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# Hybrid heuristic algorithm for two-dimensional steel coil cutting problem

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ABSTRACT

This paper is concerned with the problem of two-dimensional cutting of small rectangular items, each of which has its own deadline and size, from a large rectangular plate, whose length are more than one thousand times its width, so as to minimize the trim loss and the reduction of the times of clamping and changing speed are also concerned. This problem is different with the classical two-dimensional cutting problem. In view of the distinguishing features of the problem proposed, we put forward the definition of non-classical cutting, that is to say, put a series of items on the rectangular plates in their best layout, so as to enhance utility and efficiency at the same time. These objectives may be conflicting and a balance should be necessary, so we present a Hybrid Heuristic Algorithm (HHA), consisting of clustering, ordering, striping and integer programming etc. We demonstrate the efficiency of the proposed algorithm through the comparison with the algorithm we studied before.



## 1. Introduction

The problem of Two-Dimensional Steel Coil Cutting (TDSCC) proposed in this paper is essentially Two-Dimensional Cutting problem (TDC).

The TDC problem consists in cutting a rectangular plate into a number of smaller rectangular items, each with a given size, so that the item edges are always parallel or orthogonal to the rectangular plate edges (orthogonal cutting). The objective is to minimize the amount of waste produced. The constrained form of this problem imposes restrictions on number of items of each size required to be cut to order. The related problem of maximizing the total value of the items cut can be also converted into this problem by taking the value of item to be proportional to its area. Examples of two-dimensional orthogonal cutting problems can be found in cutting of steel or glass plates into smaller pieces, in the cutting of wood sheets to produce furniture, and so on (Baldacci & Boschetti, 2007).

In an industrial setting, the problem could be to compute how many plates are needed and how they can be cut in order to produce all the items in the list of required ordered sizes. As such, the two-dimensional orthogonal cutting problem must be solved as part of a pattern generating process in a heuristic or exact method for a two-dimensional cutting stock problem of the Gilmore–Gomory type. TDC problems are NP-hard as shown in Garey and Johnson (1979). The TDSCC problem considered in this paper is the Two-Dimensional Guillotine Cutting (TDGC) problem but has something different between TDGC, where the aspect ratio of plate used to large to converse frequently between vertical cutting and horizontal cutting. We call plate as steel coil here since its size and it is usually rolled up for transportation, illustrated in Fig. 1.

### 1.1. The literature review

The research, which was done by Gilmore and Gomory on two-dimensional guillotine stock cutting problem, could trace back to the 1960's. The problem was then getting more and more attention from theoretical and practical application. Many scholars have devoted themselves to developing many methods one after another to solve the problem, these methods can be grouped into two major types.

(i) Deterministic method: Deterministic methods take advantage of analytical properties of the problem to generate a sequence of points that converge to a global solution.
Gilmore and Gomory (1965) described optimizing stock cutting problem as integer programming problem. They established a mathematical model of guillotine problem by means of linear programming, which was transformed into knapsack sub-problems. At the same time, they constructed an effective method to solve knapsack problem (Gilmore & Gomory, 1965). Valério de Carvalho and Guimares Rodrigues (1995) described a linear programming model for a two-stage cutting stock problem that arises in a make-to-order steel company. Chen, Sarin, and Balasubramanian (1993) presented a mixed integer programming model for a class of assortment problems. Viswanathan and Bagchi (1993) proposed a exact algorithm named Best-first search methods for the problem. Li and Tsai (2001) proposed a new method

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**Fig. 1.** The appearance of steel coil.

which found the optimum of cutting problems by solving few linear mixed 0–1 problems. Li, Chang, and Tsai (2002) developed an approach using the piecewise linearization technique of the quadratic objective function to improve an approximate model for two-dimensional cutting problems. Silva, Alvelos, and Valério de Carvalho (2010) proposed an integer programming model to solve two-stage and three-stage two-dimensional cutting stock problems exactly. Abstracting the cutting problem to mathematical model makes the problem less complicated and easier to settle. But when practical problems are abstracted to mathematical models, a variety of assumptions are often indispensable to leading a large deviation appears between the obtained results and the original problems, what is worse, the solution space is sharply extended when the scale of problems expanded, it is difficult to obtain a solution within a reasonable time and the performance of solution becomes very poor.

(ii) Heuristic method: Heuristic algorithms can obtain a solution quickly, but the quality of the solution cannot be guaranteed.

Chlistofides and Whitloek (1977) presented a tree-search algorithm for guillotine problems of two-dimensional single raw material (Chlistofides & Whitloek, 1977).Their key assumption is that the number of each rectangular item was infinite. On the other hand, however, with the increase of the number of rectangular pieces, the solution space was growing exponentially and therefore optimal layout of large-scale rectangular items problem could not be effectively solved in practice.

