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Decision-making Problems for the Operation of Container Terminals

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컨테이너터미널 운영을 위한 의사결정문제의 소개

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This paper introduces several decision-making problems that need to be solved in order to facilitate the efficient operation of container terminals. These decision-making problems include the berth planning problem, the quay crane scheduling problem, the unload/load sequencing problem, the yard allocation problem, and the short-term scheduling of transporters and yard cranes. These problems can be classified into strategic decision problems, tactical decision problems, and real time operational decision problems. This paper proposes definitions of the problems that can be used to develop mathematical models for the problems.

Keywords: Container Terminal, Operation Planning, Operations Research

1. Introduction

The operation cost of container vessels is high, and these vessels spend a significant amount of time in ports. Therefore, it is important to reduce the turn-around time of vessels in ports. Vessels become increasingly larger, and it is expected that vessels with loading capacities greater than 10,000 TEU (twenty-foot-unit) become major carriers and call at main hub ports. Furthermore, automated container handling facilities have recently been developed and installed in many container terminals. This development has introduced various high-speed handling facilities and raised new and interesting research issues to enable the efficient operation of these terminals.

This paper aims to discuss container terminals with a transfer-crane-relay system in which yard cranes are used for stacking containers in the yard and yard trucks are used for transporting containers between quay cranes (QCs) and yard cranes. <Figure 1> shows the container flows in this type of container terminal.

Since a container terminal is a complicated system with various interrelated handling activities, managers of these terminals are required to make many complicated decisions based on the changing status of the container terminals. Computers are employed to plan and control various handling operations. Further, since computer systems can store a large amount of data and analyze it within a short interval of time, they have been utilized to assist human experts during decision-making processes.

There are four similar review papers on this topic regarding the decision-making models for the operation of container terminals (Meersmanns and Dekker, 2001; Steenken *et al.*, 2004; Vis and de Koster, 2003; Kim, 2005).

The next section introduces the handling facilities

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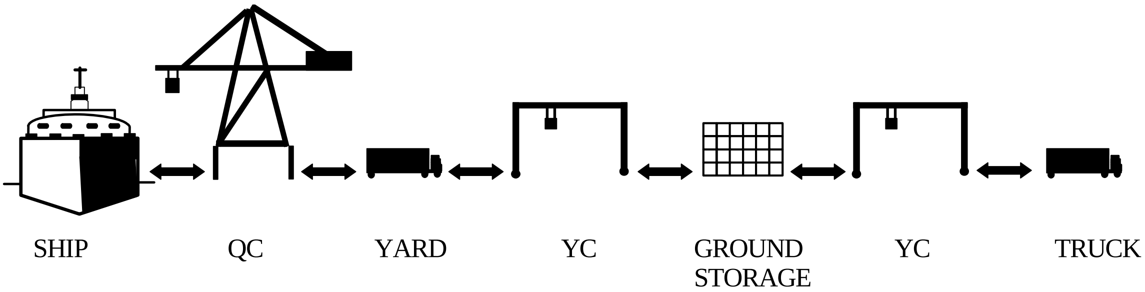


Figure 1. Container flows in a transfer-crane-relay system

and operational procedure in container terminals; section 3 describes the operation planning problems that exist in container terminals; section 4 introduces real time decision-making problems; and the last section concludes the paper.

2. Handling Activities and Facilities in Port Container Terminals

There are many different types of QCs: single trolley QC, double trolley QC, dual trolley QC, and dual-cycle elevator conveyor QC. Much effort has been devoted to developing QCs with the shortest possible cycle times. The part of the QC that directly grasps a container is called a "spreader." While a twin-lift spreader can lift up to two 20' (20 feet) containers at a time, the tandem spreader can lift up to four 20' containers or two 40' containers simultaneously.

There are different types of yard cranes (YCs) : transfer crane (TC), rail-mounted gantry crane (RMGC), automatic stacking crane (ASC), dual RMGC (DRMGC), and overhead bridge crane (OHBC). Yard blocks can be classified into two categories according to the positions at which the YCs transfer containers to/from transporters (transfer position): in the first category, transfer positions are at the ends of each block; in the second, they are at the sides of each block. In the former case of the yard layout, the blocks are usually laid out perpendicular to the direction of the berth; therefore, this layout is called the "perpendicular layout." In the latter case, the layout is called the "parallel layout." The parallel layout is usually applied in East Asian countries, while the perpendicular layout is more popular in European countries. In the parallel layout, YCs can move between yard blocks, whereas in the perpendicular layout, they cannot.

There are different types of transporters, such as yard truck (YT), straddle carrier (SC), multi-load yard truck, automated guided vehicle (AGV), shuttle carrier, reach stacker, and forklift. YTs are the most popular transporters, and they are currently used in combination with YCs in many Asian countries. SCs are used in many European countries; they are not only used for transporting containers between the yard and apron but also for storing/retrieving containers into/from the yard. Shuttle carriers are identical to SCs except for the fact that they can pass over stacks of only one tier with a container on its spreader. On the other hand, SCs can pass over stacks of two or three tiers. Thus, shuttle carriers are used only for transporting containers from one place to another.

The handling operations in container terminals are of three types : vessel operations associated with containerships, receiving/delivery operations for road trucks, and container handling and storage operations in the yard. The vessel operations include the discharging operation, during which the containers are unloaded from the vessel and stacked in a marshalling yard, and the loading operation, during which the containers are handled in the reverse direction of the discharging operation. During the discharging operation, the QCs transfer containers from a ship to a transporter. Then, the transporter delivers the inbound (import/discharging) container to a YC that lifts and stacks the container in a position in a marshalling yard. For the loading operation, the process is carried out in the opposite direction.

