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The Problem of Steel Cutting in the Steel Manufacturing Industry

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Abstract

With the continuous improvement of social productivity, steel production is increasing day by day. The consumption of raw materials is increasing, and the impact on the environment is also getting worse. The sharp rise in steel prices has led to a sharp increase in production costs and a decline in profits for all steel companies in the world. Some companies even suffered losses. Therefore, improving the utilization rate of steel plate raw materials is an urgent problem that steel companies need to solve. In the steel plate cutting problem, a perfect cutting plan can greatly increase the utilization rate of the steel plate. This method can reduce the waste of raw materials, which not only saves costs, but also helps protect the environment. According to the steel plate cutting problem encountered at this stage, this paper establishes a dynamic programming discrete set mathematical model. While considering the cost of lossy steel plate and cutting cost, we establish an optimized layout function. This function can provide a high-quality layout plan and reduce product costs.

Keywords

Dynamic Programming; Discrete Set; Permutation and Combination; Optimization Function.

1. Introduction

In the process of cutting and blanking boards in the factory, workers often need to consider what method to use to cut the most raw materials and maximize the utilization of raw materials. The design of the steel plate cutting plan is a two-dimensional blanking problem, which means that multiple raw materials are discharged in the cutting area so that they are all contained in it. The design needs to optimize the waste and remaining material area. As a two-dimensional problem needs to consider many factors, it is necessary to use a computer to find a better solution under various conditions.

Table 1. Raw material information table

Raw material number	length (mm)	width (mm)	Inventory (sheets)
1	11862	1519	5
2	9296	999	10
3	7550	1232	8
4	11091	920	2
5	7504	1573	3

Table 2. Product information table

Order number	length (mm)	width (mm)	Demand
1	4435	422	15
2	3922	282	15
3	5478	268	15

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2. Data analysis

In order to better simulate the steel cutting situation and seek universality, we selected the 5 types of thick steel plate materials commonly used in the market in the test and determined their quantity. In addition, in order to better simulate supply and demand requirements, we assume three steel order plans. details as Table 1 & Table 2.

3. Model assumptions

In order to facilitate the handling of the cutting problem, this article proposes several assumptions:

(1) It is assumed that there is no excess debris in the cutting process except for the raw materials and the cut plates;

(2) The time consumed by manual arranging of the knives is not considered; (3) The cutting method is always the work of horizontal cutting Method; (4) Ensure that the cutting line is an ideal straight line;

(5) There will be no errors during cutting, and the cutting size is the ideal size;

(6) The thickness of the knife is not counted;

(7) The steel plate has no surface roughness, which does not affect the cutting efficiency;

(8) Use a circular disc cutter for cutting;

4. Symbol description

Table 3. Symbol description

symbol	Symbol Description
L_i	Order length
W_i	Order width
M_j	Raw material length
N_j	Raw material width
j	Raw material number
K_i	Order block number
i	Number of orders
$\overline{L_0}$	Length discrete set
$\overline{W_0}$	Width discrete set
$\bar{x}$	Abscissa of cutting point
$\bar{y}$	Ordinate of cutting point
ax	Origin abscissa
ay	Origin ordinate
S_1	Total cutting area
S_2	Total order area
S_3	Total area of raw materials
A	Loss factor of steel plate
η_1	Utilization rate of steel plate in cutting state
η_2	Total steel plate utilization rate
$F(k,l)$	Two-dimensional function of steel plate usage rate in cutting state
$G(k,l)$	Two-dimensional function of total steel plate utilization
(i,j)	The maximum number of orders and raw materials used

5. Model establishment and solution

5.1 Research ideas

It is required to design a better cutting plan that cuts N1 types of products on a variety of steel materials, so that the utilization rate of steel materials is the highest and the cutting time changes with the cutting shorter. Because steel raw materials and products are divided into length and width, and the length or width of each product can be randomly arranged on the length or width of the raw

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material. They are diverse and uncertain. Therefore, first of all, we use a simple and optimized method to classify products and raw materials. Then establish the mathematical model of the discrete set of dynamic programming. While considering the cost of lossy steel plate and cutting cost, we find the plan with the highest raw material utilization rate when cutting a certain number of N1 products in a piece of raw material.

