Chapter 2
Container Terminal Operation: Current Trends and Future Challenges

Kap Hwan Kim and Hoon Lee

Abstract This study reviews various planning and control activities in container terminals. Decision-making problems for operation planning and control are defined and new trends in the technological development for each decision-making process are discussed. Relevant research directions and open questions are proposed. The functions of the Terminal Operating System (TOS), which is the software used to implement the decision-making processes, are discussed and commercial TOSs are introduced and compared.

2.1 Introduction

As a result of globalization, international trade has greatly increased and containerships have become considerably due to economy of scale. By 2011, more than 100 container vessels larger than 10,000 TEU were in operation and a further 150 were on order. Vessels of 18,000 TEU began to call at Busan from April 2013. High oil prices and labor costs are other important motivations driving changes in the maritime industry. After 9/11, various security measures have been implemented in maritime and port transportation. Carriers and port operators are improving their equipment and operation strategies in order to satisfy the regulations for environmental protection. The logistics market has changed from a supplier-oriented one to a customer-oriented one because the supply of logistics resources has exceeded the demand. Consequently, shipping liners have gained stronger negotiation power over port operators. In some cases, shipping liners demand a high performance level from terminals as part of the contract conditions, and this can include the throughput rate per berth or the turnaround time of a vessel or road trucks.

K. H. Kim (✉)
Department of Industrial Engineering, Pusan National University, Jangjeon-dong,
Gumjeong-gu, Busan 609-735, Republic of Korea
e-mail: kapkim@pusan.ac.kr

H. Lee
Institute of Logistics Systems, Total Soft Bank Ltd., 66-39, 513 Bansong-ro,
Haeundae-gu, Busan, 612-070, Republic of Korea

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By deploying mega vessels on main routes, the requirements for hub ports have also changed. Handling the expected 9,000 moves within 24 h for a vessel of 15,000 TEU calling at a port necessitates about 350 moves per hour per berth, which is more than twice the current productivity in Busan. Such a doubling of productivity will require dramatic innovation in the handling systems or operational methods.

This paper addresses decision-making problems for the operation of container terminals. There have been useful papers which reviewed publications on this issue (Vis and de Koster 2003; Stahlbock and Voss 2008; Schwarze et al. 2012). The main objective of this paper is to introduce current trends of and new challenges to researches in this field. Section 2 discusses the necessary optimization of operational decisions during the operation planning stage and the real-time operation stage. Section 3 introduces the current status of Terminal Operating System (TOS) and suggests potential improvements in TOS. Concluding remarks are presented in the final section.

2.2 Optimizing Operation Plans of Container Terminals

Operation planning is performed for the efficient utilization of key resources during critical operations, which are those closely related to the key performance indices of a container terminal. Examples of operation planning are berth planning, quay crane (QC) scheduling, loading/unload sequencing, and space planning (Crainic and Kim 2007; Kim 2007; Böse 2011). Some resources are classified as key resources because of their high cost and the consequent expense in increasing their capacity. Key resources may include berths, QCs, and storage spaces in most container terminals.

2.2.1 Berth Planning

The berth planning process schedules the usage of the quay by vessels. For the berth planning process, the information on vessel calls (ship ID of each call, the route, ports of the call, etc.), vessel specifications (length, width, tonnage, etc.), and hatch cover structure are transferred from a corresponding shipping line to the terminal. The information is then registered into the berth planning system of the terminal. The berthing positions for some vessels are pre-allocated at dedicated berths which are based on the contracts between shipping lines and the terminal.

Berth planning is the process of determining the berthing position and time of each vessel and the deployment of QCs to the vessel in a way of maximizing the service level for container vessels. It is desirable that vessel operations are completed within an operation time pre-specified by a mutual agreement between the corresponding ship carrier and the terminal operator. The QC deployment that determines the start and the end times for a QC serves a vessel and must satisfy the limitation in the total number of available QCs. Berth planning and QC deployment are inter-related because the number of QCs to be assigned to a vessel affects the berthing duration of the vessel. In addition, when the outbound containers for a vessel have already arrived at the yard, the vessel berths should be close to the storage area with the outbound containers.

A popular objective function is to minimize the total tardiness of the departures of vessels beyond their committed departure times and each vessel has a different importance to the terminal operator depending on the bargaining power of the corresponding carrier. The second popular objective is to minimize the total flow time of vessels, which means the total turnaround time of vessels (Park and Kim 2003). In addition, there are different types of constraints that must be considered when determining the berthing positions of vessels such as the depth of water along the quay and the maximum outreach of QCs installed at specific positions on the quay. Further issues for consideration are presented below.

Continuous Quay Assumption Berth planning is a well-defined problem much discussed in the literature. The quay may be considered to be the set of multiple discrete berths or a continuous line on which a vessel can berth at any position. The berth planning problem had been considered to be an assignment problem of each vessel to a berth under the assumption of discrete berths, whereas some researchers have recently started to consider the problem of determining the exact position of each vessel on a continuous quay (Imai et al. 2005; Lee et al. 2010).

Dynamic Berth Planning and Re-planning A container terminal makes a contract with shipping lines for regular calling services, weekly in most of cases. Because ships' arrival times, which depend on weather conditions, ships' operating environment, or the departure time from the preceding port, and the working conditions of the current terminal may change at any time, the berthing times and vessel positions need to be continuously changed. Therefore, planning processes and algorithms need to be studied considering these situations. The robustness may be an important property ofa good berth plan (Hendriks et al. 2010).

Considering Traffic in the Quay and the Yard At multi-berth terminals, berth planning is conducted to minimize any interference between docked vessels and berthing vessels, which may happen during the arrival and departure of vessels. When the traffic of containers for two vessels cross in the yard during shipping operation, the interference between the traffic may seriously delay the ship operation. Transshipment containers may be a source of traffic to be considered. These factors need to be considered during berth planning for more efficient operation of terminals.

Considering Tidal Difference Ports with a large tidal difference have a further issue requiring consideration during the berth scheduling for large vessels. Some ports have bridge piers to overcome the large tidal difference. Even so, berth planners must consider the water depth at the vessel arrival and departure times in order to confirm berthing feasibility. The changing water depths of the channels for vessels to approach the terminal also need to be considered in some ports. Many container terminals have similar restrictions in the timing of berthing or de-berthing.

2.2.2 Stowage Planning

Stowage planning is the process of specifying the attributes of containers to be loaded into slots in a ship bay. For some containers already loaded in the vessel, relocations within the vessel or via temporary storage areas at the apron are planned for more efficient ship operations in succeeding ports. The stowage plan, which is usually constructed by vessel carriers, does not specify each individual outbound container to be loaded into each slot.

During the stowage planning process, the rehandling of containers bound for succeeding ports must be considered. Thus, it is necessary to locate containers that are bound for preceding ports in higher tiers and locate those for succeeding ports in lower tiers. In addition, various indices of vessel stabilities and strengths must be checked. The positions of the inbound and outbound containers are preferably distributed as widely and evenly as possible over the entire range of a vessel in order to reduce the possibility of interference among QCs during the ship operation (Imai et al. 2002, 2006; Ambrosino 2006; Sciomachen and Tanfani 2007).

2.2.3 QC Work Scheduling

In order to discuss the loading and unloading operations, we introduce the concept of “container group.” 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 the same QC.

When the discharging and loading operations must be performed at the same ship bay, 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 clusters of slots cannot be transferred simultaneously when the locations of the two clusters are too close to each other, because the two adjacent QCs must be separated by at least a specific number of ship bays so that the transfer operations can be performed simultaneously without interference (Moccia 2006; Sammarra et al. 2007; Lee et al. 2008; Meisel 2009).

In practice, one example of a QC scheduling process may be described as follows: a QC work sequence is decided for tasks divided by hatch cover and hold/deck of a vessel. A basic sequencing rule is to sequence unloading tasks from the stern to the bow, and loading tasks from the bow to the stern. The most popular criterion is to finish all the tasks by multiple assigned QCs at the same time. Thus, the entire loading and unloading tasks are allocated to each QC by splitting the working area with two boundaries of the hatch for both hold and deck so that the amount of work allocated to each QC is as similar as possible among different QCs. More complicated characteristics of the QC scheduling problem are considered below.

Reduction of Planning Lead Time The cutoff time within which outbound containers are allowed to be delivered into the yard is mainly due to the time needed for the ship operation planning. A reduction in planning time would therefore reduce the cutoff time and hence improve the customer service level. Such efficiency gains can be achieved by automating the scheduling process.