During the receiving and delivery operations, when a container arrives at a container terminal by a road truck, the container is inspected at the gate to check whether all the required documents are ready and whether the container has undergone any damage. Further, at the gate, information regarding the storage place of an export container and the location of an import container is provided to the people in the road truck. When the road truck arrives at a transfer point of the yard, the yard equipment, a YC or SC, either receives the container from the truck, called the "receiving operation," or transfers the container from the stack to the truck, called the "delivery operation."

The important performance measures of container terminals are the vessel turnaround time and the road truck turnaround time. Since the maintenance cost of a vessel per day is very large, customers who are vessel carriers consider the vessel turnaround time to be the most important service measure. The road truck turnaround time is also important from the perspective of customer service. Thus, the different activities of operation planning and real time control for container terminals focus on improvement in these two performance measures through the efficient use of resources.

3. Resource and operation planning in container terminals

Before the handling operations in container terminals are actually conducted, the planners in the container terminal usually schedule the operations in advance with the goal of maximizing the efficiency of the operations. The target resources for the planning process are usually the resources that have limited capacity; thus, the priorities among the handling activities that require the resources must be determined during the planning process. The target resources include berths, QCs, YCs, other handling equipment, yard spaces, and human operators. Expensive resources usually have limited capacities and thus, become main target resources for planning (Jang *et al*., 2002; Lee and Lee, 2004). Thus, in container terminals, berths are considered to be the most critical resource (berth planning), followed by QCs (QC work scheduling). Thus, plans are usually constructed first for berths and then for QCs in a manner that satisfies the requirements for important performance measures. In the case of the storage space not being enough, the use of this space must be carefully planned before the containers start arriving at the yard (yard planning). To increase the speed of the unloading and loading operations, the operations of QCs are scheduled in detail. The two related schedules are the QC work schedule and the vessel operation plans. Before executing the loading operation, the outbound containers are moved to better positions to enable the loading operation to proceed swiftly; this process is called the re-marshalling operation. <Figure 2> shows the list of various planning activities for the operation of container terminals. <Figure 3> shows the hierarchy of various plans for the ship operation. Decisions made in the higher hierarchies may constrain decisions in the lower hierarchies.

Planning system	
Operation planning	**Resource planning**
QC work scheduling	**Berth planning**
Vessel operation planning	**Yard planning**
Re-marshalling planning	**Equipment & operator planning**

Figure 2. Various planning activities in the planning system

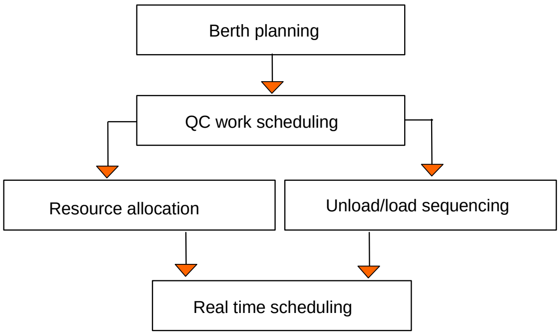


Figure 3. Planning process for the ship operation

3.1 Berth Planning

The berth planning process consists of berth scheduling and QC deployment. In berth scheduling, a containership's berthing time and berthing position, which may be either the berth ID or the bitt number on the quay, are determined. The QC deployment that determines the start and end time for a QC serves a vessel; further, the deployment of QCs must satisfy the limitation in the total number of available QCs. Berth scheduling and QC deployment are inter-related because the number of QCs to be assigned to a vessel affects the berthing duration of the vessel. Despite this inter-relationship, owing to the complexity of the integrated decision-making problem, most academic researchers have decomposed the problem into two independent issues, except in the study by Park and Kim (2003).

It is desirable that ship operations are completed within the time pre-specified by a mutual agreement between the ship carrier and terminal operator. In addition, when the outbound containers for a vessel have already arrived at the yard, it is better for the vessel berths to be at the position near to the block with the outbound containers.

A quay is usually partitioned into several berths, each of which is assigned a unique ID. Many res-earchers have treated berths as discrete resources (discrete berths). Berth planning is considered as a p-rocess for assigning each vessel to one of the berths when the vessels arrive at the quay. Many resear-chers have proposed methods for allocating vessels to discrete berths (Lai and Shih, 1992; Imai *et al*., 2001;

