Computers & Industrial Engineering 102 (2016) 208–218

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

A novel heuristic algorithm for two-dimensional rectangle packing area minimization problem with central rectangle

Lei Wu [a,b], Liang Zhang [a], Wen-Sheng Xiao [a,*], Qi Liu [a], Chao Mu [a], Yaowen Yang [b]

[a] College of Mechanical and Electronic Engineering, China University of Petroleum, Qingdao 266580, China
[b] School of Civil and Environmental Engineering, Maritime Institute @NTU, Nanyang Technological University, Singapore 639798, Singapore

ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form 31 August 2016
Accepted 13 October 2016
Available online 14 October 2016

Keywords:
Two-dimensional rectangle packing
Layout optimization
Enveloping rectangle
Central rectangle
Length-width ratio
Layout of drilling equipment

ABSTRACT

The rectangle packing area minimization problem (RPAMP) has *a* wide range of applications in the industrial production. A special RPAMP with central rectangles that must be located in the center of the final layout is proposed and named CR-RPAMP in which the length-width ratio of the final layout can be changed legitimately within a reasonable scope. In this paper, for the purpose of solving the CR-RPAMP, a novel heuristic algorithm called HACR is presented. In HACR, by constraining the aspect ratio of enveloping rectangle, the length-width ratio of the final rectangular frame can meet the requirements. Besides, by constraining the betweenness centrality of central rectangle, the central rectangle can be located in the center of the final layout. In order to minimize the area of the enveloping rectangle, the solution procedure of HACR has been projected based on defining the priority of candidate rectangle. Strategies of padding inner space are put forward to improve the filling rate of the final layout. Comprehensive experiments were conducted on 34 international instances reported in the literature. Simulation results show that the proposed novel heuristic algorithm was effective and practicable. At last, the proposed HACR is applied to research the layout of drilling equipment in deep water semi-submersible platforms.

1. Introduction

The rectangle packing area minimization problem (RPAMP) is an NP-hard problem (He, Ji, & Li, 2015; Wei, Oon, Zhu, & Lim, 2011). Such a problem can find real-world applications in a wide range of industries, such as the textile, apparel, automobile, aerospace and chemical industries (Alvarez-Valdes, Parreño, & Tamarit, 2009; He & Wu, 2013; Lodi, Martello, & Monaci, 2002). RPAMP can be divided into two classes: the strip packing problem (SPP) and the rectangle packing problem (RPP) (Richard, Michael, & Martha, 2010). The SPP is a one-variable open-dimensional problem and the RPP is a two-dimensional knapsack problem (Beasley, 2004).

Because of the importance of RPAMP, various kinds of heuristic algorithms based on different strategies have been presented to seek high-efficiency solution (Bennell, Lee, & Potts, 2013). These algorithms can be categorized into two categories: traditional heuristic algorithms and meta-heuristic algorithms (Wei, Zhang, & Chen, 2009). The traditional heuristic algorithms use the heuristic information to guide the search process. The meta-heuristic algorithms use the meta-heuristic strategies such as simulated annealing, genetic algorithm and artificial neural networks to improve the search results (Wei et al., 2009).

The earliest and most famous heuristic algorithm is bottom-left (BL) which was proposed by Brenda, Edward, and Ronald (1980), and then Bernard (1983) brought in BL fill methods in 1983. Besides, Wu, Huang, Lau, Wong, and Young (2002) introduced the less flexibility first principle to determine the packing rule. Zhang, Kang, and Deng (2006) proposed a new heuristic recursive algorithm which arranged the rectangles by using a recursive structure. Huang, Chen, and Xu (2007) presented an effective heuristic algorithm in which two important concepts, called the corner-occupying action and caving degree, were introduced to guide the packing process. Cui, Yang, Cheng, and Song (2008) presented a new heuristic recursive algorithm based on a recursive structure combined with branch-and-bound techniques.

Recently, for the purpose of gaining better solving results some scholars introduce novel heuristic algorithms (Moura & Oliveira, 2005). Martello and Monaci (2015) provided an ILP (Integer Linear Programming) model, an exact approach based on the iterated execution of a two-dimensional packing algorithm, and a randomized meta-heuristic. Simulation results showed that such approaches were valid for the case where the rectangles shave fixed orientation and the case where the rectangles can be rotated by 90°.

* Corresponding author.
E-mail address: xiaowenshengupc@163.com (W.-S. Xiao).

http://dx.doi.org/10.1016/j.cie.2016.10.011
0360-8352/

Wang and Chen (2015) described a heuristic algorithm with only a single policy: maximizing the residual space during packing. Wei et al. (2009) first presented a least wasted first strategy which evaluated the positions used by the rectangles. Then a random local search was introduced to improve the results and a least wasted first heuristic algorithm (LWF) was further developed to find a desirable solution. He et al. (2015) presented a dynamic reduction algorithm that transformed an instance of the original problem to a series of instances of the rectangle packing problem by dynamically determining the dimensions of the enveloping rectangles. Based on existing solution methods for SPP and RPP, Bortfeldt (2013) presented a generic procedure for the RPAMP. In this approach, RPAMP instance was reduced to solving multiple SPP and RPP instances.

In the modern industrial process, there is a category of specific rectangle packing problems which are different from the normal RPAMP. Several characteristics of the specific rectangle packing problem can be described as follows:

(1) There are one or more special rectangles called central rectangles among the packing rectangles $\{\pi_1, \pi_2, \ldots, \pi_n\}$. In the final layout, the special rectangles must be located in the center of the layout.
(2) The length-width ratio of the final layout is not settled, but rather located in a reasonable scope. Similarly, the length and width of the final layout can be changed legitimately.