Simultaneous Planning of Quay Side and Yard Side Operations If the containers for any two clusters of slots 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 due to the resulting interference among the corresponding yard cranes (YCs). Thus, for QC scheduling, any potential interference between YCs needs or congestion in a yard area to be considered simultaneously (Jung and Kim 2006; Choo et al. 2010; Wang and Kim 2011).

Integration with Real-Time Operation Control Function and Load/Unload Sequencing Process The real-time ship operation may not progress as planned in the QC schedule due to unexpected delay of lashing operation, delay of yard operation, and uncertain operation time of QC operators. Thus, the real-time progress needs to be considered in the QC schedule, which should be able to be updated whenever a significant disturbance happens in the QC operation.

In practice, the load/unload sequencing is done with the result of the QC schedule as a constraint to be satisfied. However, there may be cases where a minor modification of a QC schedule can significantly improve the load/unload sequence. Thus, a better schedule will be obtained if the QC scheduling is done together with the load/unload sequencing.

Increasing the Adaptability and the Rescheduling Capability of QC Scheduling Module Generally, multiple QCs are assigned to a ship. When an operation of a specific QC is delayed or a QC is broken down, the workload among QCs becomes unbalanced or the QC schedule may become disturbed. Such unbalance and disturbance may cause unexpected interference between QCs during the operation. Lashing or un-lashing operation can be delayed for containers on board. During the discharging operation, a specific container on board may have an unexpected difficulty during the un-lashing operation. A popular way to overcome these difficulties is for an under-man or a ship planner to change the work schedule adaptively. It would be helpful for a ship planning system to have the capability of automatically changing the work schedule adaptively.

Providing a Planning Process for Multiple Planners for Multiple Vessels Considering the Shared Resources Among them A popular way to support multiple planners in constructing operation plans for multiple vessels is to specify a planning boundary for each planner in the stowage plan of a vessel in order to remove conflicts between planners. In addition, the system provides the function of temporarily locking and unlocking data lists in the data base corresponding to overlapping parts in the stowage plan shared by multiple planners. However, these methods guarantee the optimality of the schedules not from the viewpoint of individual planners but from the system's viewpoint. They are usually sharing the same resource such as storage spaces and handling equipment at many different time periods. However, the sequential or random decision making by planners may not lead to the optimal decisions of the system.

2.2.4 Load/Unload Sequencing

After constructing the QC schedule, the sequence of containers for discharging and loading operations is determined. It specifies the slot in the vessel into which each outbound container should be loaded and the loading sequence of the slots (containers). The loading sequence of individual containers significantly influences the handling cost in the yard. Researchers have focused on the sequencing problem for loading operations compared to discharging operations, because determining the discharging sequence is straightforward and determining the stacking locations of discharging containers is usually done in real time. However, in loading operations, containers to be loaded into the slots in a vessel must satisfy various constraints on the slots, which are pre-specified by a stowage planner. In addition, since the locations of outbound containers may be scattered over a wide area in a marshaling yard, the time required for loading operations depends not only on the transfer time of QCs and but also on that of YCs. 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 (Jung and Kim 2006; Lee et al. 2007).

In practice, the sequencing is done in the following process: when a vessel is berthed starboard against berth, unloading work sequences in a bay profile at deck are sequentially decided from starboard to portside. A container lashing operation is to remove fixation devices (corn, lashing bar, etc.) before unloading operation and to fix them after loading operation. While planning the unload (load) sequence, consideration needs to be given to the removal (fixing) of corns and lashing bars from (to) containers on the board of a vessel, which tends to move in the horizontal direction at tier by tier. The unloading or loading work sequence in a bay profile at hold tends to move in the vertical direction stack by stack. The loading plan should satisfy the general stowage plan, which is received from the shipping line and specifies the port of destination and the weight group of the container to be loaded onto each slot. Of course, the travel distances of trucks during the ship operation and the re-shuffling for picking up the container should also be considered for the load sequencing.

Further issues for consideration are presented below:

*Postponement of Decisions on Sequencing Containers and Assignment of Slots to Containers*Traditionally, the loading sequence plan is constructed so that containers are loaded at fixed cell positions in a fixed sequence. However, to give more flexibility during the loading operation, it would be better if slot positions for outbound containers or the loading sequence for the corresponding slots can be changed adaptively.

The sequencing of slots for loading operation is constrained by some precedence constraints arising from their relative physical positions between two slots. An example is two slots in the same stack, in which the slot in the upper tier must be filled after the one in the lower tier is filled. If two slots in the same sequence list are in two different stacks, then the sequence between them may be changed, which may be finally determined at a latest possible moment. The strategy of utilizing this flexibility of loading sequence is called "flexible loading."

The other strategy to improve the adaptability of the plan is "category loading," in which case the planner creates a category consisting of multiple containers with the same attributes and the assignments of the containers in the same category to specific slots can be changed during the real-time operation. The strategy of "flexible category loading" is the combination of two strategies of "flexible loading" and "category loading," in which the decisions on the loading sequence as well as slot positions of containers in the same category are postponed until the loading operations for the slots are performed. A typical example to apply this strategy is empty containers.

Progressive Planning In principle, the loading and unloading sequence is constructed before the ship operation starts. However, the container terminal may be requested to allow arrivals of containers later than the cargo closing time. To cope with late arrival containers, the ship planning module should be able to construct the schedule incrementally. The loading plan for some part of the stowage plan may be constructed after the part of the discharging operation is performed. Progressive planning is the strategy of constructing operation plans whenever necessary.

Considering Lashing Operations and the Structure of Cell Guides The discharging and loading sequence of containers is heavily influenced by the lashing operation and the locking or unlocking of cones. On the deck, the sequence of loading or discharging tends to proceed in the horizontal direction, while it proceeds in the vertical direction in hold. These operation details need to be considered in the sequencing algorithm.

Supporting Tandem or Twin Lifts Spreaders for QCs have been improved so that they can handle various combinations of different sized containers. Spreaders with the capacity and flexibility to handle all possible combinations of 20-, 40-, and 45 ft containers quickly and efficiently have been developed. Some spreaders can also handle four 20 ft containers simultaneously and separate the two 20 ft containers longitudinally between 0 and 1.5 m.

When the twin lift loading or unloading operations for 2 × 20 ft containers are performed by a QC, it will be efficient if yard trucks (YTs) can perform twin carries with 2 × 20 ft containers. When the tandem lift loading or unloading operations for 4 × 20 ft containers are performed by a QC, it would be helpful if two YTs can be dispatched at the same time, each of which performs a twin carry with 2 × 20 ft containers. These types of operations propose new and challenging problems for the vehicle dispatching process.

Dual Command Cycle Operation Usually, a QC spreader reciprocating motion for the unloading or loading operation handles one container at once. This method will be referred to as the single cycle. Dual command cycle operation handles one loading container and another unloading container in its return path in order to handle a total of two containers in a cycle (Goodchild 2005; Goodchild and Daganzo 2006; Goodchild and Daganzo 2007; Zhang and Kim 2009). Besides QC, this procedure is equally applicable to the operation of YT and YC. Even without additional investments in equipment, this method is a productivity improvement technique that uses the facilities and existing equipment and can be expected to save costs and increase productivity. When a QC performs its operation in a dual command cycle, a YT can receive a discharged container just after delivering an outbound container to the same QC, which enables the YT to perform its operation in a dual command cycle. The same improvement may be possible during the transfer operation between YCs and YTs. When one QC is performing its loading operation in single command cycles and the other QC is doing its unloading operation in single command cycles in an adjacent location, a truck can deliver a loading container to the former QC and then receive a discharged container from the latter QC so that a dual command cycle operation can be implemented. Several studies have attempted to maximize the number of dual command cycles of QCs but relatively fewer studies have examined the dual command cycle operation for YTs and YCs.

2.2.5 Space Planning

Yard planning is the pre-planning of a space for temporarily storing containers discharged from a vessel or that for outbound containers carried in from the gate. A yard management system is operated for efficient operation of handling equipment in the yard, monitoring of the utilization of the yard space, and quick identification of the inventory level of containers. Reefer containers are stacked at an area with power supply equipped racks, and hazardous cargo containers are stored in segregated areas based on IMDG segregation rules. Empty containers are usually stored in a segregated area with reach stackers or top handlers.