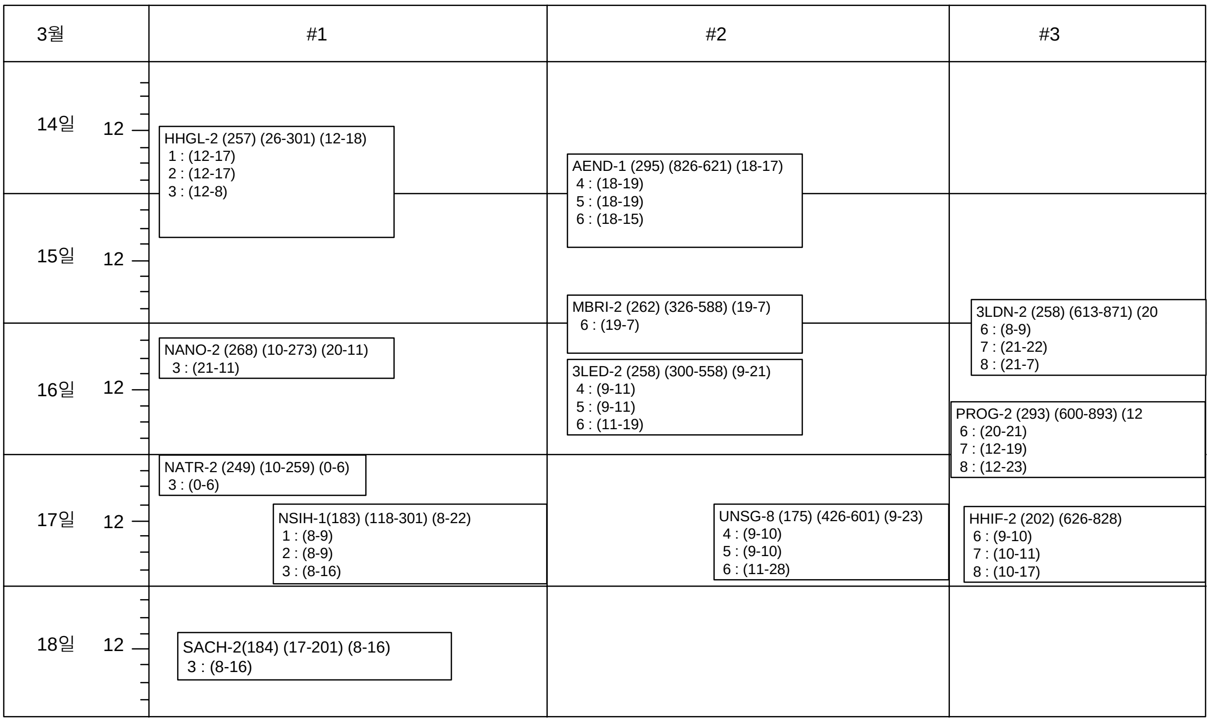


Figure 4. An example of a berth schedule

Nishimura *et al*., 2001; Imai *et al*., 2003).

A quay is merely a structure along the water, and can thus be considered as a continuous line (continuous quay) that can be shared by multiple vessels with limited lengths. Some studies (Park and Kim, 2002; Moorthy and Teo, 2006) have considered the quay as a continuous line that can be shared by multiple vessels at the same time.

A berth schedule is illustrated in <Figure 4> The vertical axis represents the time, while the horizontal axis represents the positions on the quay. Thus, the solution space can be represented by a large box on which small rectangles, representing schedules for vessels, will be placed. In other words, the horizontal side of a small rectangle represents the length of the vessel, and the position of the small rectangle on the horizontal axis represents the berthing position of a vessel on the quay. For a berth schedule to be feasible, the small rectangles must not overlap. In each small rectangle, the berthing start and end times of the corresponding vessel, the berthing position, and the start and end time for each QC assigned to the vessel are written.

As an objective, the tardiness of the departure of each vessel beyond its committed departure time should be minimized and each vessel has different weight depending on the bargaining power of the corresponding carrier. The second objective is to minimize the total flow time of vessels, which means the total turnaround time of vessels. There are different types of constraints that must be considered when determining the berthing positions of vessels. Examples include the depth of water along the quay and the maximum outreach of QCs installed at specific positions on the quay. If the depth of the water at a certain part of the quay is not enough or the outreach of the QCs installed at a part of the quay is shorter than necessary, the corresponding vessel cannot be assigned to that part of the quay.

In summary, a typical berth scheduling problem can be defined as follows:

Decision variables:

(1) Berthing position of each vessel
(2) Berthing time of each vessel
(3) Deployment of QCs to vessels

***Objectives**:*

(1) Minimize the total weighted tardiness of the vessels
(2) Minimize the total flow time of the vessels
(3) Minimize the delivery distance of containers between the berthing position and the storage locations of the containers

***Constraints**:*

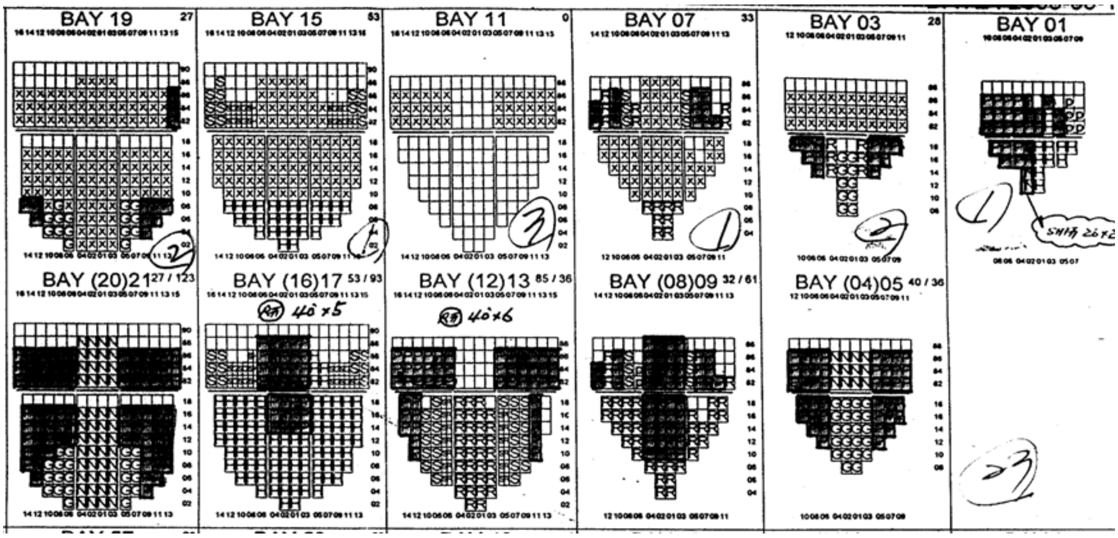
(1) The maximum number of available QCs is limited
(2) The berthing position must lie within the boundary of the quay

(3) Vessels must be served after their arrivals
(4) Each vessel has the feasible range to berth on the quay.

