Engineering Applications of Artificial Intelligence 26 (2013) 2349–2355

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

Genotype–phenotype heuristic approaches for a cutting stock problem with circular patterns

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ARTICLE INFO

Article history:
Received 1 July 2011
Received in revised form
8 August 2013
Accepted 11 August 2013
Available online 8 September 2013

Keywords:
Cutting stock problem
Sawing pattern optimization
Heuristic optimization

ABSTRACT

The cutting stock problem has been studied in the context of different industrial applications inducing NP-hard problems in most instances. However, the application in sawmill has not received the same attention. In this paper, we deal with the problem of determining the number of logs to cut over a period of several days and the geometry of sawmill patterns in order to satisfy the demand while minimizing the loss of material. First, the problem is formulated as an integer programming problem of the form of a constrained set covering problem where the knowledge of a priori cutting patterns is necessary to generate its columns. In our implementation, these patterns are obtained using a genetic algorithm (GA) or a simulated annealing method (SA). Then, two different approaches are introduced to solve the problem. The first approach includes two methods that combine a metaheuristic to generate the number of logs and a constructive heuristic to generate the cutting patterns for each of the logs. In the second approach, we use an exact procedure CPLEX to solve the integer programming model where the cutting patterns are generated with the GA method (GA+CPLEX) or the SA method (SA+CPLEX). These four methods are compared numerically on 11 semi-randomly generated problems similar to those found in real life. The best results for the loss are obtained with the two-stage GA+CPLEX approach that finds the best values for 7 problems.

1. Introduction

In the world economy, the market for finished products is becoming increasingly competitive, setting lower equilibrium prices, and thereby forcing the optimization of manufacturing costs. One of the most important factors in reducing cost is efficient use of raw materials, which reduces material loss. To achieve efficiency in the wood industry, proper cutting patterns must be generated to define the coordinates of each cut required to satisfy the demand. This gives rise to a cutting stock problem. Such problems appear in various industrial sectors that involve cutting leather, glass, metals, fabrics and wood (Cui and Huang, 2011; Pape, 2011). This family of problems has been widely studied in several different contexts inducing NP-hard problems. In most cases, it is challenging to solve even the basic problem of generating an optimal cutting pattern for a single unit of raw material (Papadimitriou and Steiglitz, 1998; Wäscher et al., 2007).

In the forestry industry, we must wait more than a decade before harvesting a tree plantation. The trunks harvested are classified according to their characteristics and are then sent to various destinations, such as cellulose plants, several types of engineered wood plants and sawmills. In a sawmill, the logs are first classified into different types according to length and diameter, and then they are cut to produce wooden boards of sizes determined by the customers' orders. During this process, some raw material is lost producing small pieces of wood or sawdust. In some cases, this lost material can be reused at a much lower commercial value that that of wooden boards. Thus, the need for optimization in this process becomes clear. However, for various reasons, optimization problems in the forestry industry are solved differently in different countries (Rönnqvist, 2003), and there are even different ways to saw different types of logs in the same sawmill. There are also sawmills that specialize in a subset of cutting methods. This variety of situations gives rise to different theoretical cases of the basic problem. To the best of our knowledge, this basic problem has not been addressed as a stock cutting problem. We consider a problem for which it has previously been determined that the greatest commercial benefit from a log is obtained by using sawing patterns that satisfy geometric constraints due to the distinction between lateral and central boards.

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0952-1976/$ - see front matter
http://dx.doi.org/10.1016/j.engappai.2013.08.003

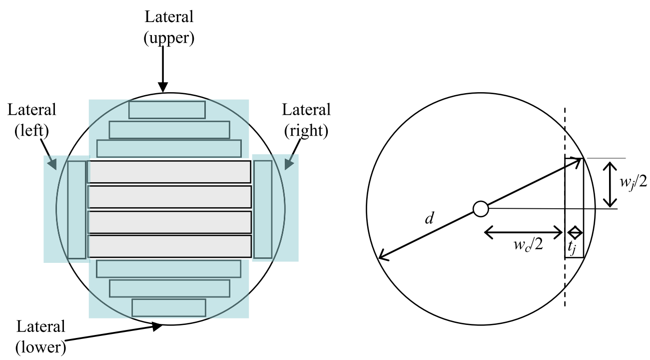

Fig. 1. Sawing pattern and geometrical constraints.

In such sawmills, two typical situations are found: the cutting patterns are either manually generated or they are generated with the support of scanners that are not always available. In the first situation because a log to be cut can have different cross-sectional areas due to small variations in the diameter, a log is considered a regular cylinder with a diameter equal to the minimum diameter of the real log. Thus, the cutting patterns are two-dimensional, generating central and lateral boards, as illustrated in Fig. 1. To satisfy a set of orders, a subset of the manually generated patterns is selected, and the number of logs of each type to be cut according to each selected pattern must be determined. This practical approach involves a high level of combinatorics and requires a long preparation time, both in the geometric generation of the circular patterns and in the selection of the optimal set of patterns. Consequently, there is a need to make the process more efficient by means of a software tool. The second situation considers the use of scanners that display a three-dimensional view of the log in the computer (Lundgren, 2000; Rinnhofer et al., 2003). In this case, the operator can simulate some possible cutting patterns; however, the optimization process is still manual. An optimization software with a short computational time could be useful if embedded in the scanner software, but in general, this is not the case.