5.2 Model establishment

In the process of cutting, it is necessary to consider the relationship between the length and width of the order and the raw materials. This article uses the cutting method commonly used in the factory: longitudinal cutting. details as follows:

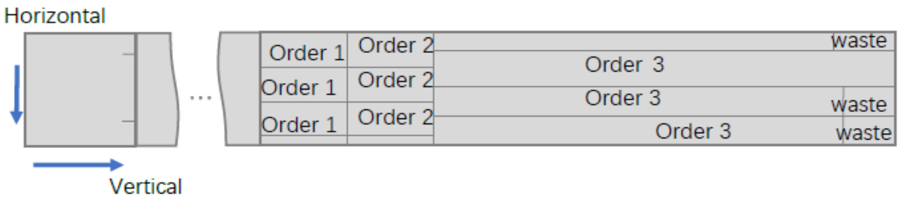

Figure 1. Cutting plan diagram

Assuming that the length of each order is $L_i(0 < i < 6)$, the width is $W_i(0 < i < 6, L_i > W_i)$, the length of the j-th raw material is M_j, and the width is N_j. On the j-th raw material, the i-th order of the K_i-thick can be cut. The purpose of optimizing layout is to maximize the use of the raw material area to improve the utilization rate of steel. All its cutting cannot exceed the range of raw materials, so there is a relationship:

$$\sum_{i=1}^{n} K_i L_i < M_j, \sum_{i=1}^{n} K_i W_i < N_j$$

Of course, for the standard two-position cutting problem, all integer rows of circular cutting positions of vertical width $\overline{W}_0$ and horizontal length $\overline{L_0}$ are constructed. In order to deal with the problem more conveniently, this two-dimensional problem is converted into two one-dimensional problems, that is, the length and width of the order are used to establish a one-dimensional knapsack problem. We use the obtained solution to construct a discrete set of order quantities, and use each element of the discrete set as a cutting line for order division. The discrete set is defined as follows:

$$\overline{L_0} = \{L_x | L_x = \textstyle\sum_{i=1}^{m} K_i L_i, 1 \le L_x \le W_1 - L_1, K \in Z_+ \cup \{0\}, 0 < m < 10, i \in (0,6)\}$$

$$\overline{W_0} = \{W_y \middle| W_y = \textstyle\sum_{i=1}^{m} K_j W_i, 1 \le W_i \le W_1 - L_1, K \in Z_+ \cup \{0\}, 0 < m < 10, i \in (0,6)\}$$

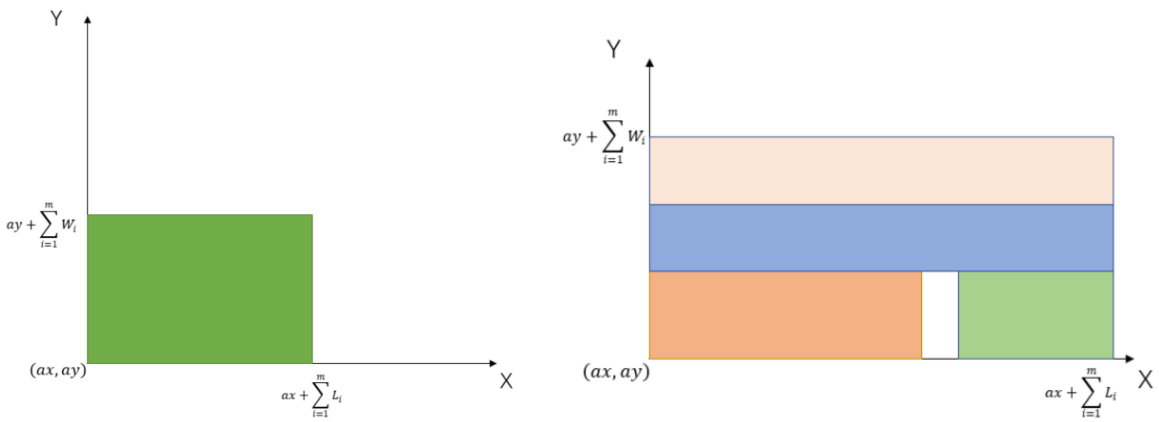

Figure 2. Order position coordinate system diagram and Order size cutting diagram

