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Distributed framework for yard planning in container terminals*

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Abstract: This study discusses a yard planning system, which considers various resources such as storage space, yard cranes, and traffic areas in container terminals. The system is based on the function for estimating resource requirements of yard plans. For a given yard plan, the proposed system allows planners to check the feasibility of the plan which requires a certain amount of workload of resources in related blocks during a planning horizon. The yard planning system in this study is aimed at balancing workloads among the blocks and providing the ability to modify current yard plans by detecting blocks and periods with overloaded workloads. The system implements its planning function in a distributed manner in which planners construct yard plans under their individual control and send and receive only limited necessary information for the negotiation.

Key words: Workload, Yard planning, Container terminal, Distributed planning
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1 Introduction

Containers are temporarily stored in the yard of container terminals in the form of blocks before they are loaded onto the target vessel or delivered to consignees. Yard cranes, which are equipped in each yard block, are charged with handling containers for receiving, delivery, loading, and discharging operations. Fig. 1 illustrates a layout of a container terminal.

Generally, according to the flow direction, containers can be classified into three categories: outbound, inbound, and trans-shipment containers. Outbound containers are received from customers by inland transportation methods such as railways and external trucks (receiving operation), and will be loaded onto a vessel (loading operation). Inbound containers are discharged from a vessel (discharging operation), and will be delivered to consignees (delivery operation). Trans-shipment containers are discharged from a vessel and will be loaded onto another vessel after some duration of stay in the storage yard.

Two types of operations will lead to the storage of containers: one is discharging operation from vessels and the other is receiving operation from external vehicles. Discharging operations for a vessel are usually completed within one day, while receiving operations for a vessel last for several days depending on the arrivals of external vehicles. In this study, it is assumed that yard plans are established before discharging operation or receiving operation (Won, 2009).

Yard planning determines the quantity of containers for a vessel to be stored at each block. One of the important considerations in the yard planning is that workloads should be spread over many storage blocks, because the progress of works may be delayed if workloads are concentrated on a few blocks. A good decision also needs to minimize the travel distance of vehicles between storage blocks and berthing positions of vessels so as to minimize the cost and time for traveling. However, the availability of resources restricts the decisions, especially limitations of the

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storage capacity of each storage block and the handling capacity of yard cranes equipped in each storage block (Won, 2009).

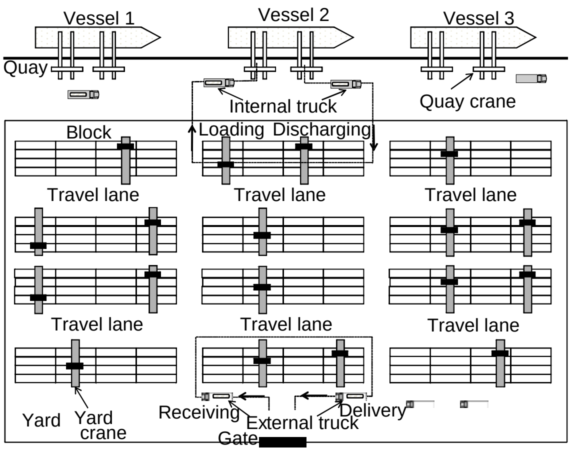

Fig. 1 Layout of a container terminal

This study defines a storage activity to be a set of containers of the same type (outbound, inbound, or trans-shipment containers) for a vessel, for which a planner attempts to reserve storage locations (specifically blocks). The yard planning in this study considers storage yards and yard cranes as resources. The required timings of resources are based on the discharging time of containers from vessels and the loading time of containers into vessels. The resources for inbound containers are consumed forward from the start time of the discharging to the completion time of the delivery. The resources for outbound containers are consumed backward from the completion time of the loading to the start time of the receiving. The resources for trans-shipment containers are consumed between the discharging time and the loading time of containers (Won, 2009). The requirements of resources are determined according to the quantity of containers handled and the amount of resources consumed by a container.

The yard planning method has been studied in many previous researches (Kozan, 2000; Preston and Kozan, 2001; Kim and Park, 2003; Zhang *et al*., 2003; Lee *et al*., 2006; Han, 2007; Bazzazi *et al*., 2009; Won, 2009). Won (2009) provided a framework for integrating various planning activities in container terminals. For each planning activity, a decision-making problem is identified, including input parameters, decision variables, objectives, constraints, time buckets, and planning horizon. That framework was developed on the basis of the concept of the capacity planning in production systems. He introduced a concept of a resource profile and a planning procedure by simultaneously considering availabilities of various resources and resource requirements of a yard plan. The yard planning problem was represented as a multi-commodity minimum cost-flow problem. A linear programming model for the yard planning was proposed.

