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# The Optimization Algorithm of Circle Stock Problem with Standard Usage Leftover

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**Abstract.** In view of the cutting stock problem of the plate fragments and scrap cannot make full use, this paper introduces the concept of standard usage leftover, uses the recursive algorithm and the sequential heuristic procedure to solve the circle cutting problem, achieving the follow-up orders specification to use the usage leftover of the previous orders. This method can make the cutting process more simple, convenient usage leftovers inventory management, as well as conform to the requirements of the blanking for a long time. Computational experimental results show that the algorithm has a high material utilization, and playing a guiding role to the actual industrial production.

**Keywords:** standard usage leftover; recursive algorithm; sequential heuristic procedure; circle stock problem

## 1 Introduce

The problem of circle stock cutting exists in many industrial processes. It is inevitable to produce leftover, which results of material waste and inventory management difficulties.<sup>[1]</sup> There are usually three models are used to solve the Cutting Stock Problem with Leftover (CSPL): minimizing bar cost; minimizing leftover and waste; minimizing the number of sheet. The model Cui<sup>[2]</sup> proposed aims at minimizing bar cost. It discusses One-dimensional Multiple Stock Size Cutting Stock Problem (1DMSSCSP). Residual length of a cutting pattern is taken as a leftover if it is longer than a threshold; as trim loss otherwise. The model Trkman<sup>[3]</sup> proposed aims at minimizing leftover and waste. It discusses General One-dimensional Cutting Stock Problem (G1D-CSP). According to the order is cyclical or not, Trkman classifies the problem into three types: (1) all items will be produced in one production cycle; (2) all items will be produced in multiple production cycle when order and material is ensure; (3) all items will be produced in multiple production cycle. But only the first production cycle task is ensured. The model Chen<sup>[1]</sup> proposed aims at minimizing sheet number. She pointed out two aspects: (1) Stock number is taken as the main part while usage leftover value is neglected; (2) As a part of stock, leftover has been included in production cost. In concrete solution method, Cui<sup>[2]</sup> used integer programming(IP) and column generation algorithm to solve 1DMSSCSP. Andrade<sup>[4]</sup> came up with mixed integer programming to solve how to use leftover. Cherri<sup>[5]</sup> discussed leftover length

and defined the concept of waste. Yurij<sup>[6]</sup> proposed the concept of standard existing algorithms are restricted to 2D objects; Miyazawa<sup>[7]</sup> presented iterative separation management which could simplified process.

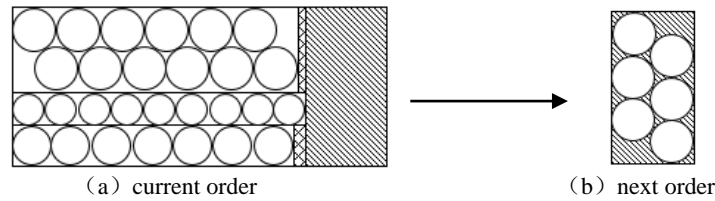
In this paper, a concept of standard leftover is proposed, and Recursive Algorithm (RA) with Sequential Heuristic Procedure (SHP) is used to maximize the sum of items and leftover value.

## 2 Mathematical Model

The meaning of circle stock problem with standard usage leftover is direct cutting along the optimal line of a vertical plate on the rectangular stock. The left side is the sheet stock used for the current order and the right is the standard leftover for the subsequent order; the material for the current order only uses the sheet on the left. There are three concepts.

(1) Leftover: remained part in the cutting stock process. The leftover sheet stock won't be placed any items in this order, it will be used in the subsequent order.

(2) Standard leftover: the usage leftover generated in current order. It has the same width with stock. The standard leftover can be used in the next order. As Fig.1 shows, the part in the lower right is standard leftover, and the cross slash area is waste.



**Fig1.** Standard leftover and the waste

(3) Waste: the remaining part in the cutting stock process. The leftover sheet stock won't be placed any items in this order, it won't be used in the subsequent order.

