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Pareto clustering search applied for 3D container ship loading plan problem

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ABSTRACT

The 3D Container ship Loading Plan Problem (CLPP) is an important problem that appears in seaport container terminal operations. This problem consists of determining how to organize the containers in a ship in order to minimize the number of movements necessary to load and unload the container ship and the instability of the ship in each port. The CLPP is well known to be NP-hard. In this paper, the hybrid method Pareto Clustering Search (PCS) is proposed to solve the CLPP and obtain a good approximation to the Pareto Front. The PCS aims to combine metaheuristics and local search heuristics, and the intensification is performed only in promising regions. Computational results considering instances available in the literature are presented to show that PCS provides better solutions for the CLPP than a mono-objective Simulated Annealing.

1. Introduction

The operational efficiency of container terminals depends on an appropriate container moving plan, known as “stowage planning”, especially because the container ship loading process demands unloading service time, and this has a high cost (Dubrovsky, Levitin, & Penn, 2002). Therefore, the aim of the stowage planning for the container ships is to optimize the number of unnecessary movements called re-handle.

According with Pacino, Delgado, Jensen, and Bebbington (2011), there are two major approaches to tackle the stowage planning problem: single phase and two phases.

For the two phase approach, first a Master plan is created by distributing the containers throughout ship bays. Then, a slot planning phase focuses on one bay at time, to determine which slot will be used to hold each container. This approach was proposed by Wilson and Roach (2000).

Although as pointed out by Ambrosino, Anghinolfi, Paolucci, and Sciomachen (2010), even the Master bay planning is very difficult, there are some exact and heuristic methods in the literature to solve it:

- Sciomachen and Tanfani (2003) presented 0/1 Integer Programming (IP) models to find optimal solutions just for very small instances;
- Imai, Nishimura, Papadimitriou, and Sasaki (2002) proposed models that deal with a simplified version of the problem using a bi-objective function that estimates container re-handles and distance between the metacenter and the center of gravity;
- Ambrosino, Anghinolfi, Paolucci, and Sciomachen (2009) implemented a three step heuristic that combines 0/1 IP model with a Tabu Search which faces some problems to enforce stability for large instances;
- Ambrosino et al. (2010) used a initial constructive heuristic with an ant colony optimization (ACO);
- Cruz-Reyes, Hernández, Melin et al. (2013) developed 0/1 IP but employed a constructive heuristic to find solution.

The single phase approach represents the cargo-space as cell-based data structure and consists of formulating a model for describing the entire stowage problem. The main drawback of this approach is that this problem is classified as NP-hard and there is no guarantee of obtaining optimal solution for commercial sized ships in a reasonable time (Wilson & Roach, 1999). For this reason, the following approaches were employed:

- Avriel, Penn, and Wittenboon (1998) developed a Suspensory heuristic with a dynamic slot-assignment scheme to create a stowage planning;

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- Dubrovsky et al. (2002) employed a genetic algorithm with a compact solution encoding, which considers fulfillment of stability constraints as a penalty in objective function;
- Azevedo et al. (2014) experimented with a variety of heuristics and metaheuristics combined with a new encoding called representation by rules to optimize a bi-objective function composed of the number of re-handles and a stability measure;
- Ding and Chou (2015) presented a heuristic that outperforms the heuristic developed by Avriel et al. (1998).

A common concern for both approaches is the trade-off between re-handle minimization and fulfilling stability constraints through constraints or objective function. Some of two phase approaches enforced stability as constraints, but do not explain, for example, how the fulfillment of the constraints done in Master bay planning will be ensured after the application of the slot planning and vice versa (Delgado, Jensen, Janstrup, Rose, & Andersen, 2012). Sometimes, for large instances even for just Master bay planning, it is difficult to treat stability as a constraint (Ambrosino et al., 2010). Otherwise consideration of stability constraints using an objective function leads to the 3D Container ship Loading Plan Problem (CLPP), which is a multi-objective problem.

A variety of papers have employed a multi-objective formulation and fixed a specific weight for each objective (Azevedo et al., 2014; Delgado et al., 2012; Imai et al., 2002; Wilson & Roach, 2000), but without a deeper discussion of how to obtain them according with decision maker preferences. Moreover, Monaco, Sammarra, and Sorrentino (2014) posed that operation port objectives should be considered that include quay cranes operation, Yard-to-quay transport time, and number of yard shifts. However, the quay crane operation and port yard operation are themselves very complex problems to formulate and solve as pointed out by Chung and Choy (2012) Legato and Trunfio (2014) Carlo, Vis, and Roodbergen (2014) Barrass and Derrett (2011), and these will not discussed in this paper. Our main contribution is a proper treatment of two conflicting objective functions of the CLPP: re-handle minimization and stability through obtaining Pareto optimal frontier.