This paper addresses the problem similar to those by Won (2009). However, Won (2009) proposed a centralized planning procedure, this study explores the possibility of a distributed planning framework which seems to be more similar to what practical planners are doing for the yard planning in container terminals. In the distributed framework, the requirements and availabilities of resources can be estimated and the feasibility of a yard plan can be verified. This paper also suggests a decentralized planning procedure which constructs the plans in a distributed manner.

2 Yard planning considering workloads

2.1 Various states of yard plans

The resource requirements come from various sources such as forecasts on future container arrivals (“forecasted requirement”), temporary plans (“temporary”), reservation plan (“reserved”), and containers already arrived (“occupied”). The forecasted requirement does not construct any plan and is for container arrivals in the distant future. For the temporary plans, the space is allocated temporarily but not fixed yet. For a reservation plan, an empty part of the yard is reserved for containers which will arrive at the yard soon. For the occupied space, containers have already arrived at the yard. Fig. 2 shows the relationships among different states of plans.

When there is not enough information about containers for a vessel, the system will forecast the required workload based on the historical data. When planners begin to obtain information on arrivals of containers from consignees or shipping liners, they construct temporary plans for the space allocation. For each temporary plan, the system checks the feasibility of the plan by estimating the required workload over the corresponding blocks during the planning period. If it is feasible, the plan will be confirmed and changed to a reservation plan. A reservation plan exclusively reserves some resources in advance so that the resources cannot be used for other plans. A reservation plan will be updated whenever a container arrives at the yard. When the container becomes to occupy some space, the state of the space is changed from “reserved” to “occupied”.

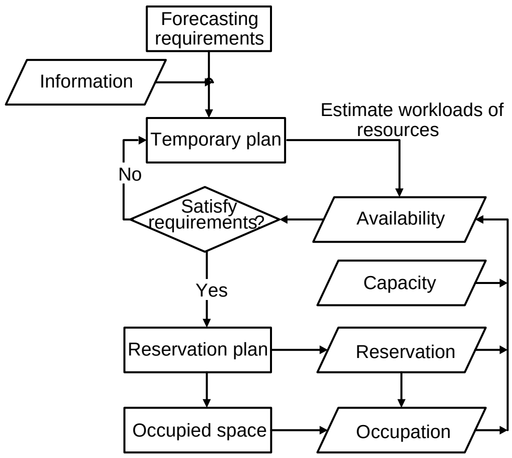

Fig. 2 Relationships among different states of yard plans

2.2 Requirements and availabilities of resources

The requirements of resources can be calculated using the quantity of containers to be handled and the amount of resources consumed to handle a container. The number of containers arriving at the yard or leaving the yard at each time period could be estimated by distributions which can be obtained from historical data. Usually, inbound containers are discharged from a vessel within one or two days, stay at the yard for 7 to 14 d, and then are delivered to customers; outbound containers are received from customers for 7 to 14 d before the arrival of a corresponding vessel, and then are loaded onto the vessel within one or two days; trans-shipment containers are discharged from one vessel within one or two days, stay at the yard for 7 to 14 d, and then are loaded onto another vessel within one or two days. The length of a period may be 8 h. However, the length of a time period may be changed depending on the degree of details for the yard plan and the computation burden.

The amount of resources consumed by a container is illustrated in Table 1. Based on these data, the workload for a specific yard plan at each corresponding block can be estimated. The feasibility of a plan can be verified by comparing the amount of each resource required by the yard plan and the remaining capacity of the resource.

Table 1 Resources consumed by a container

Resource	Required
Storage space	The number of slots that the container occupied
Yard crane	The handling time of a yard crane to receive (load) or deliver (discharge) the container

The availabilities of resources can be estimated as follows:

$$A_{rt}^{b} = C_{rt}^{b} - W_{rt}^{b} - P_{rt}^{b},$$

where A_{rt}^{b}, C_{rt}^{b}, W_{rt}^{b}, and P_{rt}^{b} represent the amount of remaining workload of resource r at time period t at block b, the capacity of resource r at time period t at block b, the amount of workload for resource r incurred by containers occupying the space at time period t at block b, and the amount of workload for resource r incurred by reservations of other plans at time period t at block b, respectively. The capacities of various resources can be calculated as shown in Table 2. Data on the handling times of various operations can be used for calculating workload of storage activities (Table 3).

