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Design of efficient packing system using genetic algorithm based on hyper heuristic approach

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ABSTRACT

In practice the maximum usage of container space arises in many applications which is one of the crucial economical requirements that have a wide impact on good transportation. A huge amount of monetary infrastructure is spent by companies on packing and transportation. This study recommends that there exists a scope for further optimization which if implemented can lead to huge saving. In this paper, we propose a new hyper heuristic approach which automates the design process for packing of two dimensional rectangular blocks. The paper contributes to the literature by introducing a new search technique where genetic algorithm is coupled with the hyper heuristic to get the optimal or sub optimal solution at an acceptable rate. The results obtained show the benefits of hyper-heuristic over traditional one when compared statistically on large benchmark dataset at the 5% level of significance. Improvements on the solution quality with high filling rate up to 99% are observed on benchmark instances.

Introduction

Packing and transportation are one of the major concerns for developed as well as developing nations. The changing scenario of growing need compels to make government policies and mission for the development of science and technologies to achieve safe, economical, efficient, secure, and meet applicable regulatory requirements for packing and transportation. A numerous efforts are being done to resolve packaging and transportation issues safely, economically, and promptly. First and foremost, objective for transport packaging must serve to protect goods in transit. This can be achieved by proper packing and placement of goods during transit as it can only ensure against unintended shocks, impacts or accidents of any kind. Good and efficient transportation has a vital role to play in the economy of any nation.

In this paper, we discuss the packing issues related to two dimensional objects like packing of rectangular strips into a larger container. The main objective is to maximize the space utilization by the rectangle and minimize the overall height of the packed rectangles. There are different categories for this problem such as placement with and without rotation of the items, placement subjected to guillotine cut or non guillotine cut. We address the placement of rectangle blocks both with and without rotation subjected to guillotine cut, *i.e.*, the placement of the rectangle blocks must be parallel to the containers axis. The paper first presents the placement strategy, carry out the fitness evaluation of the obtained design, and then use a constructive greedy hyper-heuristic approach to search a better solution. Genetic algorithm is used to improve the solution and prevent the it from being trap in local minima. Computation results on benchmark instances show the efficiency and better convergence rate.

The common approaches used to solve this class of problem are classified as exact, heuristic, and meta heuristic. Based on the nature of these approaches they proceed to find optimal or suboptimal solution for the given problem instance. In exact approaches, methods that use linear programming concept like branch-and-bound, branch-price, branch-cut-price, etc. are usually employed that involve tree search procedure. These approaches are fairly acceptable on small instances but fail to perform well on larger classes. Some of the recently proposed approaches include Belov et al. [1] investigates the constraint programming approach for orthogonal packing not allowing the rotation of pieces. The approach is based on disjunctive strategy for branching and uses linear programming based relaxation bounds. Leung et al. [2] solved some instances of irregular strip packing problem by non linear programming model with tabu search used to avoid local minima. Arahori et al. [3] proposed an exact method that represented the sub problem as g-staircase and used branch and bound to solve allowing relaxation.

Several major contributions as heuristic algorithm to solve the problem are presented in the literature. Out of many is first to count is by Baker et al. [4] which is bottom left, and being used as basis by many other heuristic and meta heuristic approaches.

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Considering both horizontal and vertical placement Asik and Özcan [5] improved the best fit heuristic by considering the bi-directional placement (BBF). This work was improved by Özcan et al. [6] by best fit based bi-directional heuristic (BBFM) taking pair of rectangles to be placed rather than single placement. The heuristic approaches exploit the feature of the problem to get optimal solution in reasonable time. However, the approach does not guarantee to get optimal for all cases. The meta heuristic approaches like genetic algorithm (GA), stimulation annealing, etc. are used to solve the strip packing problem. The GA approach considering strip packing as the permutation problem was solved by Yeung and Tang [7] named as Lowest-Fit-Left-Aligned" (LFLA) heuristic approach. Bortfeldt [8] used GA for strip packing without performing any encoding to determine the best layout design. Another GA approach was used by Gonc-alves [9] based on random key for the initial population generation to get the placement sequence for the rectangles. GA was hybridized with the placement procedure. A greedy randomized adaptive search procedure (GRASP) by Alvarez-Valdes et al. [10] based on the intuitive learning to fix the difficult strip packing problem by setting appropriate parameters with the learned information. Wei et al. [11] presented a least wasted first (LWF) strategy that evaluated based on the position occupied by the rectangle and coupled it with local search to improve the performance.

