. A solution to the problem,called a QC schedule, defines a starting time for every taskon a crane. Usually, the minimization of the makespan of the QCschedule is pursued because it represents the handling time ofthe considered vessel. Tasks to be scheduled on a QC describe the granularity in whichthe workload of a vessel is considered in a QCSP model. Tasks canbe defined on the basis of bay areas or single bays (Figure a), or onthe basis of container stacks, container groups, or individual containers(Figure b) (Bierwirth and Miesel 2010)[3].
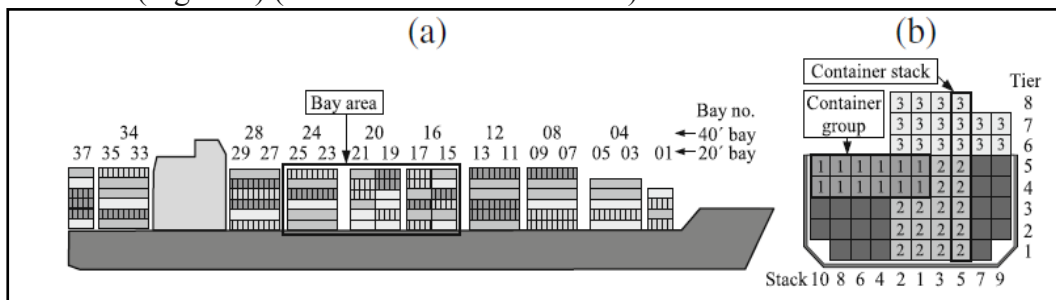

Figure (8) Storage location structure of a vessel (a) and a cross-sectional view of a bay (b).

As the number of tasks is bounded by the size of the vessel, the problem complexity is still moderate. Reducing the granularity further on allows improving crane schedules at the expense of increasing the problem complexity.

THE BAP, QCAP, QCSP INTEGRATION SCHEMES

Basically, berth allocation, QC assignment, and QC scheduling decisions can be made in a sequential fashion as shown in Figure . This way the overall problem complexity of seaside operations planning is broken down into a series of decisions. Nevertheless, existing interrelations between the planning levels are almost completely ignored by sequential planning. Often, this leads to plans of poor overall quality. Imai et al (2008)[6], presents an alternate approach to problems integration. Imai illustrated the simultaneous berth and quay crane allocation problem that minimizes the total service time and a genetic algorithm based heuristic based solution.
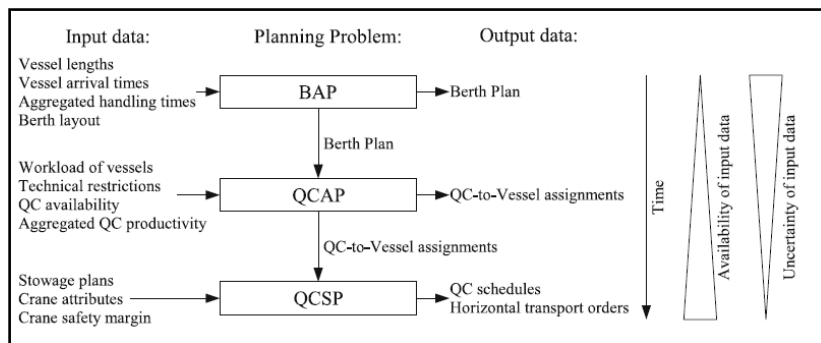

Figure (9) Integrated Sequential Solution of BA, QCA, QCS problems

In order to be able to solve the problem simultaneously, many assumptions had to be made to simplify it, for berth allocation:(a) Each berth can serve one ship at a time; (b) there are no physical or technical restrictions such as ship draft and water depth; (c) ship handling time is dependent on the berth where it is assigned; (d) ship is served after its arrival; and (e) ship handling tasks must be finished without interruption once they get started.

For crane scheduling, the following assumptions are made:(a) Ship handling requires a specific number of cranes and it does not begin till that number of cranes is available; (b) cranes cannot move from one berth to another via other berths if the other berths are engaged in ship handling; and (c) cranes get through an idle berth having some cranes present by the pushing-in and pulling-out procedure.

THE CONTAINER STORAGE SPACE ALLOCATION PROBLEM

Problem description: Containers to be handled in the yard can be classified into the following four types according to their status at different handling stages.

(a) Vessel discharge (VSDS) containers: I/B and transit containers on vessels before they are unloaded and allocated to the yard.

(b) Container yard pickup (CYPI) containers: I/B containers already in the yard waiting for picking up by customers.

(c) Container yard grounding (CYGD) containers: O/B containers before they are brought in and stored in the yard.