Yard planning 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 discharged from a vessel or when each outbound container arrives at the gate. Storage space for outbound containers is planned in advance. However, the storage location for inbound containers is determined in real time. Thus, the space planning stage for inbound containers does not usually exist in many terminals. The four popular objectives of space planning for outbound containers are: (1) minimizing the travel distance of transporters between the yard and the corresponding vessel, (2) minimizing the movements of YCs, (3) minimizing the congestion of YCs and transporters in the yard, and (4) minimizing the number 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, which is possible because the gantry travel of the YCs can be minimized. Thus, the outbound containers of the same group are usually located at the same yard-bay (Woo and Kim 2011).

Congestion is another important obstacle which lowers the productivity of the yard operation. Thus, a rule to reduce congestion is to spread the workload over a broad area in the yard (Lee et al. 2006; Bazzazi et al. 2009; Jiang et al. 2012a, b; Won et al. 2012; Sharif and Huynh 2013). Another important objective of locating containers is to minimize the possibility of relocations during retrievals (Wan and Tsai 2009; Dekker 2006). When locating outbound containers, the weights of the containers must be taken into account (Woo and Kim 2014). For maintaining vessel stability, heavy containers are usually placed in low tiers of the holds, must therefore be retrieved earlier than light containers from the yard, and hence must be stacked in higher tiers than light containers so that relocation can be avoided during their retrieval. For inbound containers, more frequent relocations are expected because the retrieval requests are issued in a random order by randomly arriving road trucks (Sauri and Martin 2011). Storage charge may be used to control the inventory level of inbound containers (Lee and Yu 2012).

The decision-making problem related to space allocation is not well-defined compared with other decision-making problems for the operation of container terminals, partially due to the difficulty in evaluating the result of the decision making. Decision-making rules that are used in practice depend highly on the terminal or on the decision-makers and thus differ from one terminal to another. They are difficult to be justified and conflict with each other in many cases. Consequently, this is a research area worth of investigation for researchers.

2.2.6 Potential Improvements in Operation Planning Processes

Integrating Planning Activities Operation plans are usually constructed in a hierarchical way. The plan in the highest hierarchy is the berth plan, followed by the QC schedule and the space plan. The load/unload sequence is determined based on the QC schedule. The load/unload sequence is basic information to construct the real-time schedule for handling equipment. The plans in the higher hierarchies become the constraints to the plans in the lower hierarchies. Because of this hierarchical decision-making structure, some serious problems may arise in the lower hierarchy of a plan, which could be solved by a minor modification of a plan in an upper hierarchy. The integration among planning activities in different hierarchies may improve the quality ofvarious operational plans.

Enhancing Rescheduling Capabilities Situations in the terminal are continuously changing. Thus, plans constructed based on the situation at a certain moment in a previous time may not remain valid throughout the implementation period of each plan. When the progress of the operations deviates too much from a plan, the plan needs to be revised. The revision process should be sufficiently fast and should not disturb the various on-going operations.

Automating the Operation Planning Process The cutoff time for outbound containers, which specifies the latest time when outbound containers can be delivered to the yard, is specified for planning of the ship operation. Normally, it takes 5–6 h for the ship planning for one vessel. Thus, if we can reduce the planning time, then a longer cutoff time may be suggested by the terminal operator to shippers, which is a service level improvement. The planning time may be reduced by automating the operation planning process.

Sharing Information on Resources Among Planners The various kinds of planners have different duties. A vessel planner is in charge of a vessel for the planning of the ship operation for the vessel. A yard planner is in charge of allocating storage space to various inflows of containers. At a first glance, although they are in charge of planning different operations, they share the same resources in many cases. For example, the yard space and the handling capacity of YCs are shared by different vessel planners and the yard planner. That is, if one planner uses more, then the other planners have to use less. However, the information on the usage of the shared resource is not usually transparent to all the planners. Various ways to make the availability of shared resources open to all the related planners need to be developed.

Evaluating Plans in Advance When too many uncertain factors or unexpected events that had not been considered in the plan arise during real-time operation, the gap between the plan and the real progress may be very large, which significantly degrades the quality of the plan. Thus, in many terminals, the plan is evaluated by using a simulation technique.

Collaborating with Outside Partners Possible improvements can be made by collaborating with outside partners including trucking companies, vessel liners, barge operators, rail operators, shippers, and forwarders. The collaborating activities may include information sharing, improving data accuracy, integrated scheduling, and devising economic measures for the collaboration (Lee and Yu 2012).

2.3 Real-Time Control

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 positions 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 20 min into the future), these decisions are 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 (Kim 2007).

The real-time control function became a critical issue with the increasing trend toward automation in advanced container terminals. Unlike traditional terminals, most real-time decisions need to be made by computer software, which must affect the performance of automated container terminals significantly. Because more than one type of equipment is involved in the terminal operation, coordination and synchronization are crucial for obtaining a high level performance. Furthermore, many unexpected events may arise and the operation time of equipment is not certain. As a result, the application of optimization to the decision-making problem is very complicated.

In spite of the complexity of the decision-making problems during the real-time control, in order to improve the agility of the control decisions, many functions, which had been conducted by operational planning systems, are being transferred to the functions of the real-time control. For example, space allocation tends to be done in a real time rather than an operation planning function. In addition, due to the improvement of information technologies, more real-time information on logistics resources has become available. The real-time control system should be able to utilize the real-time location information which became available from advanced information technologies.

Table 2.1 shows the various functions of a real-time control system. The control functions may be viewed from the perspectives of the operations and of the resources. From the former, 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 time 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 the storage location of the container being carried. The major performance measure for the carry-in and carry-out operation is the turnaround time of trucks in the terminal. However, a lower priority is usually given to the gate side operation

Table 2.1 Various control activities in the operation system

Classification	Functions	Decisions to be made
Ship operation	Berth monitoring	Problem detection, alerting & solving
	Load & discharge control	Operation scheduling
	QC operation control	Equipment scheduling
	Transporter control	
Hinterland operation	Transport monitoring	Problem detection, alerting & solving
	Gate management	
	Barge management	
	Rail operation management	
Yard operation	Yard monitoring	Problem detection, alerting & solving
	Yard positioning	Real-time container positioning
	House-keeping	Re-marshaling & shuffling
	Reefer operation control	YC scheduling
	YC control	
Resource control	Equipment management	Workforce & equipment deployment
	Operator management	

than to the vessel side operation because the control problem of discharging and loading containers is complicated but more important.

The task scheduling problem may be defined as follows: task assignment is conducted in two steps: equipment deployment and task scheduling. The former involves the deployment of a certain group of equipment pieces 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, 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 (Zhang et al. 2002; Linn and Zhang 2003).

Unlike the hinterland operation, the vessel side operation must be carefully scheduled. The discharging and loading tasks are decomposed into the elementary tasks for QCs, transporters, and YCs. These new tasks are then 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. The unloading and loading tasks introduce the following two considerations for the scheduling. Firstly, because 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, because we are considering only 5–10 tasks among several hundred assigned to each QC, it may be more reasonable to 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. Secondly, because the loading and unloading operations are performed by QCs, YCs, and transporters together, the activities of these types of equipment must be synchronized with each other. During the loading operation, it is important for trucks with containers to arrive at the QC in the right sequence. When QCs are performing their operation in twin or tandem lifting type, then the corresponding multiple transporters should arrive almost simultaneously in order to minimize the waiting time of transporters. This scheduling problem considering handover of a container between different types of equipment have not been paid attention to so much so far (Chen et al. 2007; Lau and Zhao 2008). The transporter scheduling can be integrated with the storage location determination (Lee et al. 2009; Wu et al. 2013).

There have been many researches on dispatching delivery tasks to transporters (Briskorn et al. 2006; Liu and Kulatunga 2004; Ng et al. 2007; Angeloudis 2009; Yuan 2011). Two strategies are used when assigning delivery tasks to transporters: the dedicated assignment strategy and the pooled strategy. In the former strategy, a group of transporters is assigned to a single QC, and they deliver containers only for that QC. In the latter strategy, however, all the transporters are shared by different QCs, so that any transporter can deliver containers for any QC; hence, this is a more flexible strategy for utilizing transporters (Nguyen and Kim 2013).

New and recently introduced equipment capable of moving multiple containers in a single cycle includes twin lift and tandem lift QCs, multi-load transporters, and twin lift YCs. Such equipment upgrades have necessitated new operation methods (Grunow 2004).

Further, the YTs and automated guided vehicles (AGVs) can load or unload containers with the help of cranes, while the straddle carriers (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 operations of SCs and QCs (or YCs) do not have to be synchronized, which results in a higher performance than that of YTs or AGVs. This difference between the two types of transporters requires operation methods that are different from each other (Yang et al. 2004; Vis and Harika 2004).