Leung and Zhang [12] proposed fast layer-based heuristic (FH) with the strategy of stacking rectangles, where the concept of reference line is used for packing. The greedy strategy is used to improve the result by assigning of fitness value to unpacked rectangle and selecting the one with highest fitness. A hybrid simulation annealing (HSA) algorithm by Stephen et al. [13] which combine three sequential approaches: fitness strategy to find possible solution, greedy strategy to select the best one and simulation annealing to escape from local minima. Burke et al. [14] gave a genetic programming based hyper heuristic system for better evolution to solve the strip packing problem. In this paper, we have exploited the behavior of hyper heuristic with genetic algorithm.

Motivation

Shipping of goods is a common and a day to day activity in almost all the industries. Thus, achieving highest occupancy of container capacity is an important concern. The better utilization have impact on many factors like reducing number of vehicle in shipment, reducing the cost of damage during transit, improving the transportation cost and economy saving. All these goals can be achieved if boxes are packed optimally or near optimally. Packaging decisions have a major impact on logistical productivity and efficiency. Handling efficiency in all of these situations is significantly influenced by package design, unitization, and communication characteristics. The packing problem is a type of NP-Hard problem as the number of box increases the solution cannot be obtained in polynomial time. This motivates the use of heuristic and meta-heuristic approaches. For, the packing combinatorial optimization problem with growing complexity and computational constraint the solution using exact approach in reasonable time seems to be infeasible.

Combinatorial optimization problems are core and exist everywhere in the industrial system. Various practical issues are to be considered while dealing with these problems. These issues are practical solvability as the problem size grows, *i.e.*, the complexity with size, accuracy of the developed model, processing time, etc. are important consideration point in finding the optimum solution. All these issues should be efficiently tackled by the solution methodology. However, in case of exact approach run time often increases dramatically with the problem instance and on the other hand small and moderate instance can be efficiently solved in reasonable time. The next common approach is to apply heuristic techniques which find good solution in reasonable time. However, it does not guarantee the solution quality. This encourages the use of meta-heuristic approach for combinatorial optimization problem. Meta-heuristic uses intelligent and computational efficient search techniques for better exploitation and exploration of the search space. Its use is becoming popular to solve complex real world applications of practical interest. The proposed approach based on hyper heuristic is derived from various combinations and adaptations of principles and ideas from mathematical programming, biological and physical systems, and artificial intelligence.

Contributions

The contributions made to the literature are stated in this section. The important features of the designed system are as follows:

1. A hyper-heuristic search technique is coupled with genetic algorithm for efficient packing of 2D rectangle pieces into a given huge container.
2. A packing technique that considers the placement of rectangle pieces with and without rotation.
3. A novel fitness function to evaluate the strength of the overall design layout.
4. Designed a new robust system flexible to changes and can be used to model different cutting and packing problem occurring in other major industries like shipbuilding, textile, wood, plastic, sheet metal, and leather manufacturing.
5. The performance is independent of the preprocessing of instances and the computation time is significantly reduced.
6. The efficiency of the proposed approach concluded from the computation result on the benchmark instances are reported in the result and discussion session.

Organization of paper

This paper is organized as follows: 'Problem definition and system model' introduces the problem definition and a formalization of packing problem. The theoretical background for better understanding of the approach is discussed in 'Theoretical Background', wherein the subsections we briefly discuss genetic algorithm and hyper-heuristic search methodology. 'Proposed Methodology', presents the proposed approach which details the placement strategy, the novel fitness function and the coupling with hyper-heuristic for better evaluation of the problem. 'Experimental result and discussion', reports the experimental work carried out on the benchmark instances from the literature. It presents a detail comparison and report statistical observation made when the proposed approach is compared with traditional as well as recently proposed from the literature. Finally, in 'Conclusion' we give the concluding remarks on the obtained results and comment on efficiency and effectiveness of the proposed model.

Problem definition and system model

Cutting and packing can be classified in different ways as proposed by Wäscher et al. [15] the categories are dimensions, kind of assignment, assortment of large objects, assortment of small items and on the basis of shape of the small items. Based on dimensions these are categorized as: one dimensional (1D) bin packing, two dimensional (2D) strip packing and three dimensional (3D) bin packing. In 1D Bin Packing Problem packing is considered for set of different size items into minimum required large identical objects. In case