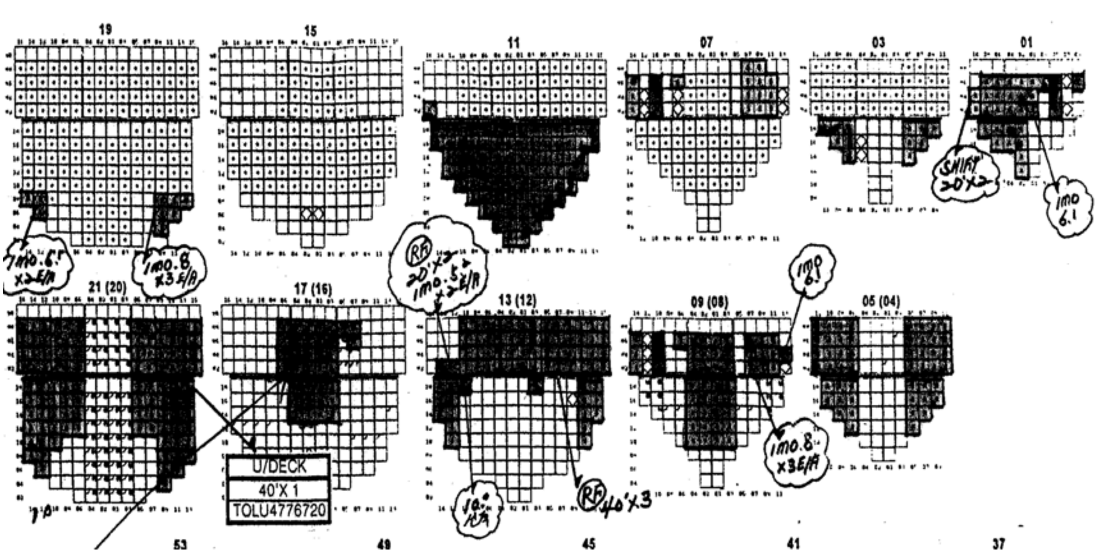
3.2 Vessel Operation Planning

The planning process of a ship's operations includes stowage planning, QC scheduling (termed "QC work scheduling" in practice), and discharge and load sequencing. Stowage planning is the process used to determine the block (cluster) of slots in a ship bay into which a specific group of containers should be stacked (Lee *et al*., 2006). In this process, however, the specific position for each individual outbound container is not determined. The stowage plan is constructed by using booking information on outbound containers. The stowage plan is usually constructed by vessel carriers. During the stowage planning process, it is necessary to consider the rehandling of the containers that are bound for succeeding ports and located in higher tiers for unloading and the containers that are bound for preceding ports and located in lower tiers. Further, the different indices of the stability and strength of the containership must be checked. <Figure 5> illustrates a stowage plan. In addition, it would be better if the positions of the inbound and outbound containers are distributed as widely and evenly over the entire range of the vessel. This will reduce the possibility of interference among QCs during the ship operation. The problem of the stowage planning may be defined as follows :

***Decision variables**:*
Loading positions (blocks of slots) of each group of



(a) A stowage plan for discharging



(b) A stowage plan for loading

Figure 5. A partial example of a stowage plan

outbound containers (of the same size and bound for the same port)

Objectives:
Minimize the number of relocations of containers before they are discharged
Minimize the discharging and the loading operation time at each visiting port

Constraints:
Stability of the vessel during the ship operation must be maintained
Containers cannot be loaded beyond the loading capacity of each bay in the vessel at any time

In order to discuss the loading and unloading operations, we introduce the concepts of "container group" and "slot cluster." Outbound containers of the same size and with the same destination port, which have to be loaded onto the same ship, are categorized under the same container group. Likewise, inbound containers of the same size that have to be unloaded by the same ship are said to be categorized under the same container group. Containers in the same group are usually transferred consecutively by QCs.

To facilitate efficient discharging and loading operations, a collection of adjacent slots are usually allocated to containers of the same group in the stowage plan of a ship as shown in <Figure 5>. A set of slots from/into which containers are discharged/loaded consecutively is called a "cluster." The cluster is the minimum unit of task for the QC scheduling. The sequence among different clusters can be changed by different QC schedules, but the sequence of individual slots in a cluster is determined by the discharge and load sequencing. Small squares correspond to slots into which containers should be loaded in this container terminal. The shaded pattern in each slot represents a specific group of containers to be loaded or picked up from the corresponding slots.

In order to construct a QC schedule (Daganzo, 1989; Kim and Park, 2004), planners are usually provided with information, such as the stowage plan of the ship, as illustrated in <Figure 5>, and the time interval during which each QC is available. In the example of the QC schedule of Figure 6, loading or unloading tasks in hold or deck of a ship-bay are considered to be a cluster. <Figure 6> shows a sequence of clusters (holds or decks containing cargo) to be transferred by the QC.