When automated guided transporters are used, the traffic control problem becomes a critical issue that must be addressed to ensure the efficiency of operations. Due to the numerous large transporters, special attention must be paid to prevent congestion and deadlocks. 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 (Evers and Koppers 1996; Möhring 2004; Vis 2006).

For the efficient operation of yard cranes, scheduling problems have been studied (Ng and Mak 2005; Lee et al. 2007; Murty 2007; Li et al. 2009; Huang et al. 2009). Further, new conceptual YCs that have recently been introduced include overhead bridge cranes that are being used in Singapore, two non-crossing rail mounted gantry crane (RMGC) in a block, two crossing RMGC in a block, and two non-crossing RMGCs with one additional crossing RMGC. New operational methods must be developed for the efficient operation of these new conceptual YCs (Kemme 2011, 2012). Impacts of different yard layouts on the operational performance of the yard needs to be studies further (Petering 2013; Lee and Kim 2010, 2013).

Some general guidelines for improving real-time control are discussed below.

Planning Principle: Schedule Activities Ahead Most real-time control functions have been performed by human operators or supervisors. For example, the location decision for an arriving container has been done by a human operator and dispatching of internal trucks has been done by a supervisor under each QC. The decision is made for the action to be taken immediately but not for a future action. However, some decisions should be made in advance for preparing future actions. For example, trucks for receiving discharged containers should be sent to the corresponding QC in advance before the QC starts releasing the containers onto the trucks. In this case, the dispatching decisions need to be made in advance a long time before the handover operation between the truck and the corresponding QC happens. Thus, pre-planning is necessary for these activities. As the control function becomes improved, more decisions will be made based on the pre-planning function rather than on myopic decision rules.

Uniform Workload Principle: Avoid Congestions One major cause of low efficiency in a container yard is congestion of trucks or YCs. Even though the real-time operation may not follow the plan, such congestion may be anticipated if operation plans are analyzed carefully. Thus, when the plans are constructed, the workload should be distributed as uniformly as possible over the entire yard space and the planning horizon.

Pooling Principle: Share Resources if Possible Utilization and efficiency must be improved when multiple resources are shared by multiple users. However, the pooling must be supported by complicated operation rules. Thus, it is necessary to develop efficient operational rules for the pooling strategy can be applied to practices.

Postponement Principle: Commit a Decision at the Latest Possible Moment Situations change dynamically during real-time operation. Thus, schedules constructed based on the previous situation become unrealistic soon after the schedules start to be implemented. One popular strategy in logistics is postponing decisions until the latest possible moment in order to overcome the uncertainty in the operation and enable the system to respond quickly to the changing situation. For that purpose, real-time information collected from IT devices needs to be fully utilized

Synchronization Principle: Minimize Waiting Time by Synchronizing Movements of Different Equipment Containers are moved among vessels, yards, hinterland transportation centers, custom offices, and container freight stations and they are transferred from one type of equipment to another. These types of equipment must be synchronized during the handover operation to prevent one type from having to wait for the arrival of the other type. An efficient scheduling method needs to be developed to reduce the waiting time during the handover operation.

Minimum Empty Travel Principle: Minimize the Empty Travels of Equipment The travel distance is directly related to energy consumption and gas emission. For minimizing the travel distance, the layout of the yard needs to be improved and the allocation of tasks to equipment and the sequencing of tasks should be carefully determined. Both the empty travel distance and the loaded travel distance, which depends on the storage locations of containers, need to be reduced.

Flexibility Principle Decision rules should be flexible enough to accommodate the changes in throughput requirement, the changes in the layout, and the introduction of new types of equipment with a minimum modification. Even in these cases, their performance should be maintained at a high level for various situations. The software should be able to be applied to various terminals with different characteristics with minimal modifications.

Adaptability Principle: Easy to Adapt to Continuously Changing Situations Decision rules should be adaptable and capable of responding to changing situations. Considering that the situation may change dynamically and unexpected events may happen, more functions have been moved from planning functions to the function of real-time control.

2.4 Terminal Operating Systems

Many commercial products, called Terminal Operating Systems (TOS), have been developed and applied in practice. This section introduces some typical and popular products. TOS is composed of sub-systems for administration, planning, scheduling, executing and reporting parts. The administration part supports the management of container move orders from shipping lines. Generally, container move orders are transferred to the terminal through electronic data interchange (EDI) or internet access. This information is basic input data for the planning part.

The vessel calls are pre-defined by contracts with shipping lines and these are inputted into the berth planning module. The actual berthing time and position of vessel are scheduled by the berth planning module. The yard planning supports automatic stacking for import, export, and transshipment containers by determining an optimal yard position for a container. The resource planning allocates human resources (crane drivers, vehicle drivers, checkers, etc.) to various handling tasks in order to support the major activities in terminals. The ship planning and rail planning supply a crane split and work programs for unloading or loading containers. Tables 2.2, 2.3, and 2.4 summarize the various features of existing TOSs.

Table 2.2 Common features of the planning system in TOS

Module	Features
Berth planning	Editing calling schedules which come from contracts with shipping lines
	Assigning vessels to berths considering QC allocation
	Supporting berth allocation considering traffic flow of transporters and container yard positions
	Estimating berthing and departure time of each vessel
	Supporting ad-hoc vessel calls which are not included in the regular calling schedule
Yard planning	Defining automatic stacking rules for import, export, and transshipment containers
	Covering inbound containers from vessels and outbound containers from the gate and the rail
	Selecting storage slots of containers considering the efficiency during retrieval operations
	Considering workload distribution over yard areas during vessel loading process
	Forecasting future container inflow, outflow, and inventory for each vessel
	Supporting the space reservation for each vessel at each bay in each block
	Shared reservation of the same space for multiple vessels or multiple container groups
	Supporting the planning and operation of housekeeping of containers
	Visualizing the yard map showing stacks by container groups
Resource Planning	Registering personnel information—skill chart, job rotation, etc.
	Defining time units and calendar information—shift, day, week, and holidays, etc.
	Identifying the workload and available human resources during each time segment
	Allocating operators to shifts and gangs
Ship operation planning	Managing container stowage orders—bay profile, loading list, handling instructions, etc.
	QC split and work scheduling
	Slot sequencing for loading and unloading
	Automatic QC scheduling and slot sequencing
	Real-time rescheduling of QC works and re- sequencing slots to overcome disturbances
	Real-time stability calculations
	Managing vessel specific considerations—vessel stability calculation, stowage restrictions, twist lock handling, hatch covers handling, booming up/down, etc.
	Managing QC specific considerations−operation productivity of each QC, balancing QCs workloads, visualization of crane split, etc.

Table 2.2 (continued)

Module	Features
	Considering operations in the yard - yard workload balancing, avoiding unnecessary moves in blocks, minimizing travel dis-tance between the yard and vessels, etc.
	Considering special handling requirements—IMDG segregation rules, late arrival connections after cargo closing time, twin/tandem lifting, double cycling, etc.
Rail operation planning	Collecting container handling order information including the loading list from rail operation companies or shippers
	Rail crane split & rail crane work scheduling considering crane specifications
	Slot sequencing for loading and unloading
	Wagon composition for each ingoing/outgoing train considering wagon specifications
	Scheduling container transport between the yard of the port container terminal and the rail terminal
	Supporting direct loading of containers from road truck onto wagons or discharging from wagons onto road trucks
	Planning operations considering QC schedules in the port container terminal

During real-time operation, TOS constructs an optimal executing schedule for QCs, vehicles, and YCs to perform the various handling tasks on time. The real-time schedule is a short-term schedule which covers a period shorter than 30 min. TOS also schedules the handover times of containers between different pieces of equipment in order to minimize the waiting of equipment. When equipment becomes available to execute the next job or when a new job requests a schedule, a dispatching decision has to be made for matching the job with a set of resources required to perform the job. The storage locations for arriving containers from a vessel, the gate, or the rail terminal are determined by a yard positioning module which has a rule set. Furthermore, the equipment scheduling and dispatching modules should support various types of operations such as flexible loading, double cycling, and twin carrying. Various features of TOSs related to the real-time scheduling function are summarized in Table 2.3.

Another important group of functions of TOSs is controlling the real-time operations in the terminal. The gate system supports the carry-in/carry-out operations of outbound/inbound containers via road trucks. The TOS identifies a road truck driver, validates the cargo card, optionally inputs the pre-information if it is not received, and inspects a container, and issues a trip card. The truck appointment/pre-advice system receives a booking for carry-in/carry-out operations, which allows fast track checks of containers at the gate.

