Computers and Operations Research 82 (2017) 139–152

Contents lists available at ScienceDirect

Computers and Operations Research

journal homepage: www.elsevier.com/locate/cor

Solving a large multicontainer loading problem in the car manufacturing industry

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ARTICLE INFO

Article history:
Received 26 April 2016
Revised 5 December 2016
Accepted 24 January 2017
Available online 28 January 2017

Keywords:
Container loading
Optimization
Packing
Metaheuristics
GRASP

ABSTRACT

Renault, a large car manufacturer with factories all over the world, has a production system in which not every factory produces all the parts required to assemble a vehicle. Every day, large quantities of car parts are sent from one factory to another, defining very large truck/container transportation problems. The main challenge faced by the Renault logistics platforms is to load the items into trucks and containers as efficiently as possible so as to minimize the number of vehicles sent. Therefore, the problem to be solved is a multicontainer loading problem in which, besides the usual geometric constraints preventing items from overlapping and exceeding the dimensions of the container, there are many other constraints, concerning the way in which items are put into layers, layers into stacks and stacks into containers, limiting the total weight and the weight supported by the items. In this paper we propose a GRASP algorithm, including constructive procedures to build solutions satisfying all the constraints, randomization strategies to produce diversity of solutions, and improvement moves to obtain high-quality solutions in short computing times. The algorithm has been tested on a set of real instances provided by the company and the results are competitive with the best results known, including some new improved solutions.

1. Introduction

Renault is one of the largest vehicle manufacturers in the world, producing a wide range of cars and vans in 32 factories around the world. Although for historical reasons most of them are located in France, Renault has factories in Western and Eastern Europe (Portugal, Spain, Russia, Romania, Turkey), Asia (Korea, India), Africa (Morocco, Algeria), and South America (Argentina, Brazil, Chile, Colombia). In its production system, not every factory produces all the parts necessary to assemble a vehicle. Although most of the factories assemble one or more models, usually some or all of the parts come from other Renault factories. This flow between factories presents logistics platforms with a very large truck/container problem for shipments worldwide. In addition to the daily loading of trucks and containers, every week logistics platforms must estimate the number of containers needed for the following weeks. They must also simulate the loading for future vehicle projects in order to find the best loading plans and the most suitable packaging. Therefore a loading tool is at the heart of the activity of logistics platforms. Minimizing the number of trucks and containers to be shipped is critical, since a gain of one cubic meter per container can generate huge annual savings for logistics platforms.

At each platform the problem to be solved is how to send the parts required by other platforms in the most efficient way. Depending on the location of the platforms, trucks or containers will be used, but in all cases they deliver their full load to a single destination, and therefore no routing decisions or multi-drop constraints are involved. They use trucks of different sizes for road transportation and 20-foot and 40-foot containers for sea transportation. In this paper we will use the term bin for both trucks and containers. The main objective is to pack the required items into bins so as to minimize the total volume of the bins used. There is also a set of secondary objectives to distinguish between solutions with the same volume.

Three-dimensional bins contain stacks packed on the floor. Each stack is composed of layers that are placed one on top of the other. A layer contains a set of rows, which are composed of items. Besides the usual geometric constraints preventing overlapping and forcing the items to be completely inside the bin, there are many constraints on the way in which items can be put together to form rows, rows to form layers and layers to form stacks. There are also constraints on the total weight of the items in each bin, the weight that the base layer of the stack can bear, and the orientation of the

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http://dx.doi.org/10.1016/j.cor.2017.01.012
0305-0548/

items. Since items are sent almost every day, some of them can be left out of the packing and sent another day, within certain limits for each type of item.

Therefore, the loading problem we are dealing with is a Multi Container Loading Problem (MCLP), with many special constraints not included in the standard Container Loading Problem. According to the typology proposed by Wäscher et al. (2007), the problem can be classified as a three-dimensional Multiple Stock Size Cutting Stock Problem (MSSCSP). In a recent survey, Zhao et al. (2016) review 113 papers covering all variants of 3D container loading and point out three possible fruitful avenues for research. The first is the multiple container packing problem, which has been much less studied than the single container problem, especially in the case of heterogeneous container types, which has received even less attention. A second research issue concerns the consideration of real-world constraints. A consistent set of real-world constraints would benefit the research community and make adoption by practitioners more likely. The final research issue has to do with the quantity and quality of benchmark data sets. Realistic and challenging data sets with clear real-world constraints would help in moving this research area forward.

The problem posed by Renault contains all these three facets. It is a large multicontainer loading problem, involving in most instances several container and truck types. The problem also involves several types of non-standard constraints concerning weight, load-bearing and stability. Moreover, Renault provided a large benchmark of real-world instances, directly taken from its databases, on which new algorithms can be extensively tested.