Albano and Orsini (1980) proposed an interactive method for two-dimensional layout (Albano, 1977). Albano and Orsini (1980) together put forward a method of cutting board lined up in groups to achieve guillotine, unloading from two-dimensional special-typed materials of which the origin was rectangular (Albano & Orsini, 1980). Beasley (1985) and Chauny, Loulou, Sadones, and Soumis (1991) improved the two-stage method and proposed different heuristic algorithms to improve the way to deal with layout of huge amount. Since then a lot of researches have been basically focused on possible heuristic algorithm, but it was discovered that in some cases, the traditional heuristic algorithm is not valid.

G and Kang (2001) developed a heuristic that found efficient layouts with low complexity for two-dimensional pallet loading problems of large size. Wu, Huang, Lau, Wong, and Young (2002) introduced an effective deterministic heuristic, less flexibility first, for solving the classical NP-complete rectangle-packing problem. Leung, Chan, and Troutt (2003) proposed an application of a mixed simulated annealing-algorithm heuristic for the two-dimensional orthogonal packing problem. Beasley (2004) also presented a heuristic algorithm for the constrained two-dimensional non-guillotine cutting problem (Beasley, 2004).

For more detailed articles about the cutting optimization problem, readers can refer to Lodi, Martello, and Monaci (2002) and Valerio de Carvalho (2002). Many approaches for two-dimensional cutting stock problem have also been proposed. Hifi (1997) discussed an improved version of algorithm proposed in Viswanathan and Bagchi (1993) for solving constrained two-dimensional cutting stock problems. They proposed a modification of this algorithm in order to improve the computational performance of the standard version. Cung, Hifi, and Cun (2000) developed a new version of the algorithm in Hifi (1997) for solving exactly some variants of (un) weighted constrained two-dimensional cutting stock problems. Leung, Yung, and Troutt (2001) applied a genetic algorithm and a simulated annealing approach to the two-dimensional non-guillotine cutting stock problem and carried out experimentation on several test cases (Leung et al., 2001). Vanderbeck (2001) developed a nested decomposition approach for two-dimensional cutting stock problem (Vanderbeck, 2001). Burke, Kendall, and Whitwell (2004) presented a new best fit heuristic for the two-dimensional rectangular stock-cutting problem and demonstrated its effectiveness (Burke et al., 2004). As for intelligent optimization algorithms, such as Genetic Algorithm GA (Jakobs, 1996) (genetic algorithm), Simulated Annealing algorithm SA (Wang, Chen, & Ma, 1998) (simulated annealing), artificial neural network (Wu & Li, 2000), Particle Swarm Optimization (Li, Song, & Zhou, 2005) (PSO) and some other intelligent optimization algorithms, are respectively developed by simulating human intelligence activities, or some natural phenomenon from different angles. Intelligent optimization algorithm does not need to establish accurate (mathematical or logical) models, neither are generally dependent on knowledge, making it better to cope with those problems that are difficult to establish an effective formal model and that could not be worked out by using traditional methods.

Heuristic methods may obtain a good solution in terms of specific issues, however, the main defect of these algorithms results in the failure to claim the solution obtained is a global optimum unless the whole solution space is completely searched.

The TDSCC problem considered in this paper is to minimize the trim loss and reduce the times of clamping and changing speed based on the available cutting combinations to meet the order demands. As stated earlier, the TDSCC problem is different with TDGC, and few literatures are related to this problem. Cintra, Miyazawa, Wakabayashi, and Xavier (2008) defined two-dimensional Strip Packing (SP) problem and propose the CGS algorithm to solve the SP problem, uses basically the algorithm CGV with two modifications. Yaodong Cui and Yiping Lu described a heuristic algorithm for a cutting stock problem in the steel bridge construction similar to the TDSCC problem (Cui & Lu, 2009), where the size of plates used could be selected within a certain range while only fixed several specifications in the TDSCC problem.

### 1.2. Background and characteristics

The simple layout of the steel processing and distribution company we studied is illustrated in Fig. 2, which mainly consists of four processing units. The steel coil is divided into several strips after the processing of vertical cutting unit, while the strip is re-rolled up as sub-coil in the re-roll-up unit. Then the sub-coil is transported to the horizontal cutting unit by crane. The sub-coil is cut as several items, which was transported to the packaging unit through conveyor belt. Not all items need to go through the treatment of vertical cutting unit when the items meet $0 \leqslant W_i - Max(l_j^i, w_j^i) \leqslant \delta_1$, where $W_i$ is the width of $i$th coil, $w_j^i$ and $l_j^i$ corresponding respectively to the width and length of $j$th item, while is a constant value depends on the width of knife.

There are some differences between stock cutting steel coil and the classical two-dimensional cutting problem, mainly in aspects as follows: