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Research on Cutting Planning of Steel Plates with Multi-constraints

[1]Yu Yueping and [2]Xu Li
[1]Ningbo Polytechnic, Xinda Str.1069, Beilun District, Ningbo, Zhejiang, 315800, China
[2]Engineering School, Zhejiang University City College, Hangzhou, Zhejiang, 310015, China

Abstract: The study presents the study on the situations of cutting planning of steel plates with the multiple constraints, a mathematical model based on linear programming theory is established. The algorithm has been implemented to optimize the nesting process of large steel plates. The achievements are helpful for the actuality and the higher utilization rate of steel plates of a large-scale steel structure manufacture works.

Key words: Cutting planning, linear programming, steel plates

INTRODUCTION

Generally, in steel members mechanical processing industry, to divide the cutting materials of steel plates, the general practice is to make a model according to the needs (pre-enlarged the incision margin) which is in the raw materials (rolled steel plate) by worker, and as tightly as possible. Finally, send it to the CNC cutting machine or flame cutting machine (Tangjitsitcharoen and Moriwaki, 2008). Since, it takes a lot of time and work, it depends on the nesting workers' experience and enthusiasm and many uncertain factors so that it is difficult to get the best utilization. For the steel plates industry, because of the high proportion of raw material costs in the total production costs, it has a great sense to improve the utilization. But using the computer-aided optimization nesting can effectively overcome these unfavorable factors and effectively improve the utilization of raw materials and nesting efficiency.

Nesting the steel plates belong to the optimization problem areas. The main goal of optimization is making it achieve optimal under various constraints (Jiang *et al.*, 2007). Linear Programming theory, an important method of optimization, it has a great sense to solve the optimization problem. This text is depended on the Linear Programming theory and the analysis of nesting steel plates under constraints. It divides the complex problem several related sub problems, establishes a mathematical model of the plan of nesting the steel plates, and realizes a software system of nesting the steel plates in the real application (Krzanowski, 2009; Sapate *et al.*, 2008).

SYSTEM DESIGN

Analysis of the steel plates nesting: Before establishment of the steel plates nesting model, first of all, it needs to analyze the actual situation of the nesting the steel plates and to determine its main constraint condition. Then it needs to establish a mathematical model, which is based on the corresponding constraints. Generally, the steel plates works are mainly processing large steel plates. For large steel plates (hereinafter referred to as large pieces), in the actual production circumstances, it mainly has the following three types of constraints:

- Steel plates geometry constraints. Generally speaking, the component geometry is mainly rectangle, also includes some rectangular trapezium, and a very few other shapes. For the rectangular trapezium component, it can be a combination of several components (usually 2). So, it transformed into a question of nesting of rectangle component. Meanwhile, for the other shapes, because of its impact on the utilization is little, so that the rectangle area is pretreated by a manner of preset envelope
- Raw material steel plate size constraints. Due to the purchase cost of the raw materials. The general size of the plates is the same (7-10 m range), but the span of general size of the nesting components is larger (0.3-15 m range). So, there will be a situation that the plate length is not enough for the nesting. Then, it takes the steel plate for cutting and welding so that it makes the nesting possible
- Processing constraints. In the actual production process, it not only includes the reserved cutting margin processing and other conventional processing but also the processing constraints which are produced by steels splicing. The constraints include the minimum splice length constraints and special steel plate processing constraints. Meanwhile, for productivity reasons, the straight flame cutting machine is used to process the large

Corresponding Author: Yu Yueping, Ningbo Polytechnic, Xinda Str.1069, Beilun District, Ningbo, Zhejiang, 315800, China

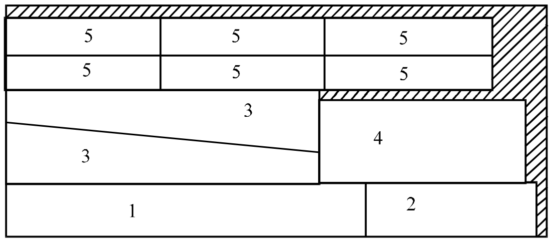

Fig. 1: A sample of cutting pattern of steel plates

piece. Due to the limitations of the processing methods, most of the programs need to use a straight strip-cutting pattern