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In order to understand the problem conveniently, the Cartesian coordinate system is introduced here. Assuming that the coordinates of the lower right corner of the order coincide with the coordinates of the lower right corner of the raw material, it is expressed as (ax, ay). Take this point as the origin and the cutting direction as the positive X-axis. Take the broad side of the raw material to be cut as the positive direction of the Y axis to establish a two-dimensional coordinate system, as shown in Figure 2. The cutting size position of the order is $(\bar{x} = ax + \sum_{i=1}^{m} L_i, \bar{y} = ay + \sum_{i=1}^{m} W_i)$.

At this time, the coordinates of the cutting point can be represented by the following set:

$$\bar{x} = \{L_x | L_x = \sum_{i=1}^{m} K_i L_i, 1 \leq L_x \leq x - L_1, K \in Z_+ \cup \{0\}, 0 < m < 10, i \in (0,6)\}$$

$$\bar{y} = \{W_y | W_y = \sum_{i=1}^{m} K_i W_i, 1 \leq W_y \leq y - W_1, K \in Z_+ \cup \{0\}, 0 < m < 10, i \in (0,6)\}$$

It can be known that expanding the upper bound of the discrete set will increase the complexity of the algorithm, but it will also expand its coverage. It can be known that expanding the upper bound of the discrete set will increase the complexity of the algorithm, but it will also expand its coverage. The coordinate collection of the cutting point reflects the cutting state. The main source of loss is the excess space between orders and the plates lost at the end of cutting raw materials. It needs to analyze the loss and build a model.

Loss 1: excess space between orders and orders

In the raw material cutting process, due to the reasonable allocation of the quantity between orders, there are always some small areas of raw materials sandwiched between orders and need to be discarded. Because of the large number of cuts and the large number of orders, it is difficult to directly obtain a small area of raw materials. It is a feasible method to calculate the total consumption area divided by the total order area by using the position of the cutting point. Assuming that the total cutting area is S_1 and the total order area is S_2, there are the following formulas:

$$S_1 = A\bar{x} * \bar{y} = A \sum_{i=1}^{m} K_i L_i * \sum_{i=1}^{m} K_i W_i$$

Where A is the loss coefficient of the steel plate, $K \in Z_+ \cup \{0\}, 0 < m < 15, i \in (0,6)$).

$$S_2 = \sum_{i=1}^{m} K_i L_i W_i$$

The utilization rate of the steel plate in the cutting state is:

$$\eta_1 = \frac{S_2}{S_1} = \frac{\sum_{i=1}^{m} K_i L_i W_i}{A \sum_{i=1}^{m} K_i L_i * \sum_{i=1}^{m} K_i W_i}$$

Loss 2: The plate that was lost when cutting the end of the raw material

Assuming that the total area of raw materials is S_3, the following formula is given:

$$S_3 = \sum_{j}^{n} M_j N_j$$

among them, $0 < n < 10$.

The total steel plate utilization rate is:

$$\eta_2 = \frac{S_1}{S_3} = \frac{A \sum_{i=1}^{m} K_i L_i * \sum_{i=1}^{m} K_i W_i}{\sum_{j}^{n} M_j N_j}$$

Let $F(k,l)$ be the two-dimensional function of the steel plate utilization rate in the cutting state, $G(k,l)$ be the two-dimensional function of the total steel plate utilization rate, and (i,j) be the calculated order and the maximum number of raw materials used.