Table 2 Resources capacity

Resource	Capacity during a period
Storage space	Maximum number of containers to be stored
Yard crane	Maximum available handling time per unit period

Table 3 Illustration of basic time data for handling containers

Resource requirement	Time (min)
Handling time of a yard crane for a receiving operation	1.521
Handling time of a yard crane for a delivery operation	2.242
Handling time of a yard crane for a loading operation	1.134
Handling time of a yard crane for an unloading operation	1.114
Duration of a period	480

3 Distributed yard planning framework

3.1 Procedures for distributed yard planning

In practice, yard plans are usually made by more than one planner in a distributed manner. However, resources are shared by all the planners, which, as a result, may cause conflicts among each other for the same resource. The lack of considerations on the limited availabilities of the shared resources during the planning process may result in infeasible plans. Thus, it is necessary to share the information about the availability of each resource to ensure the consistency among different plans.

Fig. 3 shows the framework for the distributed planning system. Table 4 shows the functions of the coordinator and the distributed planners. The coordinator retains and updates the information on the capacity of resources, the amount of reserved/occupied/available resources, and the price of resources. The coordinator has an objective to maximize its profit by adjusting the price of a resource responding to the demand for the resource. Thus, the coordinator increases the price of a resource if the demand for the resource exceeds to the supply of the resource and decreases the price in the opposite situation. For a planner, he/she accesses the coordinator to download such information as the amount of available resources and the price of resources to make his/her decision on the reservation of the space for arriving containers under his/her responsibility. If a plan is fixed by a planner, that is, the state of that plan is changed from "temporary" to "reserved", then the information on the reservation will be sent to the coordinator, which will then estimate the required amounts for related resources and timings of resource consumptions, based on data such as vessel ID, the number of containers, and the selected blocks, and update the reserved/available amounts of resources.

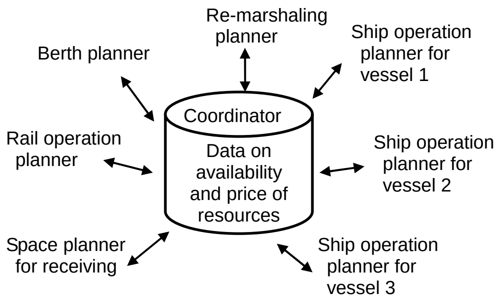

Fig. 3 Players for the distributed yard planning

Table 4 Functions of the coordinator and distributed planners

Role	Function
Coordinator	Maintain and update the dual prices of resources Maintain and update the current availabilities of resources: information on the planned, reserved, and occupied amount of each resource Suggest feasible plans from the global viewpoint
Distributed planners	Construct yard plans under his/her control and send them to the coordinator Confirm a plan by changing its state from "temporary" to "reserved" Cancel a plan

To describe the distributed yard planning procedures in detail, an activity diagram for each of the following events is provided:

1. When a planner constructs a (temporary) yard plan for a storage activity, the following procedures are initiated. Firstly the planner will download the prices and availabilities of resources from the coordinator and use this information for constructing his/her plan. Secondly, the results of the planning will be sent to the coordinator, who will then update the prices of resources (Fig. 4).

2. When a planner confirms a temporary plan by changing its state from "planned" to "reserved", the request for space reservation will be sent to the coordinator. Usually, a plan will not be confirmed until the last necessary moment. This procedure is shown in Fig. 5.

3. When the coordinator receives a temporary plan from a planner, the following procedure is initiated (Fig. 6). There may be two different modes of a

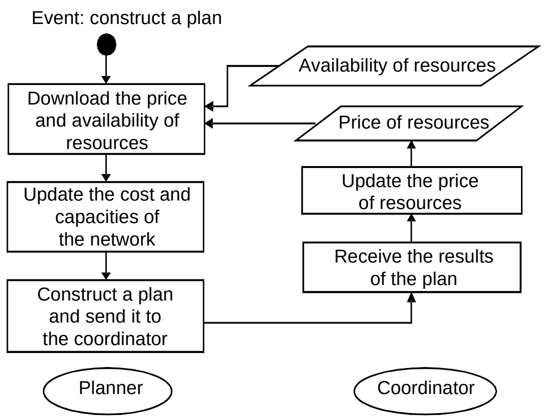

Fig. 4 Event of constructing a temporary plan

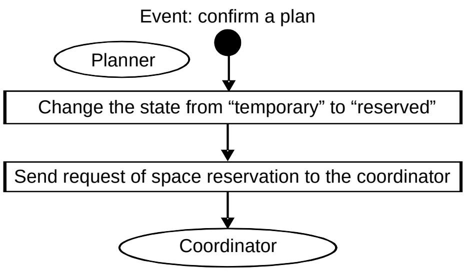

Fig. 5 Event of confirming a plan

yard-planning option for an individual planner, which are auto- and manual-mode. A plan by a planner who chooses the auto-mode can be updated by the coordinator whenever necessary without any permission by the planner, while a plan by a planner who chooses the manual-mode can be modified or updated only by the corresponding planner. As there must be frequent changes in plans and constructions of new plans, the price of resources must also be updated frequently. Thus, it may not be practical for human planners to update their plans whenever there is a change in the price of a resource. Therefore, it is recommended for human planners to choose the auto-mode for updating their plans. However, some planners may decide to update his/her plans manually, in which case more communications between the planner and the coordinator system are needed which is not always easy for human planners.