Through above analysis of the actual constraint, for the nesting problems of steel plates can be handled as follows: For constraints (1), all components can be assumed to be rectangular pieces; for constraints (2), can be assumed that the steel plate of sufficient length, without considering the steel plate stitching problems, pending a preliminary row and then dealt with the kind generated by the program; for constraints (3), can simplify the problem by pretreatment process. Therefore, the nesting problems of large steel plates can be approximated as two-dimensional optimal nesting problems of rectangular pieces. The problems of two-dimensional optimal nesting of rectangular pieces can be expressed as: for the length L and width W (generally L>W) plate (called motherboard), it will be cutting to K different types of rectangular plate components, the number of each kind of rectangular plate component is Ni (1 = i = K). The optimization goal is to use the plate as little as possible (material utilization is highest). At last, it can simplify the original problem into the problem of two-dimensional nesting of rectangular pieces, as shown in Fig. 1.

Pre-processing of the Nesting: In the actual production process, it needs nesting on the mass components at the same time. These components may be different in shape, size, and requirements of processing so that the raw material steel plates (motherboards) may be different too. For these uncertain conditions, it makes the nesting problem more complex (Je *et al*., 2009). Without some appropriate assumptions and simplified process, it may lead to a problem of combination explosion so that it is hard to figure out the nesting problem.

The main idea of system pretreatment is defining the retreatment rules to process the input data. The pretreatment rules can be divided into the following three categories:

- Shape feature rule. Due to the different shapes of the processing steel plates, and in order to transform the original steel nesting problems into the rectangular two-dimensional nesting problems mentioned above. It needs to process the shapes of the components and transform all components into rectangular ones. The shape feature rules including trapezoidal piece combination rules and other shapes of the rectangular envelope rules. To meet the corresponding rules, the components will automatically transform into the rectangle pieces for nesting.
- Size grouping rule. Size constraints are a kind of important constraint conditions in nesting. A nesting process will appear a lot of components which have the similar size. If we solve the nesting problem with the component alone, it will greatly affect the speed to solve the problem. However, through the definition of size grouping rules, according to the rules, it will arrange the components in groups. As a result, it can reduce the redundant constraints and will greatly improve the efficiency of nesting
- Priority rule. Inputting the data of the components in the system is queue storage. Before the nesting, we need to sort the queue. The order of the component nesting has great affect on the optimized results. And the reasonable ordering rule can effectively improve the utilization of nesting. The priority rule mainly refers to empirical rule and custom rule, which include the priority rules of large size components and important components. The priority rule determines the order of the nesting by weighting method

For the different nesting situation, the types of rules applicable conditions are not the same. The different configurations of the pretreatment rule can be pre-adjusted according to the different nesting conditions, to maximize the utilization of nesting. System pretreatment process is shown in Fig. 2.

Mathematical model: Rectangular piece of two-dimensional nesting problem belongs to combination optimization problem. Its algorithm complexity is very high, and it is a NP-complete problem. Meanwhile, due to the constraints limit above, the solution process is more complex. In order to complete the optimal computation in a acceptable time. It is necessary to approximate and simplify the original problem. Base on the analysis of the nesting constraints of steel plates, we can do the following two assumptions:

- All components can be arranged
- The steel plate length without constraints

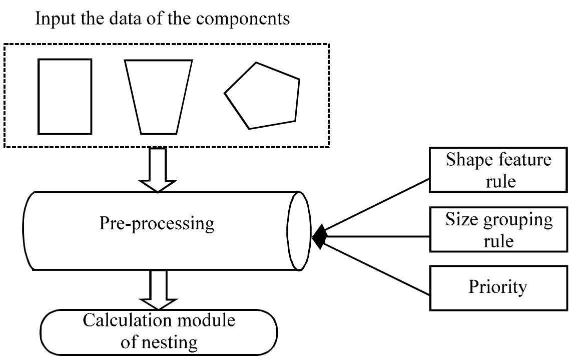

Fig. 2: Nesting pretreatment process

The premise of the assumption (a) is that the area of the steel plate is larger than the area of the component which will be nesting. The assumption (b) can be understood that the steel plate can be spliced and it can ignore the limitation of length. In the actual production process, the two assumptions are feasible. As a result, the complexity of the corresponding algorithm of the original problem will reduce. It is still quite difficult, however, after the simplification and restriction, the NP-problem can be divided into some simple sub-problem to solve.

