Computers & Industrial Engineering 89 (2015) 80–87

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Multi-objective multi-population biased random-key genetic algorithm for the 3-D container loading problem

Jia-Nian Zheng [a], Chen-Fu Chien [a,*], Mitsuo Gen [a,b]

[a] National Tsing Hua University, 101 Section 2 Kuang-Fu Road, Hsinchu 30013, Taiwan, ROC
[b] Fuzzy Logic Systems Institute, 680-41 Oaza-Kawazu, Iizuka-shi, Fukuoka 820-0067, Japan

ARTICLE INFO

Article history:
Available online 21 July 2014

Keywords:
Container loading
Genetic algorithm
Multi-objective genetic algorithm
Fuzzy logic controller
Cutting and packing

ABSTRACT

The container loading problem (CLP) has important industrial and commercial application for global logistics and supply chain. Many algorithms have been proposed for solving the 2D/3D container loading problem, yet most of them consider single objective optimization. In practice, container loading involves optimizing a number of objectives. This study aims to develop a multi-objective multi-population biased random-key genetic algorithm for the three-dimensional single container loading problem. In particular, the proposed genetic algorithm applied multi-population strategy and fuzzy logic controller (FLC) to improve efficiency and effectiveness. Indeed, the proposed approach maximizes the container space utilization and the value of total loaded boxes by employing Pareto approach and adaptive weights approach. Numerical experiments are designed to compare the results between the proposed approach and existing approaches in hard and weak heterogeneous cases to estimate the validity of this approach. The results have shown practical viability of this approach. This study concludes with discussions of contributions and future research directions.

1. Introduction

The container loading problem (CLP) has important industrial and commercial application for global logistics and supply chains. In particular, the uses of containers have been increasing for overseas and land transportation (Guenther & Kim, 2006). The CLP is a cutting and packing problem in which one or more large rectangular boxes (i.e., the containers) will be filled with smaller rectangular boxes (goods) of different sizes. Wäscher, Haußner, and Schumann (2007) proposed a typology to classify the cutting and packing problem. Their criteria include dimensionality, kind of assignment, assortment of small items, assortment of large objects, and the shapes of small items. According to the typology, the present problem focused on three-dimensional cutting and packing for single container (only one large object) with rectangular small items in different heterogeneous levels.

Many algorithms have been proposed for solving the 2D/3D container loading problem and most of them concern single objective optimization rather than multi-objective optimization problems. In the real world, almost every problem involves optimization of several objectives. The container space utilization is to maximize the space for goods of customers, and the total boxes value is to maximize the profit of the logistics company. Even there are some relationships between these two objectives since the fee is based on the volume of goods. However, these two objectives are not perfect the same since the weight of goods, the batch size, and other factors (Egeblad, Garavelli, Lisi, & Pisinger, 2010).

This study aims to develop a bi-objective multi-population biased random-key genetic algorithm and provide the solution including the location of each box and the corresponding orientation. This study focuses on single container loading problem which place a set of rectangular boxes of known dimensions and numbers into a single container of known dimensions so as to maximize the container space utilization and the total boxes value by Pareto approach and adaptive weights approach. The proposed genetic algorithm applied multi-population strategy and fuzzy logic controller (FLC) to improve efficiency and effectiveness. Thus, the logistics company can keep their space utilization and maximize the value of goods in limited container. The workers can get better result and avoid adjusting the patterns to save time.

The remaining of this paper is organized as follows: Section 2 reviews the related studies for CLP. Section 3 employs linear programming for problem structuring. Section 4 presents the proposed methodology. Section 5 discusses the results of different

* Corresponding author. Address: Department of Industrial Engineering & Engineering Management, National Tsing Hua University, 101 Section 2 Kuang Fu Road, Hsinchu 30013, Taiwan, ROC. Tel.: +886 3 5742648; fax: +886 3 5722685.

E-mail address: cfchien@mx.nthu.edu.tw (C.-F. Chien).

http://dx.doi.org/10.1016/j.cie.2014.07.012
0360-8352/

heterogeneous levels and problem scales for validation. Section 6 concludes with contribution and future research directions.

2. Literature review

Many approaches have been proposed for container loading that can be classified as the heuristic, mathematical programming, and meta-heuristic. For example, Chien and Wu (1998, 1999) proposed a framework of modularized heuristics and developed a recursive computational procedure for determining the container loading patterns. Chien and Deng (2004) proposed a heuristic for container packing to determine the container packing patterns and visualize the results with a decision support system. They ranked the boxes by its dimensions, then matched the box with the suitable empty spaces and update the information. Chien, Lee, Huang, and Wu (2009) developed an efficient computational procedure involving three-dimensional cutting for determining near-optimal container-loading patterns to minimize the waste of container space and embedded the procedure in a container-loading support system. Huang and Lin (2012) focused on the pre-marshaling problems of CLP to find priority for each box in loading process. They provided two heuristics to create the initial layout and find the movements for adjusting the layout.