The problem is characterized by the following data:

$L$  : stock length

$W$  : stock width

$K$  : number of cutting patterns

$\mathcal{T}$  : number of standard leftover types;

$l_k$  : length of leftover appearing in cutting pattern  $k$ ,  $k = 1, \dots, K$

$V_k$  : value of leftover appearing in cutting pattern  $k$

$e_{ik}$  : number of leftover type  $i$  appearing in cutting pattern  $k$

$a_{ik}$  : number of item type  $i$  appearing in cutting pattern  $k$

$x_k$  : frequency of cutting pattern  $k$

$v_i$  : value of item type  $i$ ;  $i = 1, \dots, m$

$N_{\max}$ : maximum number of standard leftover type;

$B$ :  $B=[b_1, \dots, b_m]$ ,  $b_i$  is the demand of item type  $i$

The problem can be formulated as the following programming problem:

$$\text{Maximize: } \sum_{k=1}^K (a_{ik} v_i) x_k + V_k \quad (1)$$

$$\text{Subject to: } \sum_{k=1}^K a_{ik} x_k \geq b_i \quad (2)$$

$$V_k = \sum_{k=1}^K (e_{ik} v_i) x_k \quad (3)$$

$$\tau \leq N_{\max} \quad 0 \leq l_k \leq l_{\max} \quad x_k \in N \quad \tau \in N \quad (4)$$

Function (1) is to maximize the sum value of items. Constrains (2) constrain the number of item produced. Constrains (3) is to circulate leftover value.

In fact, the total value of stocks is the sum of items value and usage leftover value because of the introduction of standard leftover concept.

### 3 Algorithm Description

#### (1) Generate Cutting Pattern

Standard leftover length is  $l_k$ , width is  $w_k$ . There will be one or multiple rows in sheets. When  $l_k=0$ , no leftover is produced. Traversing all items for this year, making inventory management of leftover to make it usable for future. RA<sup>[9]</sup> is used to solve the direct cutting problem. It will assemble a horizontal homogeneous sheet along the direction perpendicular to the width of the plate. 2 sheets are considered when calculating sheet value. One sheet length is  $x$  and width is  $y-1$  while another sheet length is  $x-1$  and width is  $y$ . The sheet with bigger value will be chosen.

$F(x, y)$ : value of stock whose length is  $x$  and width is  $y$

$d_{\min}$ : length of the smallest item

$u_i$ : value of sheet consists of item  $i$

$n_i$ : number of item  $i$  appearing in the sheet whose width is  $w_i$

The recursive algorithm can be expressed as:

If  $y < d_{\min}$  or  $(L-l_k) < d_{\min}$ ,  $F(L-l_k, y) = 0$

If  $y \geq d_{\min}$  and  $(L-l_k) \geq d_{\min}$ ,

$$F(x, y) = \begin{cases} \max\{F(L-l_k-1, y), F(L-l_k, y-1)\} \\ \max_{1 \leq i \leq m} [u_i + F(L-l_k, y-w_i)], w_i \leq y, n_i > 0 \end{cases} \quad (5)$$

When sheet stock length or width is less than  $d_{\min}$ , no item can be cut from the sheet. So stock value is equal to leftover value; otherwise, it is equal to the sum value of sheet and leftover.

#### (2) Generate Cutting Plan

The sequential heuristic algorithm is used to solve the circle stock problem with standard usage leftover. It refers to getting a series of cutting pattern with given constraints by modifying the current remaining demand and item value until the demand is 0. Finally, stocks are cut into sheets and standard leftover. The cutting plan

will be completed, and an optimized one which has the highest utilization ratio is obtained.

Input:  $L*W$ ,  $m$ ,  $d_i$ ,  $b_i$ ;

step1: input initialize  $v_i = \pi \left( \frac{d_i}{2} \right)^2$ ,  $P = \Phi$ , residual demand of item  $i$   $h_i = b_i$ ;

step2: use RA;

step3: circulate the frequency  $x_k$  and add the cutting pattern into set  $P$ ;

step4: modify item value;

step5: update  $h_i$ , if  $h_i \neq 0$ , then go to step2; otherwise, end loop.

Output: optimal cutting plan.