(d) Vessel loading (VSLD) containers: O/B and transit containers already in the yard waiting for loading to vessels.

In the storage space allocation problem the objective is to decide in which blocks to place the VSDS and CYGD containers of each vessel.

Three different types of containers are handled in a container terminal. They are inbound (import containers), outbound (export containers), and transshipment containers. The storage space allocation decision can be handled separately, or taking into consideration all the container types in the same time as illustrated in Zhang et al (2003)[4], one approach to solve this problem will be further illustrated.

At the first level, to minimize vessel berthing times, we balance the workload of RTGCs and QCs for vessels. With workloads of a vessel dispersing in different blocks, the yard cranes in the blocks serve as parallel servers processing jobs for the vessel, and the deberthing time of the vessel is the maximal processing time of these parallel servers. Balancing the workload of parallel servers generally works well to minimize the completion times of vessels. Similar results on the RTGC deployment problem confirm that balancing workloads of blocks reduces delay in container handling. There are several aspects of balancing at the first level. It is natural to balance the total number of containers handled among different blocks, which equalizes the workload of RTGCs. However, purely doing so ignores the key that VSDS and VSLD containers are related to the on-time departures of vessels. We have to balance them and also highlight their effect as compared to that of the total workload. See Section 4 for our choice of an objective function that considers these two types of balancing.

The second level determines the number of containers associated with each vessel that constitutes the total number of containers in each block in each period, in order to minimize the total distance to transport the containers between their storage blocks and the vessel berthing locations.

THE CONTAINER STACKING LOCATION ASSIGNMENT PROBLEM

Problem description: when storing or retrieving a container at the storage yard, if some containers are on the moving path of inbound or outbound container, the obstructive containers should be first retrieved from the storage yard in order to provide the inbound or outbound container with the free moving path. This problem can be defined as the assignment of the inbound and outbound containers to the storage yard with aim of minimizing the number of obstructive container moves. Allowing dynamic reallocations often leads to a significant improvement in space utilization.

The focus is to utilize the storage area in a more optimal manner thus reducing the time required for the yard machines to transfer the containers from the storage area to the

marshalling area for loading onto the ships.The location assignment problem aims to assign each import/export container to its slot. The place of that slot ensures to minimize the number of obstructive container moves to locate a container. Also the assignment puts into consideration the utilization of the storage area as possible.The typical outputs are: the container location: the index of block, bay, row, and tier of each assigned container; and the time required to access the desired container at the storage area.
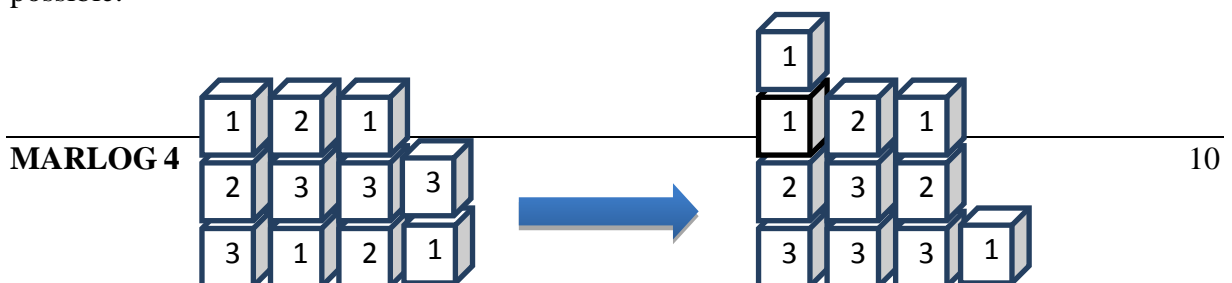
THE CONTAINER PRE-MARSHALLING PROBLEM

Problem description: export containers arrive at the terminal in random order. Typically, containers start arriving at the terminal as early as seven days in advance and containers scheduled for earlier ships are likely to arrive earlier than those that are scheduled for later ships. Therefore, by the time loading starts for a particular containership, it is often the case that many of the containers for this current ship are buried in the container stacks beneath other containers waiting to be loaded to a later ship. Containers can also be stacked in the wrong order due to lack of accurate information or other reasons. Because containers in the yard can be accessed only from the top of a stack, re-handles will be needed if the target container is not located at the top.