The discharging and loading operations must be performed at the same ship bay; further, the discharging operation must precede the loading operation. When the discharging operation is performed in a ship bay, the containers on the deck must be transferred before the containers in the hold are unloaded. Further, the loading operation in the hold must precede the loading operation on the deck of the same ship bay. It should also be noted that the QCs travel on the same track. Thus, certain pairs of clusters cannot be transferred simultaneously when the locations of the two clusters are too close to each other, this is because the two adjacent QCs must be apart from each other by at least one or two ship bays in order that the transfer operations can be performed simultaneously without interference. Moreover, if the containers for any two clusters have to be picked up at or delivered to the same location in a yard, the tasks for the two clusters cannot be performed simultaneously; otherwise, it will lead to interference among the corresponding YCs.

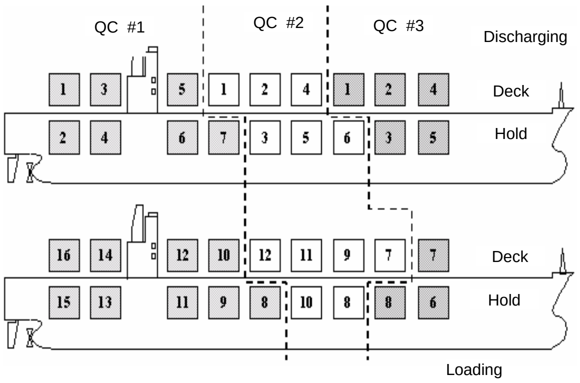


Figure 6. An example of a quay crane schedule

In summary, the QC scheduling problem can be defined as follows:

Decision variable:
Assignment of clusters (transfer tasks) to each QC
Sequence of clusters (transfer tasks) that will be carried out by the corresponding QC

Objectives:
Minimize the make-span of the entire ship operation
Minimize the total make-span of all QCs

Constraints:
Precedence relationships among different clusters (tasks) must be satisfied
Two adjacent QCs require a minimum distance for the simultaneous operation
Each QC can be scheduled within the time window during which the QC is deployed
Transfer tasks by QCs, for which containers are supplied from (stored to) the same area in the yard, cannot be conducted simultaneously due to congestion in the yard

After constructing the QC schedule, the sequence of containers for discharging and loading operations is determined. <Figure 7> illustrates a load sequence list. It shows the storage location of a container before loading and the slot in the vessel into which the container should be loaded. The loading sequence of individual containers significantly influences the handling cost in the yard. With regard to unloading containers, researchers have focused on the sequencing problem for loading operations compared to discharging operations, since determining the discharging sequence is straightforward and determining the stacking locations of containers is done in real time. In loading operations, containers to be loaded into the slots in a vessel must satisfy various constraints on the slots, as pre-specified by a stowage planner. Since the locations of outbound containers may be scattered over a wide area in a marshalling yard, the time required for loading operations depends not only on the transfer time of QCs and but also on that of YCs. Furthermore, the transfer time of a QC depends on the loading sequence of the slots, while the transfer time of a YC is affected by the loading sequence of the containers in the yard.

Since the problem of load sequencing is highly complicated, most studies (Gifford, 1981; Cojeen and Dyke, 1976; Kim *et al*., 1997; Kim *et al*., 2004) have applied heuristic algorithms to solve the problem. The following typical objectives must be pursued and the following constraints (Kim *et al*., 2004) must be satisfied by the loading sequence.

Decision variables:

Assignment of each outbound container to a slot in the vessel

Sequence of outbound containers to be loaded

Objectives:

Minimize the discharging and loading operation time of QCs

Minimize the traveling and handling time by YCs

Minimize the total difference between the weights of containers and weight classes specified for the corresponding slots

Constraints:

The QC work schedule must be followed

The maximum allowed total weight of the stack on the deck must be satisfied

The maximum allowed height of the stack of a hold must be satisfied

Recently, to speed up the ship operation, new types of QCs are introduced including QCs with twin-lift or tandem lift capabilities. For supporting the new equipment, the vessel planning method must be changed accordingly.

C/C NO : 110 LOADING SEQUENCE
VVD : CSRG-06 (NYK CASTOR)

SEQ	Container No.	Yard Location	Ship Location	Size F/E	OPR	Type	Wght	POD
1	CLHU3490367	1E-21-4-2	11-02-02	20F	OOL		26.3	RTM
2	OOLU3157834	2E-07-6-1	11-14-16	20F	OOL		21.8	RTM
3	OOLU3798890	2E-18-5-1	11-12-12	20F	OOL		24.4	RTM
4	TRLU2918137	2E-21-3-1	11-12-14	20F	OOL		23.3	RTM
5	TTNU2758810	2E-26-3-3	11-12-16	20F	OOL		21.8	RTM
6	OOLU3658878	2E-26-6-1	11-10-10	20F	OOL		24.4	RTM
7	CRXU1712610	2E-26-6-1	11-10-12	20F	OOL		23.8	RTM

Figure 7. An illustration of the load sequence list

3.3 Yard Space Planning and Assignment

One of the important factors that affects the turnaround time of vessels and road trucks is the method of allocating storage spaces for containers arriving at the marshalling yard; this is because the locations of containers significantly affect the efficiency of delivery and loading operations (Chen, 1999). The process of determining the storage location of containers can be divided into two stages: the space planning stage and the real time locating stage. In the space planning stage, the storage space is pre-planned and reserved before the containers arrive at the yard. However, the specific storage location of each individual container is determined when each inbound container is unloaded from the vessel or when each outbound container arrives at the gate. In contrast, the storage space for outbound containers is planned in advance. However, the storage location for inbound containers is determined in real time. Thus, the first stage for inbound containers is usually skipped.