Most of the existing approaches are composed of a series of heuristics. Indeed, the existing methods can be significantly affected by the priority structures and no single approach is superior to the others. However, they are not always effectiveness enough. Bischoff and Marriott (1990) examined 14 existing heuristics and discussed the implications for the design of composite heuristics. They show that the problem is domain dependent and a composite heuristic may be developed to improve the loading. Thus, some studies want to find general approaches. Chen, Lee, and Shen (1995) developed a mixed integer linear programming (MILP) to describe CLP and solved a small problem for validation. Junqueira, Morabito, and Yamashita (2012) considered more realistic constraints to develop their mixed integer linear programming. They consider vertical and horizontal stability and load bearing and fragility with center of gravity.

Since the number of integer variables is too large to reduce the efficiency, the solving approaches are needed for large scale CLP. Meta-heuristics search strategies have been the preferred method in the last years. Tarantilis, Zachariadis, and Kiranoudis (2009) hybrid local search approach and tabu search approach to solve integrated vehicle routing and 3-D CLP. Parreño, Alvarez-Valdes, Oliveira, and Tamarit (2010) applied variable neighborhood search (VNS) for CLP. They provide five new movements to find neighborhood solutions. Gonçalves and Resende (2011) developed a parallel multi-population genetic algorithm for two-dimensional, non-guillotine restricted, packing problem. They combined a random-keys based genetic algorithm with a novel fitness function and a new heuristic placement policy. Later, they expanded the algorithm to three-dimensional container loading problem (Gonçalves & Resende, 2012).

This study provided a multi-objective hybrid genetic algorithm to maximize the container space utilization and the total value of the loaded boxes. The proposed genetic algorithm applied multi-population strategy and fuzzy logic controller (FLC) (e.g., Chou, Chien, & Gen, 2014; Li, Chien, Li, Gao, & Yang, 2012; Li, Chien, Yang, & Gao, 2014) to improve efficiency and effectiveness.

3. MILP for 3D-container loading problem

The CLP is a three-dimensional cutting and packing problem in which one or more large rectangular boxes (the containers) has to be filled with smaller rectangular boxes (goods) of different sizes. Let the container length, width, and height be denoted by L, W, and H, respectively. Suppose there are N types of rectangular boxes. Let the various lengths, widths, and heights of the considered boxes be denoted by l_i, w_i, and h_i, $i = 1, 2, \ldots, N$, respectively.

We assume (1) All boxes are for the same destination; (2) The boxes are firm enough to be loaded in any location; (3) The dimensions of the boxes can be interchanged to change the orientations. We also assume other boxes with the corresponding orientations if the orientation of a specific good is changeable. In practical cases, some goods (e.g., monitors) are only loaded by the "up-arrow" direction. That is, the height dimension of the boxes remains vertical but the base dimensions can be interchanged. Thus, the good is considered in all the valid orientations (denoted as the corresponding boxes) to reduce space waste and enhance overall container efficiency.

3.1. Notation

Indices

i	: the box i
j	: the another box j

Parameters

(L, W, H)	: the length, width, and height of the container
(l_i, w_i, h_i)	: the length, width, and height of the box i
N	: the set of the boxes
v_i	: the profit of the box i
M	: a large number

Decision variables

(x_i, y_i, z_i)	: the coordinates of corner of box i
s_i	: a binary variable which is equal to 1 if box i is placed in the container
a_{ij}	: a binary variable which is equal to 1 if box i is placed on the left side of the box j
b_{ij}	: a binary variable which is equal to 1 if box i is placed on the right side of the box j
c_{ij}	: a binary variable which is equal to 1 if box i is placed on the front side of the box j
d_{ij}	: a binary variable which is equal to 1 if box i is placed on the back side of the box j
e_{ij}	: a binary variable which is equal to 1 if box i is placed on the top of the box j
f_{ij}	: a binary variable which is equal to 1 if box i is placed on the bottom of the box j

3.2. Linear programming model

Objectives:

$$\text{Max} \quad f_1 = \frac{\sum_{i \in N} l_i \times w_i \times h_i \times s_i}{L \times W \times H} \tag{1}$$

$$\text{Max} \quad f_2 = \sum_{i \in N} v_i \times s_i \tag{2}$$

s.t.

$$x_i + l_i \leqslant x_j + M(1 - a_{ij}) \quad i,j \in \mathbf{N};\ i < j \tag{3}$$

$$x_j + l_j \leqslant x_i + M(1 - b_{ij}) \quad i,j \in \mathbf{N};\ i < j \tag{4}$$

$$y_i + w_i \leqslant y_j + M(1 - c_{ij}) \quad i,j \in \mathbf{N};\ i < j \tag{5}$$

$$y_j + w_j \leqslant y_i + M(1 - d_{ij}) \quad i,j \in \mathbf{N};\ i < j \tag{6}$$

$$z_i + h_i \leqslant z_j + M(1 - e_{ij}) \quad i,j \in \mathbf{N};\ i < j \tag{7}$$

$$z_j + h_j \leqslant z_i + M(1 - f_{ij}) \quad i,j \in \mathbf{N};\ i < j \tag{8}$$

$$a_{ij} + b_{ij} + c_{ij} + d_{ij} + e_{ij} + f_{ij} \geqslant s_i + s_j - 1 \quad i,j \in \mathbf{N};\ i < j \tag{9}$$