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A generic approach for nesting of 2-D parts in 2-D sheets using genetic and heuristic algorithms

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Abstract

In this paper, a genetic and heuristic approach is proposed for the nesting of multiple two-dimensional (2-D) shaped parts in multiple 2-D shaped sheets with the aim of minimizing the wastage of the sheet material. The paper proposes a new method of representing the sheet and part geometries in discrete form to arrange the parts on the sheet quickly, irrespective of the complexity in the geometry of the sheets and parts. The proposed heuristic approach considers the sheets and parts in a sequential manner and arranges the parts on the sheets using the bottom-left strategy. The genetic algorithm generates the best sequence of the sheets and parts for nesting the parts on multiple sheets, utilizing the sheet material optimally. The effectiveness of the proposed approach is shown by comparing the results obtained with the present approach to those obtained with the approaches proposed by Jakobs (Eur J Oper Res, 88 (1996) 165), Ramesh Babu and Ramesh Babu (Int J Prod Res, 37(7) 1999 1625), and Jain and Chang (Engng Comput, 14 (1998) 206). The generic nature of the present approach is illustrated by considering a variety of parts, ranging from a simple rectangular shape to a highly irregular shape, in different combinations with or without grain orientation constraint, apart from nesting of multiple irregular shaped parts in multiple sheets of complex geometry. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In the present manufacturing scenario, cutting of two-dimensional (2-D) shaped parts from 2-D sheets, with a minimum wastage of material, is an important task. The task of arranging the parts on the sheet, known as nesting, is being attempted by several researchers employing several methods and implementing them using digital computers. While developing the nesting methods for a given set of parts and sheets, one should consider certain geometrical and technical aspects. The geometry of the parts to be cut may vary from a simple rectangular shape to a highly irregular one. In the case of irregular parts, the geometry may contain a straight line and curvilinear features. Further, 2-D parts may also contain internal features (either holes or cutouts) being regular or irregular in geometry. In a similar manner, the geometry of the sheet material can vary from regular to irregular shapes with or without defective regions. The defective areas on the sheet material are nothing but the defects on certain naturally occurring materials like granite,

wood, etc. and certain sheets produced by different manufacturing processes. While nesting the parts in sheets it is essential to avoid these regions.

Apart from the geometry of the sheets and parts, several technical aspects such as the cutting process employed, the nature of application of parts for further processing, such as bending, impose certain constraints in generation of nested pattern. Based on the cutting process employed, various cutting allowances, such as bridge width in press working operations and kerf width in unconventional cutting processes, should be included in the actual geometry of the parts considered for nesting. In certain applications, it is important to consider the direction of grain orientation while nesting the parts in the sheets.

By considering these aspects, several researchers attempted to develop methods for nesting of different shaped parts in different shaped sheets. Nesting of rectangular shaped parts in rectangular sheets is quite an easy task in view of the geometry being simple. Different mathematical techniques such as dynamic programming [1], integer programming [5] and integer linear programming [16,18] were employed for the nesting of rectangular shaped parts in rectangular sheets. These techniques are impractical and computationally infeasible when a large number of parts are to be arranged in

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sheets of larger sizes. Further, these approaches cannot handle sheets and parts of irregular shape.

In view of these limitations, attempts were made to employ heuristic approaches for nesting of 2-D shaped parts in 2-D sheets. Yanasse et al. [21] addressed a sequence-dependent heuristic algorithm that sorts out rectangular parts according to certain priority rules based on the physical attributes of parts such as length, width and area, and arranges each part from the bottom-left corner of the sheet. Heuristic techniques for nesting of irregular shaped parts are quite complex in view of the difficulty in finding out the best relative position of the parts with respect to the sheet geometry. For a given number of arbitrarily shaped parts, Cheng and Rao [4] proposed a heuristic method that clusters the irregular parts into a minimal area of convex enclosure. This cluster is formed by sliding one part over the other and maintaining the minimum distance between the centroids of the two parts.