The TOS maintains job queues for each QC and checker, and jobs are dispatched from the TOS to a crane driver or a checker by using a voice and radio data terminal

Table 2.3 Common features of the real-time decision making in TOS

Real-time operation scheduling	Supporting hierarchical task decomposition of various operations. For example, a loading operation for a container may be decomposed into elementary tasks by a YC, a truck, and a QC
	Prioritizing various tasks for handling
	Real-time monitoring the progress of an operation for a container
	Real-time problem identification for re-scheduling
	Warning for the violation of time constraints by various operation schedules
	Real-time scheduling the yard operation: pre-positioning of containers, re-shuffling containers during idle times, and the prevention of deadlocks and collisions between YCs
	Real-time scheduling transport operations: pre-positioning containers, minimizing empty travel distances of transporters, synchronizing transport operations with operations by QCs and YCs
	Scheduling rail related operations considering departure times of trains
	Scheduling reefer container operations: scheduling YC operations, scheduling temperature checks, scheduling reefer plug connection/disconnection, and scheduling tasks for reefer operators
	Supporting such transport services as dual command cycling or twin carrying
Transporter dispatching	Pooling equipment among different groups of tasks classified by individual vessel, gate, or rail
	Pooling based on actual workload of cranes—mealtime, stoppage, and productivity of cranes
	User configurable priority settings for different groups of tasks
	Automatic generation of transport orders triggered by various events at the terminal
Yard positioning	Determining storage locations for unloading moves, carrying-in moves, and re-shuffling moves
	Decision making considering driving distances of cranes/vehicles and YC workloads
	Space allocation with the capability to scatter containers among multiple blocks or consolidate containers into a single block

(RDT). Crane drivers and checkers receive container handling jobs via RDT, execute jobs, and report results of jobs. When a container terminal uses automated cranes or vehicles, the TOS needs to support an event-driven messaging interface with the control system for the automated equipment. The TOS needs to send container handling orders to each piece of automated equipment, receive feedback about the progress of each order and relate it to the operational status of the corresponding pieces of the equipment. Table 2.4 summarizes the various functions of TOS related to the real-time operation and control.

Table 2.4 Common features of the real-time operation system in TOS

Gate	Identification of the truck driver
	Validation of the cargo card
	Input of information on carry-in or carry-out (pre-advise, pre-booking information)
	Handling documents related to customs
	Managing inspection information for containers
	Creation of temporary trip card indicating the destination in the yard
	Interface to truck appointment/pre-advice system
	Interface to auto gate system—OCR handling, barriers control, etc.
Quay crane (QC)	Container location control on the platform and QC stacks
	Reporting QC position and the status of the container being handled
	Sensing the stack profile
	Registering operation delays—input possible reasons of delays or stoppage codes
	Claiming the movement range of each crane for preventing conflicts between adjacent QCs
Vehicle or Yard Truck (YT)	Receiving a container transport order
	Reporting the progress of a container transport order—vehicle position & task progress status
	Prepositioning a vehicle to receive a container
Yard crane (YC)	Receiving a container handling order in a block
	Managing re-marshaling or re-shuffling operation
	Reporting a container handling order and crane position & status
Rail crane (RC)	Receiving a container handling order in a rail terminal
	Loading/unloading a container onto/from a train
	Reporting a container handling order, the position and status of a crane
	Registering the delay of operation by a stoppage code
	Claiming the range of a crane movement for preventing interference between two cranes
Container checker	Identification of ID, the size, and the type of a container
	Identifying the dimension of an Out-of-Gage container
	Identifying IMO code of a container
	Identifying physical characteristics, seals, damage condition, and door direction of a container
Reefer checker	Controlling the connection or the disconnection of the reefer plugs
	Checking the temperature inside a container periodically
Rail checker	Checking containers before unloading and after loading
	Controlling a wagon composition

To support the various functions of TOS, many commercial TOSs have been developed and used in practice. Table 2.5 introduces some representative products: Navis SPARCS N4, CATOS, Mainsail Vanguard, TOPS, and OPUS.

NAVIS is a company located in Oakland, USA and is the world's first provider of TOS. Their product "Navis SPARCS N4" has been implemented at around 200 container terminals in the world (NAVIS 2013). SPARCS N4 is treated by standard package software. Thus, based on customer needs, the functions of the software are regularly enhanced and the enhanced version is distributed and patched to customers through a version control. Although, it is expensive to modify the software in order to consider the individual local requirements of a specific customer, the system offers customers many options and adjustments, which may be used to adapt the standard system to the unique requirements of individual customers. The selection of options and the adjusting values of control parameters are also complicated tasks and so consulting companies may help the process of option selection and parameter adjustment.

SPARCS N4 includes AutoStow, Prime Route, Expert Decking, and a variety of user-selectable functions that have been used by many customers. SPARCS N4 SDK (System Development Kit) is a system which effectively supports the interface with the 3rd party provider's systems such as gate automation, private EDI, and local billing system. "SPARCS N4 Prime Route" provides a tool to pool prime movers across cranes, while combining yard and equipment constraints with operating business rules aimed at providing efficient work assignments in real-time, shorter travel distances, and fewer un-laden moves. "SPARCS N4 Expert Decking" is a tool for assigning each container to a storage position based on the business rules and constraints of the terminal, and is aimed at providing a high utilization of yard space, reduction in re-handles, and enhanced equipment utilization. "SPARCS N4 AutoStow" selects the next container to load in real-time by using rules obtained from combining stowage factors (e.g., type, weight) with yard constraints and operating strategy aimed at reducing planning time, increasing yard productivity, and raising responsiveness to operational challenges.

TOTAL SOFT BANK (TSB) is located in Busan, Korea and offers the CATOS (Computer Automation TOS) system that has been implemented at around 70 container terminals worldwide, mostly located in Asia (Total Soft Bank 2012). TSB has a marketing strategy of accommodating individual customer's needs as much as possible to satisfy each customer's local demands. Some functions of CATOS for a customer may not be directly applicable to other customers. Because CATOS has different features from a package software and additional development effort may be necessary for the application to a specific customer.

"CATOS Berth Planning" constructs and shows the berthing schedule by using powerful graphics. "CATOS Yard Planning" maximizes the yard stacking capacity while minimizing the planning time by supporting the popular planning process and rules of space planners in practice. "CATOS Ship Planning" supports simultaneous planning for multiple vessels by multiple planners, automatic load/discharge planning, and operation simulation. "CATOS Ship Planning" constructs multiple scenario-based ship plans, one of which is implemented considering the real-time

Table 2.5 Global TOS providers

Company	Name	NAVIS	Total Soft Bank	Tideworks	RBS
	Established	1988	1988	1999	1991
	Location	Oakland, USA	Busan, Korea	Seattle, USA	Parramatta, Australia
	Site	www.navis.com	www.tsb.co.kr	www.tideworks.com	www.rbs-tops.com
Customers	America	81	8	42	2
	Europe	42	7	5	5
	M.E & Af.	49	5	0	1
	Asia	45	47	3	13
	TOTAL	217	67	50	21
Product	Platform	J2EE	J2EE,.NET	Adobe flex	Unix/Linux, NET
	Name	Navis SPARCS N4	CATOS	Mainsail vanguard$^{\text{TM}}$	TOPS advance
	Administration	Navis SPARCS N4 platform EDI−EDI management	CATOS operation management CATOS Billing, Web-IP, EDI	Terminal billing Forecast®−customer website Data interchange	TOPS container, billing TOPS Web terminal view, EDI server
	Planning	Vessel—managing vessel activities and berth scheduling AutoStow−vessel and rail planning Yard−optimized control of yard space and container handling equipment Expert decking—yard management Rail—management of rail operations	CATOS –Vessel define – Berth Planning – Ship Planning –Yard planning – Rail planning	Spinnaker® –Vessel berthing –Vessel planning –Yard planning with yard navigator – Rail planning	TOPX Vessel Management—Vessel profile editor, berth planning and scheduling, vessel planning TOPX yard/truck management—Yard layout editor, yard allocation management, truck exception handling TOPX rail management—train schedule, rail planning

Table 2.5 (continued)