The four popular objectives of space planning for outbound containers include: (1) minimizing the travel distance of transporters, (2) minimizing the travel distance of YCs, (3) minimizing the congestion of YCs and transporters in the yard, and (4) minimizing the possibility of relocations.

With regard to the first objective, the outbound containers are usually stacked in positions close to the berthing position of the corresponding vessel. For the second objective, the speed of the transfer operation can be increased if the containers are transferred consecutively at the same yard-bay, this is possible because the gantry travel of the YCs can be minimized.

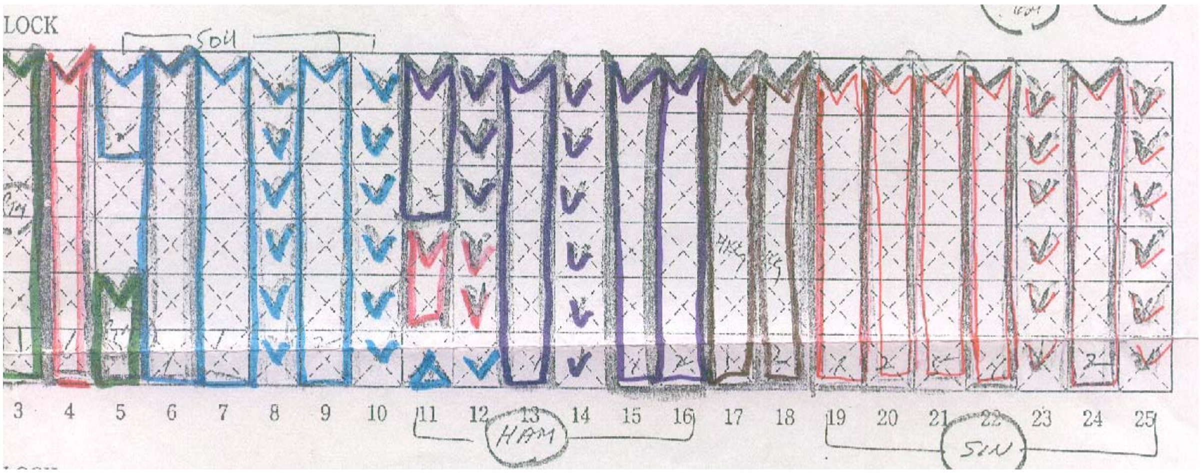


Figure 8. An illustration of a yard space plan

Thus, the outbound containers of the same group are usually located at the same yard-bay.

<Figure 8> illustrates the result of space allocation for outbound containers in a yard that is manually constructed. Thus, space must be allocated before the outbound containers start arriving at the yard (Taleb-Ibrahimi, 1993). Note that several adjacent yard bays are allocated to a container group to reduce the travel time of the YCs.

Congestion is another factor that lowers the productivity of the yard operation. Thus, to reduce the congestion, it is better to spread the workload over many different blocks. This can be done by scattering incoming outbound containers and discharged inbound containers over many different blocks. Further, when the sequence of loading outbound containers is determined, the containers should not be picked up consecutively from the same block, this contradicts the principle of minimizing the travel distance of YCs. Thus, some compromise may be necessary.

Another important objective of locating containers is to minimize the possibility of relocations during retrievals. When locating outbound containers, the weights of the containers must be taken into account. For maintaining the stability of vessels, heavy containers are usually placed in low tiers of the holds; therefore, they are retrieved earlier than light containers from the yard. Thus, in the yard, the heavy containers must be stacked in higher tiers than light containers so that relocation can be avoided during the retrievals of heavy containers. Outbound containers are usually classified into "heavy," "medium," and "light" containers according to their weights. One principle practiced includes stacking the outbound containers of the same weight class in the same stack; this can be done in real time.

In summary, the space planning problem for outbound containers can be defined as follows:

Decision variables:

Storage yard bays assigned to each group of outbound containers

Objectives:

Minimize the travel and handling times of YCs

Minimize the travel distances for yard trucks to transport containers between storage blocks and vessel berthing locations

Minimize the congestions of trucks and YCs during the loading operation

Minimize the possibility of relocations

Constraints:

Limitation on the maximum space available at each storage block

4. Real Time Scheduling for YCs and Transporters

The plans in the previous section are constructed for critical resources (berths, QCs, and, in some cases, storage spaces) and tasks (loading and unloading operations). However, it is impossible or impractical to plan all the details of handling activities in advance. Thus, for the remaining activities, decisions on the utilization of equipment and the assignment of tasks to each piece of equipment are usually made on a real time basis. Examples include the assignment of tasks to transporters, the assignment of tasks to YCs, and the assignment of specific storage position for incoming containers. Two reasons for these activities not being pre-planned are the high uncertainties of the situation and the lower importance of the resources, as compared with the importance of resources like berths or

QCs. In decision making, although a schedule can be constructed for the events of the near future (less than 10 minutes into the future), this decision is essentially made in response to an event that has occurred at that moment. Further, even the decisions included in the various plans can be modified and updated during the implementation, responding to the deviation of the situation from expectations or forecasts.