Generally, the container stacking problem is classified into three main types: the pre-marshalling problem, the remarshalling problem and the container retrieval problem (Steeken et al 2004)[1]. The pre-marshaling problem, is the problem of converting an initial layout of a bay into a desired final layout within which containers are stacked above each other with the priority of stacking the containers that will be served first at the top of the stack as shown in

Figure (Geith et al. 2013)[7]. This will minimize or eliminate future additional reshuffles by the YC. In the case of the container retrieval problem, it is desired to remove a container from the bay with minimum number of reshuffles, and then remove another container and so on till the bay is empty. The three classes of the problem are of prime importance knowing that in large container terminals, the average number of movements made by yard cranes is 15,000 movements per day, which means that the reduction of such moves will dramatically improve operations and efficiency.

One way to reduce the number of re-handles while loading is through pre-marshalling. In a container yard, pre-marshalling means to re-position the export containers before the loading process starts, so that the containers can be loaded with few or no re-handles. Pre-marshalling requires additional cost, but is executed when the ship has to be loaded as fast as possible.

Figure (10) The container Pre-marshalling problem

The optimization goal is to minimize the number of movements required to transform the container yard from the initial layout to the desired final layout. The final layout is determined from the vessel stowage plan. The typical problem inputs are: the total number of stacks in the blocks and their maximum stacking height; the number of container types, size, and weights; and the movement cost of yard equipment per unit distance within the marshalling yard. And the typical outputs are: the optimum Sequence of containers movements to reach the desired layout; and the number of relocations.

Typical solution methods include integer programming models, branch and bound, and heuristics. The most recent work is by Geith et al (2012)[7] that illustrates a labeling and sorting heuristic that achieved improved results in medium sized problems than other heuristics in the literature.

SCHEDULING OF MATERIAL HANDLING EQUIPMENT IN CONTAINER YARD

Problem description: scheduling yard equipment is concerned with the operation order of quay cranes, dispatching yard trucks to containers, and dispatching yard cranes to yard trucks in storage yard. These problems are interrelated, and the efficiency of container terminal operations depends on the coordination of different types of equipment.

The scheduling problem of a container handling system is formulated as a Hybrid Flow Shop Scheduling (HFSS) problem. A hybrid flow shop consists of a series of production stages, each of which has several machines operating in parallel. Some stages may have only one machine, but at least one stage must have multiple machines. The flow of jobs through the shop is unidirectional.Each job is processed by one machine at each stage and it must go through one or more stages.

The elements of the problem are:

- Jobs: Each container must go through several handling operations, and can be associated with a job. A job is defined as a complete loading/unloading process for a container.
- Machines: There are three different sets of machines: quay cranes, yard cranes, and yard trucks.
- Operations: Each job consists of three operations: a transfer operation of a container from/ onto the ship, a transfer operation within the storage yard, a transfer operation between quay cranes and yard cranes by yard trucks.

  The objective of the scheduling problem is to minimize the make span (total service time) with highest equipements utilization. Some researches aim for minimizing the total operating cost.

  Scheduling problems are solved using several methods in order to achieve the objective of minimizing the make span to serve a set of loading and unloading ships in a given time horizon and minimize the total cost. The following are typical outputs required from solving the problem:

- The assignment of each operation of the containers for every equipment in every stage.
- The precedence of operations on specific equipment.
- The starting time of each container at every stage.
- The number of operations assigned to the same machine.
- The completion time of the last container.

In order to solve the scheduling problems in yard planning there is several methods used to get the optimum solution. Some of these methods give exact solutions and some give approximate solutions. Exact algorithms include mixed integer linear programming models, and branch and bound models,while, approximate algorithms include heuristics, genetic algorithms and discrete event simulation.

Discrete Event Simulation:Many complex systems such as manufacturing, supply chain, and container terminals are too complex to be modeled analytically. Discrete event simulation has been a useful tool for evaluating the performance of such systems. However, simulation can only evaluate a given design, not providing optimization function. Therefore, the integration of simulation and optimization is needed. Simulation optimization is the process of finding the best values of some decision variables for a system where the performance is evaluated based on the output of a simulation model of this system. Discrete event simulation models of container terminals can be used to model a specific area of interest like the yard side for example as shown in Figure , or can be used to model the full terminal as shown in Figure . Using simulation models a set of scenarios can be generated and tested to select the best plan to execute.

Figure (11) A simulation model for the yard operations

Figure (12) A compreghensive simulation model of a container terminal

CONCLUSIONS

As the container transport system is capital intensive, the turnaround time of ships at container terminals is an important factor for liner shipping companies to decrease their cost. The turnaround time includes berthing, unloading, loading and departure, therefore, optimization of every operation is critical to the overall performance of the container terminal.This paper presented an introduction to container terminal planning and operational decision making problems.In order for modern container terminals to operate efficiently, it is becoming an imperative need to use advanced operations research methods, allowing an effective decision support framework for container terminal planners.

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