This work is a continuation of the studies presented by Azevedo et al. (2014), which presented a literature review of the CLPP and proposed three metaheuristics (Genetic Algorithm, Beam Search, and Simulated Annealing) with representation by rules. This representation is useful to prevent infeasible solutions. The authors conducted studies with two objectives (number of movements and instability). However, only one objective is optimized at a time by the algorithm.

As showed by Azevedo et al. (2014), prioritizing the ship instability in the objective could greatly impact arrangement of containers and increase the number of movements.

This paper presents a new alternative to solve the CLPP by finding the Pareto optimal frontier. We propose an adaptation of a hybrid method known as Clustering Search (CS) (Oliveira, Chaves, & Lorena, 2013), which we call Pareto Clustering Search (PCS). The main idea of the PCS is to identify promising areas of the search space by generating solutions through a metaheuristic and clustering them into groups that are further explored with local search heuristics. We use the Pareto Simulated Annealing (PSA) (Duh & Brown, 2007) to generate solutions using the representation by rules (Azevedo et al., 2014). The PCS applied to CLPP provides some advantages for searching the solution space when compared to the mono-objective Simulated Annealing proposed by Azevedo et al. (2014).

The remainder of the paper is organized as follows. Section 2 presents the CLPP properties. In the Section 3, we first describe the basic ideas of CS and then we introduce the new multi-objective approach, describing in detail the PCS applied to the CLPP. The computational results are presented in Section 4. Finally, Section 5 contains the concluding remarks.

2. 3D Container ship loading plan problem

The solution of the 3D Container ship Loading Plan Problem (CLPP) should produce a stowage plan that is strongly related with the cellular structure of container ships, as shown in Fig. 1. This structure means containers may only be reached by removing any containers stacked on top of them in a column. There are two unloading cases:

a) Containers to be unloaded at a given port are at the top of the stack.
b) Containers to be unloaded at a given port are blocked by one or more containers that are to remain aboard the container ship. These must be unloaded and reloaded after all containers in the column for that port have been unloaded. This movement of unloading and loading blocking containers is called re-handling.

The CLPP problems are not independent. Once a container ship arrives or leaves a port, it is necessary to perform unloading and loading containers according to a previous stowage planning. The CLPP model tries to produce container ship arrangement that minimizes the number of movements and instability. As shown in Fig. 2, this is a hard problem because the arrangement in one port could greatly affect the arrangement in future ports. The elements (i, j) in Fig. 2(a) determine the quantity of containers that should be transported from port i (row i) to others ports j (columns j on row i). Fig. 2(b) shows the container ship arrangement in each port after unloading (U) and loading (L) operations.

Azevedo et al. (2014) formulated a mathematical model of the CLPP. The following assumptions have been made for the sake of

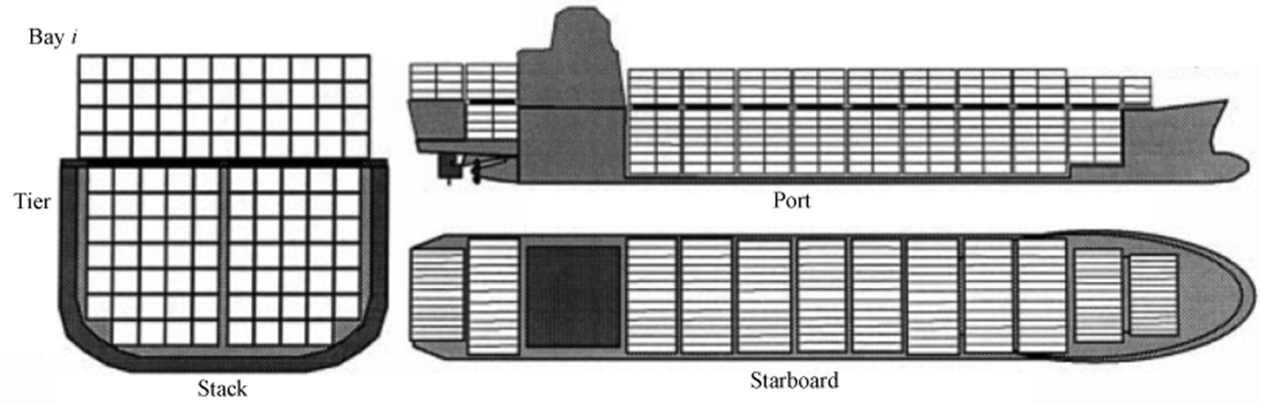

Fig. 1. Container ship cellular structure (*Source*: Wilson and Roach, 2000).