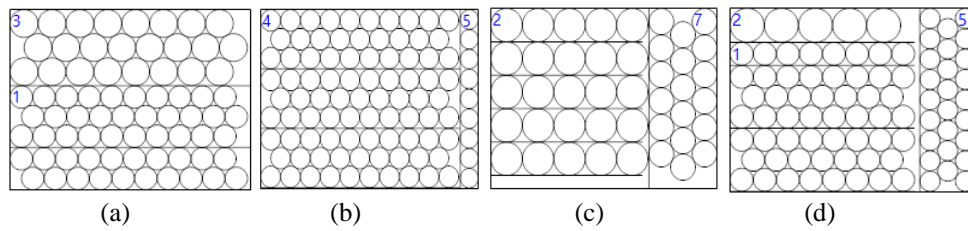
## 4 Experiment

Experiments are on VS2013 platform with C# on windows10, and the computer is 2.60GHz, 8 GB RAM. Experiments are compared with literature [9]. The range of parameter values is shown in table1. Random generating 500 test instances. The upper bound of leftover length and type is 700mm and 10 respectively.

**Table1.** Range of parameter value in experiment

name	range	name	range
Stock length(mm)	2000-3000	Stock width(mm)	1000-1500
Item type	2-5	Item diameter	100-500
Item demand	500-3000	Maximum rows in sheet	3

Fig.2 is a cutting plan of one of the random instances. Amount of item is 4, and diameters are 188, 278, 232, and 182. Demands are 2770, 1350, 700, 950. The computational experimental results show that stock number is 115, the cutting pattern is 4, and the standard leftover is 3. The cutting patterns are shown in table 2. The average utilization is 74.69% while the one in paper[9] is 70.81%, which shows the average is enhanced by 3.88%.



**Fig2.** Random instances

**Table2.** Cutting patterns of instance

Cutting pattern	Item type	Item number	Stock number	Leftover(item diameter * rows)	Utilization ratio
(a)	4	87	11	166*1	82.16%
(b)	1,3	50,24	30	No leftover	80.15%
(c)	1,2	54,5	24	166*3	79.05%
(d)	2	25	50	220*3	73.59%

In experiments, according to whether or not to produce leftover, the effective of producing standard leftover on the utilization ratio improvement of stocks is analyzed. Stock size is 2000\*1000. Randomly produce 10 circle items. Item diameter: 209, 159, 318, 179, 244, 375, 117, 348, 401, 157; Item required: 2857, 2747, 1514, 1993,2108, 551, 2794, 2689, 1518, 992.

Table3 shows the cutting stock plan when leftover is allowed. There are 10 type cutting patterns. When leftover is not allowed, the cutting patterns are shown in table 4. The same type cutting patterns is 10. But the average utilization and the total stocks are different. The difference shows in table 5. We can learn that the former utilization is 5.35% higher than the latter, and the former plates are 34 more than the latter.

**Table3.** The patterns with leftovers

Cutting pattern	Item type	Item number	Stock number	Leftover size(item diameter mm *rows)	Utilization
(a)	4,7	22,100	28	No leftover	81.66%
(b)	1,10	27,36	28	No leftover	81.38%
(c)	4	64	22	No leftover	80.74%
(d)	1,2	18,48	58	No leftover	78.74%
(e)	3,5	6,23	92	No leftover	77.81%
(f)	1	34	32	189*3	78.17%
(g)	8	14	193	257*1	74.56%
(h)	3,9	9,4	107	189*2	73.83%
(i)	9	8	137	189*2	63.31%
(j)	6	8	69	473*1	61.92%

**Table4.** The patterns without leftovers

Cutting pattern	Item type	Item number	Stock number	Leftover(item diameter * rows)	Utilization
(a)	4,7	22,100	28	No leftover	81.66%
(b)	1,10	27,36	28	No leftover	81.38%
(c)	4	64	22	No leftover	80.74%
(d)	1,2	18,48	58	No leftover	78.74%
(e)	3,5	6,23	92	No leftover	77.81%
(f)	1	45	24	No leftover	77.40%
(g)	3	18	54	No leftover	71.67%
(h)	8	15	180	No leftover	71.53%
(i)	6	10	56	No leftover	55.37%
(j)	9	8	190	No leftover	50.65%

**Table5.** The difference between with leftovers and without leftovers

	Used stocks	Average Utilization
<b>with leftovers</b>	732	72.22%
<b>without leftovers</b>	766	66.87%

## 4. Conclusion

In this paper, the concept of standard leftover generated, so that it can be available for the later orders. The constraints of leftover will make it convenient for inventory management, which is benefit for long period order. Experiments show the combination of sequential heuristic algorithm and recursive algorithm has a higher material utilization. It will play a guiding role in actual production.

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