For the nesting problems of the steel plates, its objectives can be summarized as follows: using the least plates to complete all components nesting. For the problems after the assumptions, we can create a mathematical model are as follows:

$$\text{Min } Y = CX, \text{ s.t. } AX \geq B, X \geq 0 \tag{1}$$

In Eq. 1:

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & a_{ij} & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix}^{m\times n}$$

$$B = [b_1, b_2 \ldots, b_m]^T$$

$$C = [c_1, c_2 \ldots, c_n]$$

$$X = [x_1, x_2 \ldots, x_n]^T$$

Here:

Y: The entire area of steel sheets;
C: The letter c_j in the formula represents the value of steel sheets that used in the scheme j of cutting pattern. Here simply we replace the value with the area of steel sheet needed in relevant scheme instead in general
X: The letter x_j in the formula represents consumed number of steel sheets in the scheme j of cutting pattern.
A: The matrix m×n, the letter a_{ij} represents number of the component i in the scheme j of cutting pattern in the matrix
B: The letter b_i in the formula represents the entire number of the component i waiting for cutting pattern.

Nesting algorithm design: According to the linear programming theory of Gilmore-Gemory, the mathematical model above can be solved through the following process:

- **Determine the initial feasible solution and the unit value of the steel plate:** The initial cutting pattern expresses that the method i of cutting pattern just includes the component i its selves without any other kinds. Then, X = B and i = 1, 2…m; the unit value of steel sheets can represents the relevant area L×H (L>>H in assumption)
- **Figure out the value vector of the current component:** Determine the $V = CA^{-1} = [v_1, v_2, ..., v_m]$ by the use of linear programming theory
- **According to the specific nesting mode to calculate the former straight strip width and value vector:** The normal components are just considered as the unique width of straight plate because of $l_i >> h_i$ in general. So, got the below:

$$W = [w_1, w_2, ..., w_{2m}]$$
$$U = [u_1, u_2, ..., u_{2m}]$$

Here:

W: Width vector of straight plate
U: Value vector of straight plate and with the conditions as:

$$w_{2i-1} = h_i$$
$$w_{2i} = h_i$$
$$u_{2i-1} = v_i \times \text{int}(\frac{L}{h_i})$$

- Find the optimal solution in the current solutions. The solving process of knapsack function is shown in the references listed below

According to linear programming theory of Gilmore and Gemory, suppose current method of cutting pattern is:

$$P = [p_1, p_2, ..., p_m]^T$$

here the letter p_i represents the number of component i, $i \in [1, m]$. The P is optimization if LH-VP<0.