The problem size, involving up to 85 bins in some cases, and the need to obtain solutions in short computing times make the problem impossible to solve exactly by using Integer Linear Programming (ILP) models. Instead, we have developed a Greedy Randomized Adaptive Search Procedure (GRASP) for building high-quality feasible solutions within the time limits set by the company. In the constructive phase the algorithm fills bins one at a time until all the items are packed, ensuring that all the packing constraints are satisfied, including a look-ahead strategy to decide the next bin type to be used. The constructive process is randomized to obtain diverse solutions throughout the iterative process, by combining two randomizing strategies. Also, several local search moves have been developed to improve the quality of the solutions, some of them specifically designed for the multicontainer case. The computational study shows that the proposed algorithm obtains high-quality solutions in all cases and improves on the best solutions known for some instances.

The remainder of the paper is organized as follows. An overview of related existing research is presented in Section 2. In Section 3 the problem is formally described and in Section 4 the test instances are analyzed to better understand the structure of the problem. The GRASP algorithm is described in Section 5, while Section 6 contains the computational study. Finally, Section 7 gathers our conclusions and proposals of further research.

2. Previous work

The Single Container Loading Problem (SCLP) has been extensively studied. A large variety of heuristic and metaheuristic algorithms have been proposed for solving it. Besides the geometric constraints, realistic constraints, similar to those we are facing in this study, have been receiving increasing attention for some time now. In 1995, Bischoff and Ratcliff (1995) listed twelve conditions to be considered when solving practical problems for which feasible loading plans are to be constructed. More recently, Bortfeldt and Wäscher (2013) have written an exhaustive review of the container loading problem and its relevant constraints.

Some of these practical constraints are related to weight. On the one hand, there is a maximum weight that can be loaded into the container (Bortfeldt et al., 2003; Gehring and Bortfeldt, 1997; Terno et al., 2000). Indeed, when the cargo is heavy, weight becomes a very restrictive constraint, more so than volume or space occupied. On the other hand, weight distribution constraints require the weight of the cargo to be spread along the container floor to avoid displacements during the journey and to balance the load between truck axles when the container is transported by truck. To achieve a good weight distribution, the center of gravity of the load should be in the geometric mid-point of the container floor, as in Bischoff and Marriott (1990), or must not be located more than a certain distance from it, as in Bortfeldt and Gehring (2001) and Gehring and Bortfeldt (1997).

Another very common constraint concerns the orientation of the pieces. Although in some cases the orientation is not restricted (Parreño et al., 2008; Ratcliff and Bischoff, 1998), it is more usual that only one vertical orientation is permitted, while 90° rotations of items in the horizontal plane are allowed (Haessler and Talbot, 1990; Iori and Martello, 2010). Sometimes, items cannot be rotated at all (Junqueira et al., 2012; Morabito and Arenales, 1994).

Stackability or load-bearing constraints are also introduced to avoid damaging the items located at the bottom of the stacks. They can be defined by limiting the number of items that an item can bear above it (Bischoff and Ratcliff, 1995), or by prohibiting items of a particular type being placed on top of another type (Scheithauer and Terno, 1996; Terno et al., 2000), or by the maximum weight that can be applied to an item per unit area (Junqueira et al., 2012; Alonso et al., 2014).

Another constraints are related to the stability of the load. Vertical or static stability prevents items from falling when the vehicle is not moving (Ramos et al., 2016). An item must be supported from below at a given percentage of the surface of its base. If this percentage is 100%, we speak of full base support (Araujo and Armentano, 2007; Eley, 2002; Fanslau and Bortfeldt, 2010; Ngoi et al., 1994). In the case of lower percentages we speak of partial base support (Jin et al., 2004; Junqueira et al., 2012). Horizontal or dynamic stability ensures that items will not move when the container is moving. This constraint deals with the capacity of items to support the inertia of their bodies (Ramos et al., 2015).

In comparison, the multiple container loading problem (MCLP) has been less studied. The MCLP was first introduced by Ivancic et al. (1989). The authors solved it using a sequential loading approach and published 47 benchmark instances in which all the containers have the same size. Bischoff et al. (1995) modified their single-container heuristic, applying it to the case of multiple containers. Eley (2002) used a set cover formulation for linear integer programming using pre-generated packing patterns, which were found using a tree search-based heuristic. Che et al. (2011) addressed a multiple container loading cost minimization problem using heuristics for a set cover formulation that extends the work of Eley (2002), and improved on the results for the instances proposed by Ivancic et al. (1989). Takahara (2005) dealt with the problem using two lists: an ordered list of items and an ordered list of pallets and containers in which the items have to be loaded. These lists are handled applying several metaheuristic procedures. Ceschia and Schaerf (2013) also dealt with a multi-container problem, but as in their case a truck can serve several customers, multi-drop constraints have to be imposed. They develop local search metaheuristics to solve problems of realistic size. If the order in which the customers have to be served is not fixed beforehand, we have to decide not only the packing of the items but also the assignment of customers to trucks and the route of the truck. The problem is then a combination of a vehicle routing and a multi-container loading problem and is receiving increasing attention in the literature (Iori and Martello, 2010; 2013; Pollaris et al., 2015).