Company	Name	NAVIS	Total Soft Bank	Tideworks	RBS
	Executing	Monitor−monitor the performance of terminal operations Quay commander—crane scheduling and monitoring PrimeRoute—container handling equipment control Radio Data Terminal (RDT)—real-time managing jobs of all equipment Marine Telematics Solutions	CATOS Terminal Monitoring CATOS berth monitoring CATOS C3IT server Container Handling Equipment Supervisor—automatic job scheduling and CHE dispatching Supporting RDT CATOS SCADA−external systems integration	Terminal view$^{\text{TM}}$ —3D visualization tool Traffi—Control$^{\text{TM}}$ −Equipment Dispatching and monitoring Supporting RDT GateVision®—Gate Automation	TOPX equipment control—work queues and work instructions list, monitoring and control equipment by the type of work Supporting RDT Supporting the third party solution
	Advanced functions	ASC Manager−managing automated stacking cranes	ATC Supervisor−controlling and monitoring unmanned RMGC TSB Port Emulator−terminal operation evaluating with TOS		TOPS SimOne –Full 3D emulation of terminals
Company	Name	CyberLogitec	Yantai Huadong Soft-Tech	PSA	HIT
	Established	2000	1993	1964	1969
	Location	Seoul, Korea	Yantai, China	Singapore	Hong Kong
	Site	www.cyberlogitec.com	www.huadong.net	www.singaporepsa.com	www.hit.com.hk
Customers	America	2	–	–	–
	Europe	1	–	–	3
	M.E & Af.	2	–	–	1
	Asia	14	41	5	7
	TOTAL	19	41	5	11
Product	Platform	J2EE, RCP/Flex	Unix/Windows	Unix/Linux	J2EE

Table 2.5 (continued)

Company	Name	NAVIS	Total Soft Bank	Tideworks	RBS
	Name	OPUS Terminal	HD-CiTOS	CITOS	nGen
	Administration	OPUS terminal–management OPUS Terminal–Billing E-Service (Web Portal) OPUS EDI	Business Information subsystem Electronic data interchange subsystem	PortNet TradeNet	Tractor Appointment system, eBilling, EDI, customer plus
	Planning	OPUS terminal Vessel profile –Berth planning –Vessel planning –Yard planning –Rail planning	Intelligent planning subsystem –Berth Plan –Vessel operation plan –Vessel stowage –Yard plan –Train operation plan –Resource plan	Planning systems –Berth Planning & Monitoring –Yard Planning –Vessel planning –Resource planning –Engineering Management	Ship planning system (GUIDER) Yard automation
	Executing	OPUS Terminal –Terminal monitoring –Job scheduling & controller –Equipment pooling –Auto grounding Supporting RDT Providing automation packages (OCR, RFID, DGPS)	Basic operation subsystem –Vessel Dispatching –Train Management –Document Management –Customer Service –Yard Management –Quayside Security Management –Workload Handling	Operations systems –Ship Operation –Yard Operation –Yard Space Manager –Yard Consolidation –PM Tracking –Flow-Through Gate –Equipment PCs	Operations Monitoring System –Tall Pier-side Operations System –Radio Data System –WIFI Paging –Gate Automation, –Mobile Terminal Message System

Table 2.5 (continued)

Company	Name	NAVIS	Total Soft Bank	Tideworks	RBS
	Advanced functions	OPUS Terminal—job controller for automated YCs Eagle EyE—terminal asset and container monitoring & control	Intelligent Operation Subsystem –Wireless Data Terminal Transmission –Truck Auto-dispatching –Smart Gate Control –Quayside Operation Monitoring	Control Centre Systems –Vessel Operations, Monitoring & Control –Yard Operations, Monitoring & Control –Vessel Plan Analyzer	Next Generation Terminal Management System Computer Simulation

operation situation. The auto ship planning module supports various types of handling equipment such as transfer cranes and SCs and various operation types such as double cycling, truck pooling, and category loading. “CATOS C3IT Server” is responsible for decision making on resource allocation, locating containers, and problem alerting and solving in real time. “Container Handling Equipment Supervisor” is used to ensure on-time delivery of containers and reduce un-laden travel distance via container handling equipment (CHE) pooling, job scheduling and automatic CHE dispatching. “ATC Supervisor” controls job orders for unmanned yard equipment in real time and performs advanced automatic job-scheduling. “TSB Port Emulator” is used to simulate various operational scenarios built on various terminal operation parameters and historical operation data.

Mainsail VanguardTM is sold by Tideworks (2013), which is located in Seattle. Mainsail Vanguard$^{\text{TM}}$ has been implemented at around 50 container terminals worldwide, mostly North and South America. To overcome a poor EDI service environment of customers in some regions, Tideworks directly supports 24-h EDI services by reliable data processing through a data/operation center at the headquarters. Tideworks includes 3D visualization modules in Mainsail Vanguard$^{\text{TM}}$. Mainsail Vanguard$^{\text{TM}}$ provides functions such as real-time inventory management, flexible workflow tools, and instantaneous communication with customers and partners. “Active Inventory Control” carries out inventory management of containers, chassis, rolling stock, break-bulk, over-dimensional cargo, and hazardous materials. “Spinnaker Planning Management System®” integrates various planning tools in one workspace to increase cargo throughput capacity and reduce the vessel turnaround time. It includes the following modules: vessel planning module, yard planning module for automatic container location assignment, rail planning module, vessel workflow and scheduling tools for creating bay-by-bay work lists by shift and gang, and berth planning module. Traffic Control$^{\text{TM}}$ provides a dynamic control function for a terminal’s container handling equipment and it replaces radio communication and paper instructions with accurate, real-time, electronic dispatching of work instructions to operators. Forecast® is a web portal that enables terminals to communicate more easily with shipping lines, trucking companies, brokers, and other parties.

“TOPS” is a product by REALTIME BUSINESS SOLUTIONS, which is located in Parramatta. “TOPS” has been implemented at around 21 container terminals worldwide (RBS 2013). “TOPS” provides the following various operational capabilities: yard management, vessel management, berth management, crane allocation, container handling equipment management, rail management, gate management, booking and pre-advice of containers, truck management and enquiry, user security and access control, and reports. “TOPS” supports twin lifting, dual cycling of QCs, double moves (inbound and outbound containers) by a truck without exiting the terminal, and automated housekeeping. “TOPS” is a UNIX-based system in which configuring the shared memory affords excellent data synchronization processing speed. Therefore, “TOPS” as a single system can smoothly handle all the transactions for a container terminal of over 10 million TEU. In addition, “TOPS” is based on X-windows which have advantages in graphical user interface. “TOPS” application is provided by two major components: the foundation system (TOPO) and the graphical planning and equipment control system (TOPX).

CyberLogitec (CLT) is a subsidiary company of Han-Jin Shipping Lines. Thus, the experience of the company in those container terminals has been well reflected in OPUS TerminalTM, which has been implemented at around 19 container terminals. OPUS TerminalTM is a recently developed system whose programming language is Java. The planning and operating modules in TOS are not dependent on the operating system (e.g., Windows, UNIX, etc.) (CyberLogitec 2013).

"OPUS Terminal Planning System" allows multiple users to be involved in the planning process by sharing the same part of the data base and it consists of the following three modules. "Berth Planning" covers the long-term schedule, the dedicate berth management, liner's private voyage number management, and berth chart. "Vessel Planning" provides a flexible planning tool for extraordinary circumstances, managing container handling orders, twin/tandem planning, dual cycling operation, multi user planning, evaluating ship plans, checking vessel stability, and handling late cargo arrivals after cargo closing time. "Yard Planning" estimates the workload in the yard in the near future, allocates yard space based on gate-in pattern, and changes stacking rules in accordance with current yard utilization ratio.

"OPUS TOS" allows users to monitor and control terminal operation such as vessel operation, terminal equipment workload or exceptional cases, transfer point congestion in quay, yard and gate site. It includes the following six functions. "Vessel operation" supports global pooling and partial pooling function for prime movers and twin/tandem operation. "Yard operation" offers the functions of balancing workload among yard equipments, minimizing equipment interference, and performing efficient re-marshalling operation based on the dynamic terminal situation. "Terminal job scheduling and controller module" creates job orders just in time based on operation plans. "Terminal Equipment Pooling" dispatches transporters in real time between the storage area to the quay side with the aim of maximizing the utilization of the transporters. "Auto grounding" allows users to dynamically manage yard operation and to change operation policies and yard stacking rules. "Auto housekeeping" searches candidate containers for housekeeping automatically and creates housekeeping orders.

