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Comparison of solution approaches for the train load planning problem in seaport terminals

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ABSTRACT

In this paper the train load planning problem arising in a seaport container terminal is considered. This problem consists in determining the optimal assignment of containers to wagon slots in order to maximize the train utilization and, at the same time, to minimize unproductive operations in the terminal. Different solution approaches based on a mathematical programming model are compared. The best solution procedure, satisfactory both in terms of quality of the obtained solutions and for the computational times, is identified through extensive experimental tests. This procedure could be included in a planning tool to be used in real seaport terminals.

1. Introduction

Seaport container terminals are very complex systems in which a high degree of coordination and efficiency is needed in order to ensure a fast transshipment process. Moreover, because of the huge growth rates on major maritime container routes, the competition among container ports has considerably increased in the last decades (Günther and Kim, 2006). Competitive performances of a terminal operator can be achieved by using, among other things, information technology and automated control technology (Vis and de Koster, 2003). As a consequence, enhanced planning and management procedures are required, offering great opportunities and bringing significant challenges for researchers (Crainic and Kim, 2007).

Two important surveys, Steenken et al. (2004) and Stahlbock and Voss (2008), are focused on optimization methods for planning the operations in maritime container terminals. The authors of these surveys classify the optimization approaches present in the literature according to the different processes in a seaport terminal, i.e. ship planning, storage and stacking planning, and transport optimization (divided in quayside, landside, and crane movements). Referring to such a classification, the present work is devoted to landside transport optimization since optimization approaches for the determination of loading plans for trains are developed and presented. In particular, as highlighted by Steenken et al. (2004), a loading plan indicates on which wagon a container has to be placed; this decision generally depends on the destination, type and weight of the container, the maximum load of the wagon, the train composition and the container location in the storage area. Two recent reviews related to transport operations and storage yard operations in container terminals have been proposed by Carlo et al. (2014a,b).

In this paper, the train load planning problem arising in a seaport terminal is considered. This problem has been inspired from a real case in an Italian port. It is worth noting, as better outlined in the next section, that seaport terminals have

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peculiar characteristics which highly differentiate them from inland terminals and, further, seaport terminals of the Mediterranean area are different from maritime terminals of other regions. In the considered case, the main objective of terminal operators is to maximize the train utilization and to minimize unproductive operations during the loading process. In particular, in seaport terminals (especially in the Italian ones which are commonly characterized by lack of space), containers are stored in stacks, four or five tiers high. During the train loading phase it can happen that the container to be picked up is not on the top of the stack, hence requiring a reshuffle, also called rehandle (i.e. unproductive operation). In order to reduce reshuffles, terminal operators allow backward empty moves of the crane loading the train, that represent again unproductive operations, as will be better explained in Section 3. The problem under investigation is the assignment of containers to wagon slots, given a train (with a specific composition of wagons) and given a number of containers (with different characteristics) stored in a given stacking area. In order to solve this problem, a MILP model for maximizing the train utilization and for minimizing the unproductive operations is adopted.

The main contribution of this paper is related to the definition of some solution procedures based on the MILP model. These solution procedures are devised in order to be used in a planning tool that can be applied to solve real train load planning problems. Even though the problem dimensions of real instances are not very large, the optimal solution of these instances requires high computational times. For this reason, three solution procedures are proposed, which are compared through some experimental tests considering real-dimension instances. The best solution procedure among the three proposed approaches is able to determine effective solutions in an acceptable computational time and, hence, can be suitable for practical use in seaport terminals.

Finally, note that the proposed model (conceived starting from a real case) has a general form and could be applied in any other container terminal where the train load is realized in order to maximize the train utilization and to reduce the unproductive operations. These are very common objectives in seaport terminals, while in inland terminals other aspects are primarily pursued, as outlined in the next section. Indeed, in most inland terminals, yard space is not a critical resource and reshuffles rarely occur.

The paper is organized as follows. In Section 2 the main contributions found in the literature related to train load planning problems are described and compared with the present paper. Section 3 introduces and describes the train load planning problem. In Section 4 the problem is formulated as a mixed-integer linear programming model. Section 5 is devoted to the definition of three solution procedures for the problem under investigation. In Section 6 the experimental results are described and discussed in detail. Finally, some conclusive remarks are reported in Section 7.

2. Literature review

In the literature, some research studies can be found focusing on planning problems related to train load operations. Most of them are devoted to landside intermodal terminals (refer to Macharis and Bontekoning (2004) and Bontekoning et al. (2004) for a survey on intermodal rail-truck freight transport and to Boysen et al. (2013) for a review on rail-road and rail-rail transhipment yards). Boysen et al. (2010) propose a dynamic programming approach to determine yard areas for gantry cranes in rail-rail transhipment yards. These yards are operated in distinct pulses of trains, i.e. a given number of trains (one per track) are served in parallel by gantry cranes available in the yard and jointly leave the system. Boysen et al. (2010) state that assigning crane areas is a sub-problem of the overall scheduling problem arising in a rail-rail transhipment yard involving (i) scheduling of the service slots of trains by assigning them to pulses, (ii) decisions on the containers' positions on trains, (iii) assignment of each train to a railway track, (iv) assignment of container moves to cranes, and (v) decisions on the sequence of container moves per crane. A case similar to the one described by Boysen et al. (2010) is studied by Kellner et al. (2012) where a mathematical model and different heuristic solution procedures are presented in order to face the train location problem. This problem consists of assigning each train of a given pulse to a railway track and deciding about each train's parking position on the track, so that the distances of container movements are minimized and the overall workload is equally shared among cranes.

The present work is devoted to the definition of the loading plan for trains, i.e. item (ii) of the classification reported above, introduced by Boysen et al. (2010). Few works in the literature deal with this problem and most of them are referred to inland terminals, while this work is focused on the train loading problem faced by maritime terminal operators. Bostel and Dejax (1998) propose some models and heuristic methods for container allocation problems related to trains but they focus on rail-rail terminals with rapid transfer yards. Therefore, they consider the possibility of transferring containers directly from one train to another, while this is not the case of the present work. Corry and Kozan (2006) consider a terminal where containers are transferred to and from trucks on a platform adjacent to the rail tracks provided with a short-term storage area. The problem faced by Corry and Kozan (2006) is the assignment of containers to train slots but the authors treat only one type of container and they do not consider weight restrictions of the wagons. The cost function includes the minimization of the container handling time and the optimization of the weight distribution on the train. In their subsequent work, Corry and Kozan (2008), include more types of containers and the objective regards the minimization of the train length and the total handling time. In the computation of the total time the authors also consider the time required for the changes of pins, which are fastening devices to secure containers on wagons. Since the resulting mixed-integer programming model described by Corry and Kozan (2008) cannot be solved in acceptable times for practical problems, heuristic algorithms based on local search and simulated annealing are proposed.