An optimization methodology for intermodal terminal management

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A solution to the problems of resource allocation and scheduling of loading and unloading operations in a container terminal is presented. The two problems are formulated and solved hierarchically. First, the solution of the resource allocation problem returns, over a number of work shifts, a set of quay cranes used to load and unload containers from the moored ships and the set of yard cranes to store those containers on the yard. Then, a scheduling problem is formulated to compute the loading and unloading lists of containers for each allocated crane. The feasibility of the solution is verified against a detailed, discrete-event based, simulation model of the terminal. The simulation results show that the optimized resource allocation, which reduces the costs by 1/3, can be effectively adopted in combination with the optimized loading and unloading list. Moreover, the simulation shows that the optimized lists reduce the number of crane conflicts on the yard and the average length of the truck queues in the terminal.

Keywords: Intermodal terminals, flexible job shop, resources allocation, containers optimization

1. Introduction

Intercontinental cargo transport has been continuously increasing since the advent of container shipping in the 1950s. Nowadays 95% of world cargo is moved by ship. Ports play the role of exchange hubs where containers are moved from ships to trains and trucks and their efficiency is fundamental to sustain the mounting cargo traffic. To cope with increased traffic demands and with decreasing profit margins the terminal operators need to improve the management of terminal processes such as ship berthing, ship loading and unloading, straddle crane routing, resource allocation, yard space management.

All of these problems are strictly interrelated; for instance, the choice of the position of the containers on the yard impacts on the decisions made regarding the allocation of resources, the allocation of resources constrains the scheduling of loading and unloading operations, and so on. The complexity of these processes makes it necessary to use efficient methods for the optimization of the overall system: operations research techniques and simulation have been proven particularly apt to solve these kinds of problems (see, for instance, Kozan and Preston, 1999; Kim and Bae, 1999; Kim and Kim, 1999; Magnanti and Wong, 1984).

The approach currently adopted by most terminal managers splits the problem by treating each ship as an independent entity: a ship planner is dedicated to plan loading and unloading operations for a single ship and to allocate the needed resources in terms of quay cranes, yard cranes, lifters and manpower. Since there is no cooperation among different ship planners, this method is a source of conflicts and performance degradation mainly in the case of resources that must be shared among parallel loading and unloading

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activities. The complexity of the process leads to the separation of management activities, but even from the mathematical point of view formulating a single problem is not viable, given the complexity of the resulting model.

This paper proposes a methodological approach (Section 3) to solve the problem which still considers the interactions among the ship planners, but reduces the problem complexity by iteratively modeling it at different levels of detail. At the highest level, container moves during loading and unloading operations are seen as a flow inside the terminal. The goal is to determine the best allocation of resources (RA) on the yard with the objective of minimizing the costs of the terminal. This is done very efficiently by modeling the problem as a network design problem and by using a mixed-integer linear program solved by a branch-and-bound search (Section 4). At the lowest level, given the exact position of containers in the yard, the goal is to schedule the sequence of loading/unloading operations (LUL) in order to optimize the use of the allocated resources and to make sure that the predicted flow is sustainable. The problem at this level is modeled as a scheduling problem and solved using a new neighborhood function and a new self-tuning tabu search (Section 5). Last, a simulation module is used as a test bench to evaluate the overall policies produced by the optimization modules (Section 6). The application of the computer-generated policies to the simulated model (Section 7) of La Spezia Container Terminal (LSCT) shows a noticeable increase in terminal performance: the same amount of work can be performed by only spending about 67% of the resource costs originally planned at the terminal, while still respecting the deadlines imposed on the load/unload operations (Section 2).

2. The intermodal container terminal

An intermodal container terminal is a place where containers enter and leave by multiple means of transport, as trucks, trains and vessels. In the following we consider the case of the LSCT, which is exemplified in Fig. 1.

The terminal is composed of the yard, where containers are stocked, and of the piers, where ships dock. Ships are served by quay cranes; quay cranes on the same pier can slide on rails to serve different sections of a ship, the bays. The position of a container (on ship and on yard) is identified by the triple bay, row (the second planar coordinate, besides the bay), and tier (the position in the container stack).

Shuttle trucks move containers from the quays to the yard areas and back. The terminal yard is divided into five areas: CA, CB, CC, A and R, which are used for temporary storage of containers. Containers in the R area are accessed by front lifters. The remaining areas are served by yard cranes. Yard cranes can only move over the related area. Their task is to load containers into the area from shuttle trucks (the cranes in CA and CB do it also from trains) and vice versa. In the LSCT there are ten front lifters and ten yard cranes (four on CA, two on CB and CC, two on A).

When a ship arrives in the terminal, it is first unloaded by a set of quay cranes. The unloaded containers will be stored in sub-regions of the yard areas, named import areas, where they can be stored by shuttle trucks, by yard cranes or by front lifters. When the unloading operations are completed the loading stage can start: containers which must be loaded on the ship are first discharged from the yard, loaded on shuttle trucks using yard cranes or front lifters, then each shuttle truck carries one container at a time to the ship where it will be loaded by using a quay crane.

3. The methodology

The problem of resource allocation is the most important since the terminal costs are a function of the resources (i.e., the quay cranes, the yard cranes,