Yantai Huadong Soft-Tech Company was founded in 1993 in China, whose product name is HD-CiTOS (Huadong Computer Intelligent Terminal Operation System) (Yantai Huadong Soft-Tech 2014)). It is applied to more than 40 container terminals which are located along the eastern coast and rivers in China and whose total throughput amounts to 7 million TEUs per year. Basic functions of the software include system initialization, base material maintenance, vessel dispatching, train dispatching, comprehensive inquires, etc. Intelligent planning subsystem is a core of CiTOS which consists of vessel handling plan, container stockpiling plan, train handling plan, various material plan, and so on. Decision support subsystem supports decision makers through historical data analysis.

PSA introduced business-to-business port logistics portal services (PortNet) in 1984 and a terminal operating system (CITOS, Computer Integrated Terminal Operations System) is launched in 1998 ((PSA 2014). CITOS is managing 52 berths and

188 quay cranes at 5 container terminals in Singapore. PortNET and CITOS both systems are integrated seamless to improve an efficiency of port logistics and container handling service. The PortNet is a web based portal service and supports many kinds of services: slot management, space booking (EZShip), global equipment management system (GEMS), electronic billing of charges (EZBill), cargo booking support (CargoD2D), throughput analysis, vessel information system (TRAVIS), and preplan container stowage on board the vessel (COPLANS). The planning systems includes berth planning & monitoring system (BPMS), yard planning systems (YPS), vessel planning systems (VPS), resource planning system (RPS) and engineering management systems (EAMS). And, operations systems includes ship operation system (SOS), yard operation system (YOS), yard space manager (YSM), yard consolidation system (YCS), PM tracking system (PMTS), flow-through gate system and equipment PCs (QCPC, YCPC, QCOPC, PMPC).

Hong Kong International Terminals introduced Next Generation Terminal Management System (nGen) in 2005, which adopted industry-standard and open-platform technologies such as Java and XML that make scalable across all non-proprietary computer hardware and operating system (Hong Kong International Terminals 2014). nGen is a modular system that offers a flexible architecture for plug-and-play options to sub systems. Operations monitoring system (OMS) visualizes terminal operations and container stacking information. Ship Planning System optimizes sequences of discharging and loading operations. Radio Data System (RDS) provides container movement's information to mobile computers. Yard Automation provides a variety of enquiry, reporting and analysis facilities to assist in the management of container inventory. Tractor Appointment System supports scheduling & collecting inbound containers. Mobile Terminal Message System delivers container handling information to user's mobile phones and Computer Simulation supports properly integrated and optimized operation plans before the deployment.

The four new challenges to TOS are automation, optimization by using IT, evaluation and analysis, and web and mobile. Automation is a global trend in container terminals. A control system for automated stacking cranes (ASCs) or automated RMGC (ARMGC) in cases of automated container terminals is generally now included in terminal operating systems. However, unmanned vehicle control systems (include AGV) have been provided by third party providers. A single terminal operating system, into which an unmanned vehicle control system fully is integrated, is expected to enter the market in the near future.

Optimization is another effective tool to improve the productivity in container terminals. An optimization technique could be effective through the support of real-time information technologies. Examples of the information technology applications are an equipment identification technologies using RFID/IoT (Radio-Frequency Identification, Internet of Things), improved reliability of wireless communication using mesh network, and sensor devices that can collect a variety of real-time information of equipment and work sites. By using the collected real-time information, decision making for job scheduling and equipment dispatching will become more realistic and effective.

Before TOS is deployed to real operations, it will need to be evaluated and tested. Because of its numerous operation parameters, the evaluation and testing of TOS will require a lot of money and time. Evaluation tools for this purpose have been developed from the mid 2000s and have been mainly used in some TOS implementation projects. Such evaluation tools can be widely used to support a process improvement after the operating system is installed.

The rapidly increasing demand for smart phones and tablets has boosted the cloud service market and altered the market leaders in ERP products; later it will incur the same changes in the market of TOS products. The next generation TOS is expected to incorporate some features of open architecture and standard web-based systems to support a variety of mobile devices.

2.5 Conclusions

This paper has reviewed various decision-making problems in container terminals. Potential research issues and directions were proposed for operation planning and real-time control activities. Extensive areas requiring further research were identified. The various functions offered by popular Terminal Operating Systems (TOSs) were introduced. In addition, the most popular TOSs in the present market were introduced, along with their key features. Finally, recent trends of TOSs responding to changes in the technological and market environment were highlighted.

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References

Ambrosino, D., Sciomachen, A., & Tanfani, E. (2006). A decomposition heuristics for the container ship stowage problem. *Journal of Heuristics, 12,* 211–233.

Angeloudis, P., & Bell, M. G. H. (2009). An uncertainty-aware AGV assignment algorithm for automated container terminals. *Transportation Research Part E, 46*(3), 354–366.

Bazzazi, M., Safaei, N., & Javadian, N. (2009). A genetic algorithm to solve the storage space allocation problem. *Computers & Industrial Engineering, 56,* 44–52.

Briskorn, D., Drexl, A., & Hartmann, S. (2006). Inventory-based dispatching of automated guided vehicles on container terminals. *OR Spectrum, 28,* 611–630.

Böse, J. W. (2011) Handbook of terminal planning. Operations research/computer science interface series (Vol. 49). New York: Springer.

Chen, L., Bostel, N., Dejax, P., Cai, J., & Xi, L. (2007). A tabu search algorithm for integrated scheduling problem of container handling systems in a maritime terminal. *European Journal of Operational Research, 181,* 40–58.

Choo, S., Klabjan, D., & Simchi-Levi, D. (2010). Multiship crane sequencing with yard congestion constraints. *Transportation Science, 44*(1), 98–115.

Crainic, T. G., & Kim, K. H. (2007) Intermodal transportation. In C. Barnhart & G. Laporte (Eds.), *Handbook in OR & MS* (Vol. 14, pp. 467–537). Amsterdam: Elsevier.

CyberLogitec (2013) OPUS Terminal. http://www.cyberlogitec.com/terminal. Accessed Oct 2013.

Dekker, R., Voogd, P., & van Asperen E. (2006). Advanced methods for container stacking. *OR Spectrum, 28,* 563–586.

Evers, J. M., & Koppers, S. A. (1996). Automated guided vehicle traffic control at a container terminal. *Transportation Research Part A, 30*(1), 21–34.

Goodchild, A. V. (2005) Crane double cycling in container ports: algorithms, evaluation, and planning, PhD dissertation, University of California, Berkeley.

Goodchild, A. V., & Daganzo, C. F. (2006). Double-cycling strategies for container ships and their effect on ship loading and unloading operations. *Transportation Science, 40*(4), 473–483.

Goodchild, A. V., & Daganzo, C. F. (2007). Crane double cycling in container ports: Planning methods and evaluation. *Transportation Research Part B, 41*(8), 875–891.

Grunow, M., Günther, H.-O., & Lehmann, M. (2004). Dispatching multi-load AGVs in highly automated seaport container terminals. *OR Spectrum, 26*(2), 211–236.

Hendriks, M., Laumanns, M., Lefeber, E., & Udding, J. T. (2010). Robust cyclic berth planning of container vessels. *OR Spectrum, 32,* 501–517.

Hong Kong International Terminals (HIT) (2014). nGen. http://www.hit.com.hk/en/Innovation. Accessed Jan 2014

Huang, Y., Liang, C., & Yang, Y. (2009). The optimum route problem by genetic algorithm for load/unloading of yard cranes. *Computers & Industrial Engineering, 56,* 993–1001.

Imai, A., Sun, X., Nishimura, E., Papadimitriou, S., & Sasaki, K. (2002). The containership loading problem. *International Journal of Maritime Economics, 4,* 126–148.

Imai, A., Sun, X., Nishimura, E., & Papadimitriou, S. (2005). Berth allocation in a container port: Using a continuous location space approach. *Transportation Research part B, 39,* 199–221.

Imai, A., Sasaki, K., Sun, X., Nishimura, E., & Papadimitriou, S. (2006). Multi-objective simultaneous stowage and load planning for a container ship with container rehandles in yard stacks. *European Journal of Operational Research, 171,* 373–389.

Jiang, X., Chew, E. P., Lee, L. H., & Tan, K. C. (2012a). Flexible space-sharing strategy for storage yard management in a transshipment hub port. *OR Spectrum, 35*(2), 417–439.

Jiang, X., Chew, E. P., Lee, L. H., & Tan, K. C. (2012b). A container yard storage strategy for improving land utilization and operation efficiency in a transshipment hub port. *European Journal of Operational Research, 221,* 64–73.

Jung, S. H., & Kim, K. H. (2006). Load scheduling for multiple quay cranes in port container terminals. *Journal of Intelligent Manufacturing, 17,* 479–492.