In a similar way, Lamousin and Waggenspack [12] developed a heuristic method for the nesting of irregular parts in irregular sheets using the concept of No Fit Polygon (NFP). The NFP is the path traced by the outer most vertex of a part, as the part slides in contact with the boundary of the sheet. Then the part is placed at the bottom-left position on the NFP. With this particular method, it is not possible to place the parts at narrow regions of the sheet. Considering this, Lamousin and Waggenspack [13] proposed a heuristic method to nest irregular parts in irregular sheets by matching convex features of the part with concave features on the boundary of the sheet material. However, it was reported that the utilization of the sheet material, with this approach, is inferior to the heuristic method that uses NFP concept. Whelan and Batchelor [20] used the machine vision technique and proposed a sequence dependent heuristic for arranging irregular shaped parts in sheets with irregular boundaries. The purpose of this machine vision technique is to identify the overlapping of the parts on the sheet easily, irrespective of the complexity in the geometry of the parts and sheets.

In general, the heuristic approaches follow certain fixed deterministic procedures in the nesting of 2-D shaped parts in 2-D sheets. Moreover, these approaches consider the parts in only one particular sequence. Hence, there is no possibility of considering the different sequences of the parts for generating different patterns of nesting. Thus, the nested pattern generated with any heuristic that considers the parts in one particular sequence may not give out the optimal utilization of sheet material.

In view of the above limitations with heuristic methods, several researchers attempted to employ certain modern heuristic approaches such as Artificial Neural Networks (ANN), Simulated Annealing (SA) and Genetic Algorithms (GA) for nesting of 2-D parts in 2-D sheets. Jakobs [11] employed a genetic and heuristic approach for nesting of polygons, enclosed in rectangular modules, in a single rectangular sheet. The heuristic algorithm arranges the

parts on the sheet at the bottom-left position by moving them, in *bottom-left-bottom* direction, from the top-right corner of the sheet. In this particular work, the GA gives out the best sequence of parts for their optimal nesting in the sheet. Similarly, Ramesh Babu and Ramesh Babu [15] proposed a genetic and heuristic approach for the nesting of multiple rectangular parts in multiple rectangular sheets with a view to arrive at the optimal number of sheets required for the nesting of the parts, apart from minimizing the wastage of the sheet material. The heuristic, proposed in this particular approach, identifies the new possible positions for the next part, each time after the part is located at the bottom-left position of the sheet. Hence, the parts can reach interior regions existing in the previously nested area, which can thus improve the utilization of the sheet material.

Han and Na [8] employed neural network and simulated annealing (SA) techniques for nesting of multiple irregular shaped parts in a single rectangular sheet. In this approach, neural networks generate initial good layout by moving the parts to the left and bottom position of the sheet and SA improves this layout by translating, rotating and swapping of the parts. Similarly, certain hybrid approaches, using local heuristics and genetic algorithms, were proposed for the nesting of irregular shaped parts in regular and irregular sheets [2,6]. In all these approaches, the parts were arranged very close to each other based on the geometry of the parts. But, in practice, unanticipated geometry of the parts and sheets may be expected, for each order of parts to be produced. In such a situation, these geometry dependent heuristics may not generate the optimal nested patterns.

In view of the above, attempts were made to represent the geometry of the parts and sheets in discrete form, which permits to consider any shape of the parts/sheets and then to use genetic approaches for the nesting of 2-D parts in 2-D sheets [9,10,14]. In these approaches, a limited number of orientations of the parts were considered. Hence, they cannot generate optimal nested patterns for irregular shaped parts. Further, the nature of the discrete representation scheme and the parts arrangement strategy adopted, in these approaches, make the nesting process computationally expensive. Moreover, these methods considered only a single sheet for nesting of the multiple parts, thus leaving a scope for developing nesting algorithms considering different parts with different orientations and the sheets of different geometry and quantity.

The proposed work focuses on developing effective and geometry independent approach for nesting of multiple 2-D complex parts in multiple 2-D complex sheets, considering the parts with or without internal features and the sheets with or without defective regions. The internal features can vary from simple holes to cutouts of any geometry. Similarly, the defective regions on the sheets can range from simple to complex in their geometry. Both the parts and sheets considered may comprise line and curvilinear features. The parts and sheets are represented in discrete form with novel integer coding to make the algorithm faster