<Figure 9> shows the various functions of a real time control system. The control functions may be viewed from the perspectives of the operations and the resources. From the perspective of operations, the control system monitors and controls the operations at the gate side and the vessel side. The control of the gate side is relatively simple. The system controls the flow of road trucks from the gate and to the storage yard and vice versa. Congestion in the yard is the most important consideration for trucks with outbound containers. The truck is routed to the block that has the lowest work load at the moment of the arrival of containers, if the block has an empty space reserved for the group of containers corresponding to the arriving container. Controlling the flow of trucks for inbound containers is simple because the trucks have no choice in terms of selecting a container. The major performance measure for the delivery and receiving operation is the turnaround time of trucks in the terminal. However, note that lower priority is usually given to the gate side operations than to the vessel side operations.

The control problem of discharging and loading containers is complicated but important. Unlike the gate side operations, the vessel side operation must be carefully scheduled. The discharging and loading tasks are decomposed into the tasks for QCs, transporters, and YCs. Then, the decomposed tasks are scheduled. The task scheduling problem involves the assignment of tasks to each piece of equipment and the sequencing of the assigned tasks to be carried out (Kozan and Preston, 1999; Bish, 2003; Hartmann, 2004). For the unloading and loading tasks, considerations for the scheduling are as follows: (1) Since the most important objective of the unloading and loading operations is to minimize the turnaround time, the maximum make-span of QCs may be minimized as a primary objective. However, we are considering only 5-10 tasks among several hundreds tasks assigned to each QC, we use the total weighted idle time as an objective term instead of the maximum make-span of QCs. Instead, the higher weight can be assigned to the QC whose operation is delayed longer compared with the other QCs; (2) the loading and unloading operations are performed by QCs, YCs, and transporters together. Thus, the activities of these types of equipments must be synchronized with each other. <Figure 10> shows the synchronization requirements among QCs, transporters (AGVs), and YCs, and (3) the unloading and loading operations are given higher priority than the receiving and delivery operations.

The task scheduling problem may be defined as follows:

Decision variables:

Sequence of discharging and loading operations by each QC

Assignment of delivery tasks to each transporter

Sequence of deliveries of containers by each transporter

Assignment of transfer tasks to each YC

Sequence of transfer operations for each YC

Objectives:

Minimize the total weighted idle time of QCs

Minimize the total waiting time of road trucks

Minimize the total travel time and the waiting time of transporters

Minimize the total handling time and the waiting time of YCs

Constraints:

The transfer operation of a container between a QC and transporter must be synchronized

Since the size of the scheduling problem is very large, it would be difficult to schedule all the activities for numerous pieces of equipment simultaneously, in real time. Thus, the scheduling function must be decomposed into sub-problems that should be solved in a distributed manner. For example, the detailed activities of each piece of equipment can be scheduled by a control system dedicated to a particular piece of equipment. <Figure 11> illustrates a schedule for YCs in a block, these cranes are working together by avoiding interference with each other.

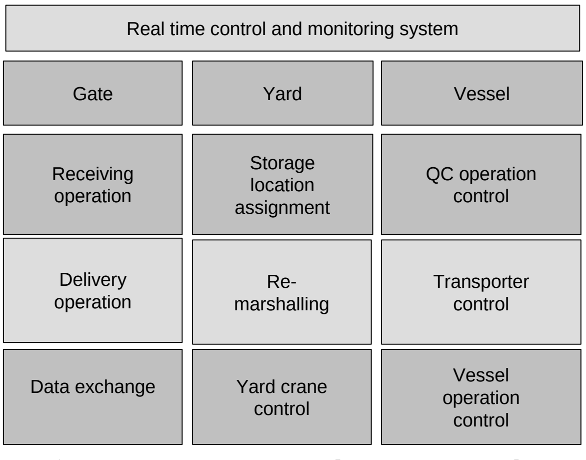


Figure 9. Various control activities in the operation system

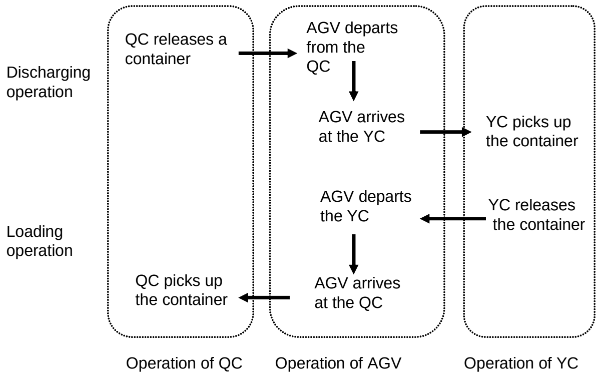


Figure 10. Synchronization requirements between equipment

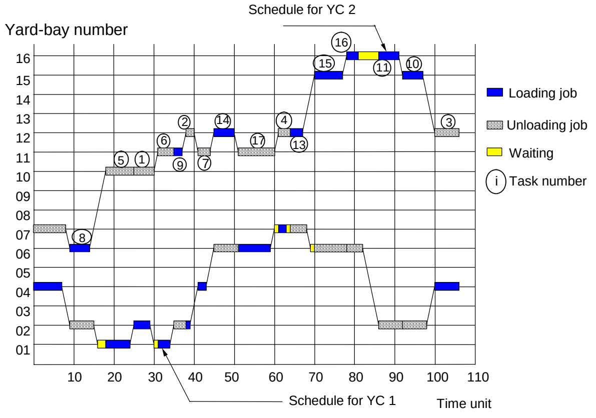


Figure 11. Real time schedule for two yard cranes

Task assignment is conducted in two steps. equipment deployment and task scheduling. The equipment deployment problem involves the deployment of a certain group of equipments to specific types of tasks. For example, a group of YCs may be dedicated to delivery and receiving tasks for a certain period of time (Zhang *et al*., 2002; Cheung *et al*. 2002; Linn and Zhang, 2003), and a group of YTs may be assigned to the task of delivering a group of containers from one block to another for a certain period of time. This type of decision must be made before the start of the real time assignment of tasks to each piece of equipment.