Kemme, N. (2011). RMG crane scheduling and stacking. In J. W. Bose (Ed.), *Handbook of terminal planning*. New York: Springer.

Kemme, N. (2012). Effects of storage block layout and automated yard cranes systems on the performance of seaport container terminals. *OR Spectrum, 34,* 563–591.

Kim, K. H. (2007). Decision-making problems for the operation of container terminals. *Journal of the Korean Institute of Industrial Engineers, 33*(3), 290–302.

Lau, H. Y. K., & Zhao, Y. (2008). Integrated scheduling of handling equipment at automated container terminals. *International Journal of Production Economics, 112*(2), 665–682.

Lee, B. K., & Kim, K. H. (2010). Optimizing the block size in container yards. *Transportation Research Part E, 46*(1), 120–135.

Lee, B. K., & Kim, K. H. (2013). Optimizing the yard layout in container terminals. *OR Spectrum, 35*(2), 363–398.

Lee, C. Y., & Yu, M. Z. (2012) Inbound container storage price competition between the container terminal and a remote container yard. *Flexible Services and Manufacturing Journal,* 24(3), 320–348.

Lee, L. H., Chew, E. P., Tan, K. C., & Han, Y. B. (2006). A yard storage strategy for minimizing traffic management in transshipment hubs. *OR Spectrum, 28,* 539–561.

Lee, D. H., Cao, Z., & Meng, Q. (2007). Scheduling of two-transtainer systems for loading outbound containers in port container terminals with simulated annealing algorithm. *International Journal of Production Economics, 107,* 115–124.

Lee, D. H., Wang, H. Q., & Miao, L. (2008). Quay crane scheduling with non-interference constraints in port container terminals. *Transportation Research Part E, 44,* 124–135.

Lee, D. H., Cao, J. X., & Chen, J. H. (2009). A heuristic algorithm for yard truck scheduling and storage allocation problems. *Transportation Research Part E, 45*(5), 810–820.

Lee, D. H., Chen, J. H., & Cao, J. X. (2010). The continuous berth allocation problem: A greedy randomized adaptive search solution. *Transportation Research Part E, 46*(6), 1017–1029.

Li, W., Petering, M. E. H., Goh, M., & de Souza R. (2009). Discrete time model and algorithms for container yard crane scheduling. *European Journal of Operational Research, 198*(1), 165–172.

Linn, R., & Zhang, C. (2003). A heuristic for dynamic yard crane deployment in a container terminal. *IIE Transactions, 35,* 161–174.

Liu D. K., & Kulatunga (2007). Simultaneous planning and scheduling for multi-autonomous vehicles. *Studies in Computational Intelligence, 49*, 437–464.

Meisel, F. (2009). *Seaside operations planning in container terminals*. Berlin: Physica-Verlag.

Moccia, L., Cordeau, J.-F., Gaudioso, M., & Laporte, G. (2006). A branch-and-cut algorithm for the quay crane scheduling problem in a container terminal. *Naval Research Logistics, 53,* 45–59.

Möhring, R. H., Köhler, E., Gawrilow, E., & Stenzel, B. (2004) Conflict-free real-time AGV routing. Preprint 026-2004, Technical University Berlin, Institute of Mathematics

Murty, K. G. (2007). Yard crane pools and optimum layouts for storage yards of container terminals. *Journal of Indutrial and Systems Engineering, 1*(3), 190–199.

NAVIS. (2013) Container terminal operation. http://www.navis.com/solutions/container. Accessed Sept 2013

Ng, W. C., & Mak, K. L. (2005). An effective heuristic for scheduling a yard crane to handle jobs with different ready times. *Engineering Optimization, 37*(8), 867–877.

Ng, W. C., Mak, K. L., & Zhang, Y. X. (2007). Scheduling trucks in container terminals using a genetic algorithm. *Engineering Optimization, 39*(1), 33–47.

Nguyen, V. D., & Kim, K. H. (2013). Heuristic algorithms for constructing transporter pools in container terminals. *IEEE Transactions on Intelligent Transportation Systems, 14*(2), 517–526.

Park, Y. M., & Kim, K. H. (2003). A scheduling method for berth and quay cranes. *OR Spectrum, 25*(1), 1–23.

Petering, M. H. (2009). Effect of block width and storage yard layout on marine container terminal performance. *Transportation Research Part E, 45*(4), 591–610.

PSA (2014) CITOS. https://www.singaporepsa.com/our-commitment/innovation. Accessed in Jan 2014

Realtime B. Solutions (R. B. S.). (2013) Terminal Operation Package System (TOPS). http://rbs-tops.com/product-details/. Accessed Sept 2013

Tideworks. (2013) Mainsail Vanguard^{TM} Marine terminal operating system. http://www.tideworks.com/products/mainsail/. Accessed Sept 2013.

Total Soft Bank. (2013) CATOS. http://www.tsb.co.kr/RBS/Fn/FreeForm/View.php?RBIdx=Ver1_38. Accessed Sept 2013.

Sammarra, M., Cordeau, J. F., Laporte, G., & Monaco, M. F. (2007). A tabu search heuristic for the quay crane scheduling problem. *Journal of Scheduling, 10,* 327–336.

Sauri, S., & Martin, E. (2011). Space allocating strategies for improving import yard performance at marine terminals. *Transportation Research Part E, 47,* 1038–1057.

Schwarze, S., Voss, S., Zhou, G., & Zhou, G. (2012). Scientometric analysis of container terminals and ports literature and interaction with publications on distribution networks. In H. Hu, et al. (Eds.), Computational logistics, volume 7555 of lecture notes in computer science (pp. 33–52). Berlin: Springer.

Sciomachen, A., & Tanfani, E. (2007). A 3D-BPP approaoch for optimizing stowage plans and terminal productivity. *European Journal of Operational Research, 183*(3), 1433–1446.

Sharif, Q., & Huynh, N. (2013). Storage space allocation at marine container terminals using ant-based control. *Expert Systems with Applications, 40,* 2323–2330.

Stahlbock, R., & Voss, S. (2008). Operations research at container terminals: A literature update. *OR Spectrum, 30,* 1–52.

Vis, I. F. A. (2006). Survey of research in the design and control of automated guided vehicle systems. *European Journal of Operational Research, 170*(3), 677–709.

Vis, I. F. A., & de Koster R. (2003). Trasshipment of containers at a container terminal: An overview. *European Journal of Operational Research, 147,* 1–16.

Vis, I. F. A., & Harika, I. (2004). Comparison of vehicle types at an automated container terminal. *OR Spectrum, 26,* 117–143.

Wan, Y., & Tsai, P. C. (2009). The assignment of storage locations to containers for a container stack. *Naval Research Logistics, 56,* 699–713.

Wang, Y., & Kim, K. H. (2011). A quay crane scheduling algorithm considering the workload of yard cranes in a container yard. *Journal of Intelligent Manufacturing, 22,* 459–470.

Won, S. H., Zhang, X., & Kim, K. H. (2012). Workload-based yard-planning system in container terminals. *Journal of Intelligent Manufacturing, 23*(6), 2193–2206.

Woo, Y. J., & Kim, K. H. (2011). Estimating the space requirement for outbound container inventories in port container terminals. *International Journal of Production Economics, 133,* 293–301.

Wu, Y., Luo, J., Zhang, D., & Dong, M. (2013). An integrated programming model for storage management and vehicle scheduling at container terminals. *Research in Transportation Economics, 42,* 13–27.

Yang, C. H., Choi, Y. S., & Ha, T. Y. (2004). Simulation-based performance evaluation of transport vehicles at automated container terminals. *OR Spectrum, 26*(2), 149–170.

Yantai Huadong Soft-Tech. (2014) HD-CiTOS. http://www.huadong.net/UploadFile/datum/CiTOS.pdf. Accessed in Jan 2014.

Yuan, S., Skinner, B. T., Huang, S., Liu, D. K., Dissanayake, G., Lau, H., & Pagac, D. (2011). A job grouping approach for planning container transfers at automated seaport container terminals. *Advanced Engineering Informatics, 25,* 413–426.

Zhang, H. P., & Kim, K. H. (2009). Maximizing the number of dual-cycle operations of quay cranes in container terminals. *Computers & Industrial Engineering, 56*(3), 979–992.

Zhang, C., Wan, Y., Liu, J., & Linn, R. (2002). Dynamic crane deployment in container storage yards. *Transportation Research, B 36,* 537–555.

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