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$$F(k,l) = \frac{\sum_{i=1}^{m} K_i L_i W_i}{A \sum_{i=1}^{m} K_i L_i * \sum_{i=1}^{m} K_i W_i}$$

$$G(k,l) = \frac{A \sum_{i=1}^{m} K_i L_i * \sum_{i=1}^{m} K_i W_i}{\sum_{j}^{n} M_j N_j}$$

5.3 Model solving

The above two sets of functions are brought into Matlab software for fitting, and the data in the order information table and product information table are imported in sequence, and the following results are obtained:

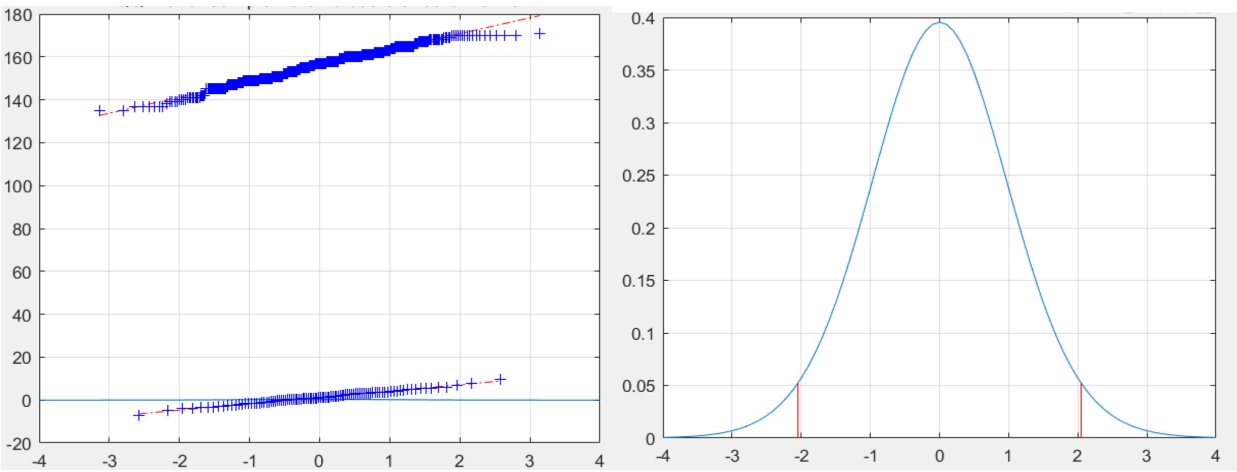

Figure 3. The difference between orders and raw materials and the fitting curve of the utilization rate of raw materials and waste

Table 4. Data result

	Order 1	Order 2	Order 3	Utilization rate
Ingredient 1	3.3	2.2	5.4	84%
Ingredient 2	4.5	5.1	7.3	79%
Ingredient 3	6.5	5.3	6.4	80%
Ingredient 4	2.2	1.0	0	86%
Ingredient 5	3.6	2.4	2.7	72%

From the results obtained, it can be seen that the larger size steel plate can be used for cutting options for more orders, and the smaller size steel plate cannot be used if it cannot meet the order requirements. Under the specific cutting conditions, the principle of "big plates cut for large orders and small plates cut for small orders" should be followed, which can effectively improve the yield rate.

6. Error analysis

In cutting problems, cutting loss is the main cause of errors. Cutting loss will incur costs. From the third question, the cost of cutting mainly appears in the cost of cutting on the long side, the cost of cutting on the short side, the area cost of loss and the cost of changing the tool. When establishing a mathematical model, the variable represented by the cost will definitely affect the relationship between the raw material and the order in the cutting state.

7. Promotion of the model

Through the combination of the discrete set of divide and conquer and the dynamic programming algorithm, the optimized cutting plan of the plate is designed and applied to the plate processing

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production line. This makes the production line run smoothly and improves the production rate and utilization of materials. It can realize the intelligent and automatic control of plate cutting. Such research can not only reduce the work pressure of workers, but also increase the rate of finished products cut into goods, so that our manufacturing industry can obtain greater economic benefits in the production of goods.

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