In this paper, we call the specific rectangle packing problem CR-RPAMP (rectangle packing area minimization problem with central rectangles). The objective is to allocate all the items into the enveloping rectangle by minimizing the area.

The layout problem of drilling equipment in semisubmersible drilling platforms is a typical CR-RPAMP. The drilling equipment layout is an important part of the general design of drilling rig systems. A reasonable layout scheme can retain the drilling platform stability, security, reliability, and other indicators in a better state (Xiao, Wu, Tian, & Wang, 2015). As the most important equipment, the drilling floor must be located in the center of the main deck of the semisubmersible drilling platform. And other equipment and modules should be placed around the drilling floor. To reduce the cost of construction, the area of layout should be as small as possible. In addition, all the drilling equipment should be packed into an enveloping rectangle with a reasonable length-width ratio for the purpose of high-efficient work. Moreover, there are many other CR-RPAMPs being similar to the layout problem of drilling equipment in modern semisubmersible drilling platforms. Apparently, it is significant to research the heuristic algorithm for solving the CR-RPAMP.

In this paper, a novel heuristic algorithm is recommended to solve CR-RPAMP. As we know, the central rectangles are the center of final layout. To restrict the location of the central rectangles, two new definitions, named aspect ratio of enveloping rectangle and centrality of central rectangle, are brought in. For the purpose of determining the priority of rectangles, three new definitions, named matching degree of edge, filling rate of enveloping rectangle and filling rate of increment area, are introduced. For the sake of raising the filling rate of final layout, the conception of inner space and filling strategies for inner-space are presented. Combining these definitions and strategies, the solving procedure for CR-RPAMP is described in pseudo code.

The subsequent sections are organized as follows: Section 2 gives the model of RPAMP. Section 3 states the description of CR-RPAMP. Section 4 presents simulation testing. In Section 5 the HACR is used to solve problem of the layout design of drilling rigs. Conclusions are summarized in Section 6.

2. Model of RPAMP

Given a set of n rectangular items with each item $\pi_i (1 \ll i \ll n)$ having width w_i and height h_i. Evidently, the area of each rectangle item can be expressed as $area_{\pi_i} = w_i \cdot h_i$. The RPAMP requires determining a feasible arrangement of all the items on a larger rectangular plane with variable dimensions (He et al., 2015).

According to the literature (Lodi, Martello, & Vigo, 1999), the RPAMP can be similarly categorized into four types: OG, RG, OF, RF (Bortfeldt, 2013; Wei et al., 2009).

OF: orientation of all pieces is fixed (O) and guillotine cutting is not required (F).
RF: pieces may be rotated by 90° (R) and guillotine cutting is not required (F).
OG: orientation of all pieces is fixed (O) and guillotine cutting is required (G).
RG: pieces may be rotated by 90° (R) and guillotine cutting is required (G).

This paper discusses the type of RF: the items may be rotated by 90° and no guillotine constraint is stipulated.

A two-dimensional Cartesian Reference Frame is established based on the plane of layout (Fig. 1). For each item π_i, let (x_{i1}, y_{i1}) and (x_{i2}, y_{i2}) denote the coordinates of the bottom-left and upper-right vertexes, respectively (He et al., 2015). Then, RPAMP can be formulated as follows:

$$(x_{i2} - x_{i1}, y_{i2} - y_{i1}) \in \{(w_i, h_i), (h_i, w_i)\} \quad (1)$$

$$\max\ (x_{i1} - x_{j2}, x_{j1} - x_{i2}, y_{i1} - y_{j2}, y_{j1} - y_{i2}) \geqslant 0 \quad (2)$$

$$0 \leqslant x_{ik} \leqslant W_n, 0 \leqslant y_{ik} \leqslant H_n, k \in \{1, 2\} \quad (3)$$

$$\min\ (W_n \cdot H_n) \quad (4)$$

In formulas (1)–(4), i and j apply to $1, 2 \ldots, n$, and $i \neq j$. Formula (1) means that each item should be placed orthogonally on the sheet; formula (2) implies that no overlap occurs between any two items (He et al., 2015); formula (3) means all the items are placed completely in the enveloping rectangle; formula (4) is the objective function, it means minimizing the area of the enveloping rectangle which having width W_n and height H_n.

3. Description of CR-RPAMP

Similarly, a set of n rectangular items with each item $i (1 \ll i \ll n)$ having width w_i and height h_i are given.

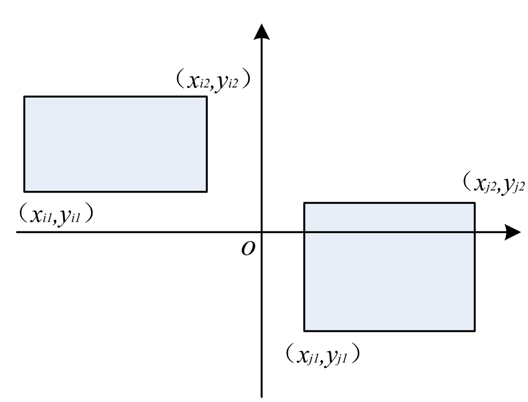

Fig. 1. Two-dimensional Cartesian reference frame.