There are two types of strategies employed when assigning delivery tasks to transporters: the dedicated assignment strategy and the pooled strategy. In the case of the former strategy, a group of transporters is assigned to a single QC, and they deliver containers only for that QC. In contrast, in the latter strategy, all the transporters are shared by different QCs, and thus, any transporter can deliver containers for any QC; hence, this is a more flexible strategy for utilizing transporters.

The two other different strategies are the single cycle strategy and the dual cycle strategy. When the former strategy is applied to the operation of transporters, a transporter delivers a container to a block (or a QC) and returns empty. However, when the latter strategy is applied (Bish *et al*., 2005), a transporter delivers a container not only when it moves from the apron to the yard but also when it moves from the yard to the apron. The dedicated assignment strategy is usually applied when the single cycle strategy is used.

The concept of the dual cycle operation can be applied to QCs. When the dual cycle operation is performed, discharging and loading operations are combined to a dual cycle operation in which a QC delivers an inbound container from the sea side to the land side, and delivers an outbound container when it returns from the land side to the sea side. When the dual cycle operation is applied to the QCs, the planning method for the vessel operation must be changed significantly (Goodchild and Daganzo, 2006). For the dual cycle operation by QCs to be implemented, the pooled utilization of transporters must be realized simultaneously. In addition, the dual cycle operation of YCs will be beneficial. A new operation scenario may be necessary.

Recently, new equipment that is capable of moving multiple containers in a single cycle has been introduced. Examples of this are the twin lift and tandem lift QCs, multi-load transporters, and twin lift yard cranes. New operation methods should be provided for these new concept equipments (Grunow *et al*., 2004; 2006). Further, the YTs and AGVs can load or unload containers with the help of cranes, while the SCs and shuttle carriers can not only deliver containers but also pick them up from the ground by themselves. Thus, although the containers can be transferred by a QC to a YT or AGV only if the YT or AGV is ready under the QC, the operation of SCs and shuttle carriers does not have to be synchronized, which results in a higher performance than that of YTs or AGVs (Vis and Harika, 2004; Yang *et al*., 2004). This difference between the two types of transporters requires operation methods that are different from each other.

When automated guided transporters are used, the following issue must be addressed to ensure the efficiency of operations: the traffic control problem is a critical issue (Evers and Koppers, 1996; Choi *et al*., 2004). Since the number of transporters is very large (more than 150 AGVs are being used in the ECT) and the size of each transporter is also large, special attention must be paid to prevent congestion and deadlocks (Lehmann *et al*., 2006). The transporters in container terminals are free-ranging vehicles that can move to any position on the apron with the help of GPS, transponders, or microwave radars. Thus, the guide path network must be stored in the memory of the supervisory control computer. Once the guide path network is designed, the route for a travel order can be determined. The guide path network and the algorithm to determine the routes of transporters impact the performance of the transportation system significantly; this is another important issue that should be investigated by researchers.

Further, new conceptual YCs have recently been introduced. Some examples of these are OHBCs that are being used in Singapore, two non-crossing RMGC in a block (Euromax container terminal), two crossing RMGC in a block (CTA in Hamburg), and two non-crossing RMGCs with one additional crossing RMGC (CTB in Hamburg). New operational methods must be developed for the efficient operation of these new conceptual YCs.

5. Conclusions

This paper has discussed various equipments and operations in container terminals. It attempted to outline the various operational problems that can be solved by researchers. These problems were classified as planning problems and real time control problems, depending on the length of the planning horizon for each planning process. Although the operational problem was decomposed into many sub-problems, they were closely interrelated with each other.

Considering that researches in this field are in the initial stage, this paper has attempted to define the decision-making problems by describing the decision variables, objectives, and constraints. These definitions can be used to develop mathematical models, if applicable. However, problem definition will differ from one container terminal to the other depending on the situation of each individual container terminal. For example, the considerations for space planning in Hong Kong, where the available space is very limited, may be different from those in European countries, where the space is not so limited; however, the labor cost is a major issue in these countries.

Automation of container terminals will provides many research issues. Automation has been realized in some container terminals, such as the ECT in Rotterdam, CTA in Hamburg, and Thames port in the UK. Also, a container terminal already installed an automated container yard and several Korean containers are under development with the objective of automated operation. Automation requires detailed operation orders and decisions for equipment created by human operators in conventional container terminals. Thus, the operations researchers now face much more challenging problems for supporting the automation of container terminals.

Until recently, only a limited number of researchers have been doing studies on container terminal problems. However, from several years ago, more researchers in Korea, Singapore, Hong Kong, and European countries have been devoting their effort into this field. Managers in container terminals and officers in government became to realize that the problems in container terminals may be solved by OR people. Thus, it is expected that, in the near future, OR people will play a key role for solving many important problems in container terminals, which could not have been solved by academic people in other disciplines and people in practice so far.

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