In this paper, we consider the problem of determining both the geometry of the sawing patterns and the number of logs of each type that must be cut from each sawing pattern over several days of sawmill operation to satisfy a set of customer orders while minimizing the loss of material. Because the geometric sawing pattern format implicitly obeys rules for producing a good commercial value for the log, there is a close relationship between minimizing the loss and maximizing the commercial benefit. To be consistent with the approach taken in practice, we consider a log as a regular cylinder with a homogeneous diameter equal to the log's smallest diameter. We call this problem the Stock Sawing Problem (SSP). This problem, which corresponds to the operational planning level of a sawmill (Rönnqvist, 2003), has received relatively little attention in the literature on cutting and packing problems. However, at the tactical level, various tactical planning problems have been studied (Faaland and Briggs, 1984; Todoroki and Rönnqvist, 1999, 2002).

The SSP corresponds to a variant of the "three-dimensional, rectangular boxes, multiple stock sizes, cutting stock problem" because small rectangular boxes (wooden boards) of different sizes must be cut from large objects (logs) that, in this case, are cylinders. Consequently, cutting regular cylinders reduces the problem to a variant of the "two-dimensional, rectangular, multiple stock size, cutting stock problem," (Dyckhoff, 1990, Wäscher et al., 2007). No study on this type of problem is referenced in the classification presented by Wäscher et al. (2007), mainly because only in the last decade has optimization in forestry begun to make extensive use of operations research techniques (Weintraub et al., 2007).

The nonexistence of either a mathematical formulation or heuristic approaches to solve the SSP prevents an evaluation of the technical feasibility of solving real-size instances of the problem in short computational times. Such computational tools would allow the use of decision-making support software to decrease the loss of material in the production of sawn lumber.

In this paper, we propose an integer programming model for the SSP, formulated as a constrained set covering problem requiring the knowledge of a priori cutting patterns. However, to reduce the computational time required to solve real-life instances, we limit the size of the set of patterns. To compare the performance of this approach, in which the commercial software CPLEX is used to solve the integer programming model for the SSP, we also propose implementations of two metaheuristics: genetic algorithms (GA) and simulated annealing (SA). We have chosen these metaheuristics because both SA and GA (Talbi, 2009) have been proven to be efficient in solving other cutting problems. Burke et al. (2009) approach the orthogonal cutting stock problem with simulated annealing, and they obtain good solutions in a few minutes of execution time for several small instances taken from the literature. In addition, using a genetic algorithm, Hadjiconstantinou and Iori (2007) solve instances of large-size rectangular cutting problems in a matter of minutes.

Section 2 presents the mathematical model for the SSP. In Section 3, we introduce two approaches to solving the problem. The first approach includes two methods combining the metaheuristic GA or SA to generate the number of logs and a constructive heuristic to generate the cutting patterns for the logs. In the second approach, we employ the exact CPLEX procedure to solve the integer programming model in which the cutting patterns are generated with the GA (GA+CPLEX) or the SA (SA+CPLEX). These four methods are compared numerically in Section 4 for 11 semi-randomly generated problems similar to those found in real life. Section 5 presents the main conclusions.

2. Modeling the Stock Sawing Problem (SSP)

In rectangular cutting problems (Álvarez-Valdés et al., 2007), the selection of the optimal set of cutting patterns can be formulated as an integer programming problem (Gilmore and Gomory, 1961). For the SSP, such a formulation is also valid, but in this case, nonlinearities arise due to the circular geometry of the patterns used. To introduce a new variable, a new pattern must be generated. Hence, the computational time increases with the number of orders and the planning period considered.

Referring to the model for rectangular cutting stock problems, we propose an integer programming model for the SSP ($\text{Model}_{\text{SSP}}$), considering that there are different types of large items. The following notation is used to formulate the model:

R = the number of log types: $j=1, \ldots, R$,
M = the number of different wooden boards types found in the orders: $m=1, \ldots, M$,
D_m = the number of wooden boards of type m required to satisfy the demand,
A_j = the number of logs of type j available in stock,
v_j = the volume (in m^3) of a log of type j,
P_j = the number of sawing patterns available to process logs of type j,
β_k^j = sawing pattern k available to process logs of type j: $k=1, \ldots, P_j$.

Note that in addition to the width and the thickness, we use the area (central or lateral) to characterize each wooden board type m required to satisfy the demand. Furthermore, in this formulation, we assume that all logs and wooden boards have the same length, but the model can be extended easily to use different lengths.