4. When the coordinator receives a reservation plan, the information about the amount of reserved resources and the amounts of available resources will be updated. As the reduction in availabilities of resources may affect the other plans, the event of updating a yard plan will be triggered (Fig. 7).

5. When the coordinator receives a cancellation of a reservation plan, the reservation on the related resources will be cancelled, and consequently the amount of available resources will be updated, which affects the decisions of other plans. Therefore, the event of updating a yard plan will be executed to update all those temporary plans (Fig. 8).

3.2 Issues related to implementation of the distributed yard planning system

A remaining issue to be discussed is how to set and update prices of resources by the coordinator and how to construct a good plan by planners. This study does not assume that the methods must be based on

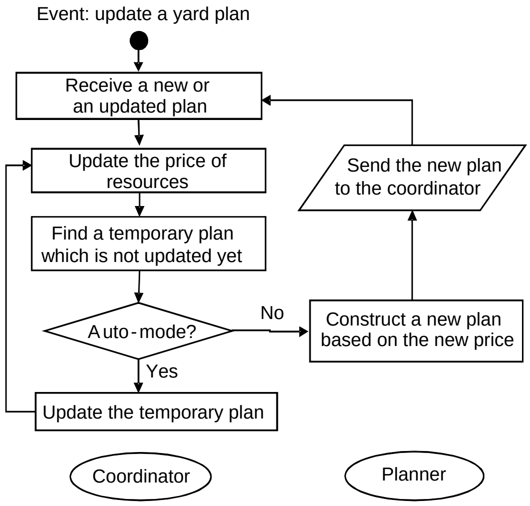

Fig. 6 Event of updating a temporary plan

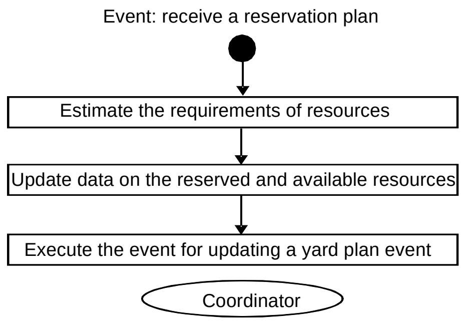

Fig. 7 Event of receiving a reservation plan

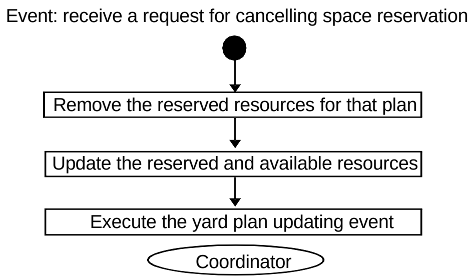

Fig. 8 Event of receiving request for cancelling a reservation plan

optimization techniques. The method in this study works even in the case where the decisions are based on human subjective decisions. However, the qualities of the final plans will depend on the qualities of decisions made by players in this system. Mathematical programming approaches may be used to support the decision processes of each player in the system. One possible approach is the subgradient optimization (Zhang, 2010). Because the problem in this study may be formulated as a multi-commodity minimum cost-flow problem, the formulation for the yard planning problem can be decomposed into multiple single-commodity problems, each of which correspond to the yard planning problem assigned to each planner. The procedure of updating prices of resources can be implemented using the procedure of updating Lagrangean multipliers. However, in this case, it is assumed that individual planners respond to every renewed price by updating their plans, which may not be practical when the individual planners are human. Thus, it may be necessary to develop software to support planners which will help decision-making processes of planners.

4 Conclusions

This paper addressed the yard planning problem by considering workloads of various resources in container terminals. A framework for the yard planning was proposed based on the capacity planning, which provided a method to estimate the workloads of various resources for a yard plan and availabilities of resources, and allowed verification of the feasibility of a yard plan.

This paper suggested a framework of a distributed yard planning system in which individual planners can construct or suggest a yard plan related to storage activities on which they are responsible, yet a coordinator guides them to make decisions from the global viewpoint. This study proposed a detailed procedure for each possible event during the planning procedure.

Although this study proposed a framework for the distributed yard planning, detailed decision-making algorithms for participating players need to be developed. The algorithms need to have capabilities to guide players to the direction of the global optimization of the yard system.

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