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Heuristic algorithm for a cutting stock problem in the steel bridge construction

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Abstract

A rectangular two-dimensional cutting stock problem in the steel bridge construction is discussed. It is the problem of cutting a set of rectangular items from plates with arbitrary sizes that lie in the supplier specified ranges, such that the necessary plate area is minimized. Several types of cutting patterns are used to compose the cutting plan. All of them are easy to generate and cut except the last one. The algorithm uses both recursive and dynamic programming techniques to generate patterns of the last type. The computational results of 22 practical instances indicate that the algorithm can produce solutions close to optimal, and the computation time is reasonable for practical use.

Keywords: Cutting stock; Two-dimensional cutting; Steel bridge construction; Steel structure

1. Introduction

Fabrication of structural metals is an important stage in the steel bridge construction. It consists of operations necessary to prepare members or groups of members for use in structures. It includes the procuring of the required materials prior to shop operations, actual shop operations, and loading for delivery of the fabricated parts to the bridge site.

The blanks of most members made of steel plate are rectangular. The size and required number of each blank type are known from the detail drawings to be used in the complete fabrication of all structural metals. The necessary plate to produce the blanks for a steel bridge usually amounts to hundreds or thousands of tons. Some blanks have sizes which are too large to be produced from plate of ordinary size that is available in stores in the market. As a result, the contractor just purchases all necessary plates from the producer of the plates. The sizes and numbers of steel plates to be purchased are usually determined from hand-generated cutting patterns of the blanks. The number of different plate sizes in an order may be in the range of one to hundreds. The objective is to cut all required number of blanks with minimum plate cost. A plate can assume any size in the range specified by the supplier, and the order quantity for a particular size cannot be smaller than the supplier specified minimum order quantity. This problem is referred to as the TDCSBC (the two-dimensional cutting stock problem in bridge construction). It is different from classical ones, in

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which the plates to be used are already in inventory before the generating of cutting patterns, and they have only a few sizes.

Three types of two-dimensional cutting stock (TDCS) problems have been addressed in the literature [1]. The first is the single stock-size cutting stock problem [2–5], in which a set of order items has to be cut from stock plates of a specified single size, and the number or the value of the necessary stock plates has to be minimized. The second is the multiple stock-size cutting stock problem [6–9]. Problems of this kind include the natural extensions of the TDCS to more than one stock size. The third is the residual cutting stock problem [10], in which the number of different stock plate sizes is large. Its name is chosen to be "residual cutting stock problem" because in practice this case comes about whenever the plates are to be used which represent unused parts of input material from previous cutting stock processes. The TDCSBC discussed in this paper may represent the fourth type: The Infinite stock-size cutting stock problem in which the number of stock sizes may be taken as infinite. The authors have not seen published papers dealing with problems of this type.

As mentioned previously, a plate can assume any size in the supplier specified range, and the order for a particular size must not be smaller than the supplier specified minimum order quantity $Q_{\min}$. If $Q_{\min} = 0$ and no constraint on the size that a plate may assume, it is trifling to discuss the TDCSBC, because for each blank one may purchase a plate with equal size. It is also trifling to discuss the TDCSBC when the required number of each blank type is sufficiently large, because one can often group several pieces of the same blank type together to form a zero-waste cutting pattern that has plate size in the specified range. Unfortunately, for practical TDCSBC problems, although the number of blank types is often large, the required number of a particular type is often small.

Chambers and Dyson [11] considered a two-dimension assortment problem in which the possible widths and lengths for stock plates are integers in given ranges. The best set of k stock plate sizes is to be chosen to produce from which all required number of blanks such that the plate cost is minimized, where it is usually assumed that k takes values 1–4. If the TDCSBC is considered as an assortment problem, restricting k to small values may be harmful to material utilization. Allowing k values in wide ranges may not be practical because of the vast solution space.

This paper presents a heuristic algorithm for the TDCSBC. The contents below are organized as follows: Section 2 introduces the TDCSBC and a practical instance; Section 3 describes the proposed pattern types and the algorithm; Section 4 tests the algorithm on three groups of practical instances; and Section 5 terminates the paper with conclusions.

2. The problem

Practical instances are helpful in formulating the TDCSBC. Assume that m blank types are to be cut. The length, width, and demand of each type are known. Table 1 shows the blank data of an instance with plate thickness of 19 mm There are 66 blank types and 184 blanks. The length, width, and demand of the first type is 6795, 200, and 6, respectively, and so on.

Table 1
The blank data of an instance (length unit: mm)

ID	Length, width, and demand				
001-005	6795, 200, 6	6794, 200, 2	13 516, 200, 2	13 517, 200, 2	10 318, 200, 1
006-010	10 327, 200, 1	10 336, 200, 1	10 345, 200, 1	4904, 214, 1	4948, 214, 1
011-015	4992, 214, 1	5036, 214, 1	2856, 200, 1	2859, 200, 1	2862, 200, 1
016-020	2864, 200, 1	8421, 200, 5	13 520, 200, 1	13 521, 200, 3	10 388, 200, 1
021-025	10 397, 200, 1	10 406, 200, 1	10 415, 200, 1	5257, 214, 1	5301, 214, 1
026-030	5345, 214, 1	5389, 214, 1	2878, 200, 1	2881, 200, 1	2884, 200, 1
031-035	2887, 200, 1	8422, 200, 3	814, 748, 1	811, 748, 3	866, 748, 1
036-040	864, 748, 2	863, 748, 1	2474, 215, 2	2474, 1625, 2	2468, 1501, 2
041-045	2468, 1642, 2	2450, 1037, 2	2450, 1035, 4	2450, 1034, 2	2745, 1107, 2
046-050	1617, 190, 4	1613, 190, 4	1587, 190, 4	1583, 190, 4	1499, 190, 4
051-055	1500, 190, 8	1501, 190, 4	1572, 190, 4	1578, 190, 4	1622, 190, 4
056-060	1628, 190, 4	900, 190, 4	911, 190, 4	986, 190, 4	998, 190, 4
061-065	1320, 80, 8	1320, 420, 20	2700, 1320, 4	695, 680, 8	240, 240, 2
066	900, 700, 4				