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Multi-objective optimization for the train load planning problem with two cranes in seaport terminals

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Abstract: This paper deals with the train load planning problem arising in seaport terminals. In particular, the train load planning problem in case of two cranes is studied, corresponding to the optimal assignment of containers to the wagons on which they are loaded and to the cranes which perform the loading operations. This optimal assignment is realized by considering the simultaneous optimization of several objectives. Hence, the train load planning problem is formulated as a multi-objective optimization problem and three multi-objective optimization techniques are applied and compared to solve it. Some preliminary experimental results are shown in order to compare the three methods.

1. INTRODUCTION AND LITERATURE REVIEW

This paper presents a problem arising in seaport terminals and devoted to landside transport optimization (see [1] for a survey), that is the *train load planning problem* (TLPP). The TLPP is related to the definition of a loading plan, indicating on which wagon a container has to be placed. In the literature, studies focusing on the TLPP are generally related to landside intermodal terminals. In [2], the TLPP is treated with the aim of minimizing the train length, and the total handling time including also the time required for the changes of pins. In [3] many types of containers are considered and many weight restrictions related to wagon configurations are taken into account: the aim of this TLPP is to maximize the train utilization, minimize the setup costs due to the changes of pins and minimize the costs related to moving containers from the storage area to wagons.

Studies on the TLPP in seaport terminals start with [4], which is based on [3] for the way of modeling wagon weight constraints and configurations. More specifically, [4] treats the case of train sequential loading (i.e. backward empty crane moves are forbidden) and explicitly considers the minimization of reshuffles in the storage area, together with the maximization of the value of the loaded containers. The problem described in [4] is then extended in [5] in order to consider the case of train loading in which both reshuffles in the storage area and backward crane moves are allowed (for this problem some solution methods are proposed in [6]). Moreover, in [7], different train loading policies and different stacking strategies, adopted in the yard where containers can be stored, are compared. Finally, in [8] the problem presented in [4] for the sequential train loading is extended to consider a sequence of trains with different destinations and to manage the repositioning of rehandled containers in the storage area.

In this paper, the TLPP is investigated for the case in which two cranes are used for loading the train. In particular, starting from the Mixed-Integer Linear Programming (MILP) model for the sequential loading presented in [5], the planning must be defined pursuing two additional aims: the minimization of pin changes and the minimization of the distances between the container locations in the storage area and the assigned wagons. Considering the case of two cranes, in order to speed up the loading operations, a further objective is to balance the number of operations that each crane has to execute. The resulting problem is a multi-objective optimization problem (MOOP), hard to be solved also for the presence of five different objectives. Moreover, each maritime terminal (each decision maker) assigns different priorities to these objectives, making the problem even harder to be treated.

Generally, three classes of approaches for solving a MOOP are identified (see for instance [9, 10]): a priori approaches, interactive approaches, and a posteriori approaches. In a priori approaches the decision maker provides preferences for the different objectives before the start of the solving process, in interactive approaches the decision maker's choices are made during the problem solving process, whereas in a posteriori approaches a set of potentially non-dominated solutions is first generated, and then the decision maker chooses among those solutions. Another classification for the MOOP solution approaches distinguishes among scalar methods, Pareto methods, and other methods. Among the scalar approaches which use mathematical transformations, some of the most known methods are the Weight Sum Method (WSM), the Goal-programming technique and the ε-constraint method. Pareto methods, instead, apply the concept of Pareto dominance to compare solutions. Note that, in the last years, multi-objective methods are used in many heuristics or meta-heuristics; for example, Multi-Objective Simulated Annealing (MOSA) [11] and Pareto Local Search techniques [12] are based

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on the Pareto dominance. These techniques rely on the principle that the next current solution is chosen from the non-dominated solutions of the neighborhood. In this paper a multi-objective formulation for the TLPP with two cranes is proposed together with three multi-objective optimization approaches (WSM, Goal-programming and ε-constraint method) used for solving it.

The paper is organized as follows. Section 2 describes the TLPP with two cranes, while Section 3 provides the multi-objective formulation for this problem. Three multi-objective optimization approaches are proposed in Section 4 and then compared, through preliminary experimental results, in Section 5. Conclusive remarks are drawn in Section 6.

2. THE CONSIDERED PROBLEM

The TLPP with two cranes addressed in this paper relies on the following main assumptions:

- the planning is related to one train at a time;
- the stacks in the storage area are composed of containers having the same destination, hence the planning of a train only includes the subset of the stored containers with the same destination of the train;
- the two cranes load the train sequentially and cannot overtake each other;
- the real wagon weight constraints are considered.

The TLPP with two cranes can be stated as follows: given a set of containers with different characteristics (length, weight, commercial value and storage position), one train composed of a set of wagons of different types (i.e. with different length and weight constraints, and with different load configurations), and two cranes for loading the train, the decision to be taken regards how to assign containers to wagon slots and which crane loads each container. These decisions are taken considering some constraints, mainly on the load configurations of wagons, on the proper sequence of the operations realized by the cranes, on weight limitations for slots, wagons and train.

Several objectives have been considered in the TLPP with two cranes under investigation, i.e.:

(1) maximize the commercial value of loaded containers;
(2) minimize the number of reshuffles in the storage area;
(3) minimize the number of pin changes in the wagons;
(4) minimize the total covered distance between the storage area and the wagons;
(5) minimize the unbalance between the number of operations realized by the two cranes.

The first objective is related to the fact that containers in the storage area are characterized by different commercial values, which are related to their priorities or their due times. In the TLPP the total commercial value of the loaded containers is maximized, so that containers that are more urgent or more relevant are favoured in the loading process. The second objective is related to the minimization of reshuffles, which are unproductive operations realized during the picking of containers in the yard from the stacks; minimizing reshuffles imply the reduction of times and costs. The third point is related to the fact that, when a train arrives, its wagons are characterized by a given configuration of pins (which depends on the lengths of containers previously loaded on the wagons): if the new loading plan requires the change of pins, higher times are necessary to prepare the wagons through a manual operation by terminal operators. The forth objective is the minimization of the total distance between the place where containers are positioned in the storage area and the position on the wagon where they are loaded; minimizing this distance corresponds again to reduce times and costs in the terminal operations. Finally, the number of operations realized by the two cranes should be balanced, in order to equilibrate their work load and to reduce the total loading time.

3. MULTI-OBJECTIVE FORMULATION

In order to provide a formulation for the MOOP of the train load planning with two cranes described in Section 2, only the first three objectives are considered explicitly, whereas the other two are imposed to be lower than a threshold.

The problem parameters are:

- W number of wagons;
- S number of train slots;
- $\mathcal{S}_w$ set of slots for wagon $w = 1, \ldots, W$;
- $\mathcal{B}_w$ set of weight configurations for wagon $w = 1, \ldots, W$;
- $\bar{\mathcal{B}}_w$ set of weight configurations for wagon $w = 1, \ldots, W$ which require pin changes;
- $\phi_{w,b}$ number of pin changes for weight configuration $b \in \bar{\mathcal{B}}_w$ of wagon $w = 1, \ldots, W$;
- $\mathcal{B}_{s,w}$ set of weight configurations of slot s of wagon w, $w = 1, \ldots, W$, $s \in S_w$;
- μ_s length of slot $s = 1, \ldots, S$ (either 20' or 40');
- ρ_s position of slot $s = 1, \ldots, S$ in the train (expressed in TEUs);
- $\bar{\omega}_w$ weight capacity of wagon $w = 1, \ldots, W$ (in tons);
- $\delta_{b,s}$ maximum weight for slot $s \in S_w$, $w = 1, \ldots, W$, in the weight configuration $b \in \mathcal{B}_w$ (in tons);
- $\bar{\Omega}$ weight capacity of the train (in tons).
- C number of containers in the storage area;
- ω_i weight of container $i = 1, \ldots, C$ (in tons);
- λ_i length of container $i = 1, \ldots, C$ (either 20' or 40');
- π_i value of container $i = 1, \ldots, C$;
- $\gamma_{i,j}$, $i, j \in \{1, \ldots, C\}$, $i \neq j$, relative position of container i with respect to j, $\gamma_{i,j} = 1$ indicates that i is located over j.
- $d_{i,s}$ distance between container $i = 1, \ldots, C$ and slot $s = 1, \ldots, S$ (in TEUs);
- $\bar{D}$ bound on the total distance (in TEUs);
- $\bar{U}$ bound on the total unbalance, i.e. maximum difference between the number of operations realized by the two cranes;
- T maximum number of possible loading operations (equal to the number of 20' slots in the train).

The decision variables are:

- $x_{i,s,t,h} \in \{0, 1\}$, $i = 1, \ldots, C$, $s = 1, \ldots, S$, $t = 1, \ldots, T$, $h = 1, 2$, equal to 1 if operation t is the load of container i on slot s by crane h;
- $f_{w,b} \in \{0, 1\}$, $w = 1, \ldots, W$, $b \in \mathcal{B}_w$, equal to 1 if weight configuration b is chosen for wagon w;