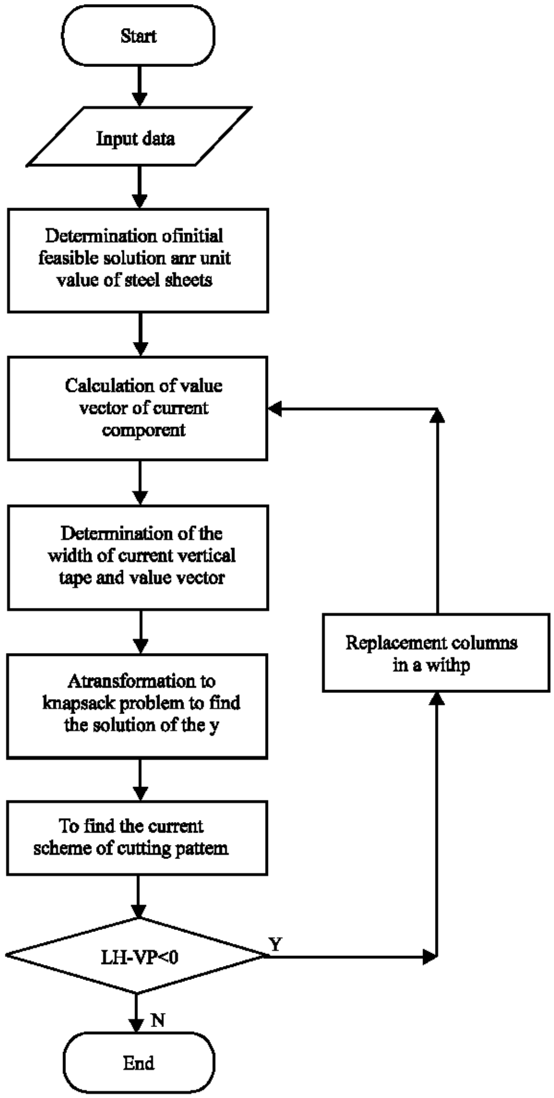

Fig. 3: Flow chart of the main algorithm

Suppose:

$$Y = [y_1, y_2, ..., y_{2m}]$$

here letter y_i represents number of vertical tape j, j∈[1, ...2m]. The sample matrix operations can determine the method P according to the Y.

The following mathematical model is got for the Y:

$$u = \max(\sum_{i=1}^{2m} u_i, y_i) \quad \text{s.t.} \sum_{i=1}^{2m} w_i y_i \le H; y_i \ge 0, i = 1, 2, ..., 2m \tag{2}$$

Equation 2 is possible to establish knapsack function to be solved because it's a typical knapsack problem:

$$F(x) = \max\{\sum_{i=1}^{2m} u_i y_i, \sum_{i=1}^{2m} w_i y_i \le x\} \tag{3}$$

here y_i is a nonnegative integer.

The solution of the Y leads to the solution of the P. One of queues in the A replaces the P if LH-VP<0 and turning to the second step next; Otherwise, the current solution is the optimization. The algorithm process of this mathematical model is shown in the Fig. 3.

Based on the algorithm above, to solve linear programming problems by solving auxiliary sub-problems (Knapsack problem), and eventually be able to get a preliminary optimization program. But this is not the result of the final nesting solution. For the algorithm above of the nesting of the steel component makes some appropriate assumptions and simplifications. Steel plate splicing constraints should be taken into consideration. And the final results need to do some further treatment. The processing procedure is as follows:

- Base on the nesting process parameters, and then determine the maximum splice length of steel plates
- Run the entire preliminary nesting program, to determine the stitching breakpoint. For the adjacent breakpoint, so we should adjust the entire program
- Based on the breakpoints, and then determine its stitching program. Before it we need to make some stitching rules. Such as a longer program should be stitching first, the least number of the total stitching, using cyclic search stitching. However, for few process requirements can not be met and can not be spliced breakpoint. We can save it to a library of more than expected, and adjust manually or take it into the next stitching
- After you complete the stitching, and make it a proposal, at last, the final nesting result output by graphics or cutting stock single

SOFTWARE APPLICATION

The cutting pattern of steel components as an intermediate step in the entire machining of steel components is closely related to design, machining, statistics and so on. So, the design of system software should be based on rule of optimized process and high efficiency. The actual working process of cutting pattern system of steel components is shown in Fig. 4.

As shown in Fig. 4, cutting pattern department gets the list of components waiting for cutting pattern from design department and inventory of steel sheets from warehouse at the same time by interior LAN and imports them into cutting pattern system directly in interior

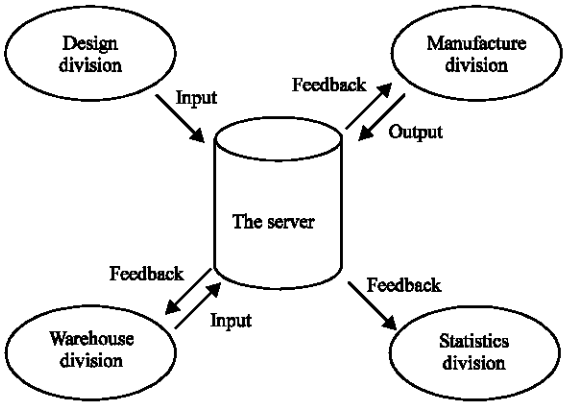

Fig. 4: Application process of system of cutting pattern of steel sheets

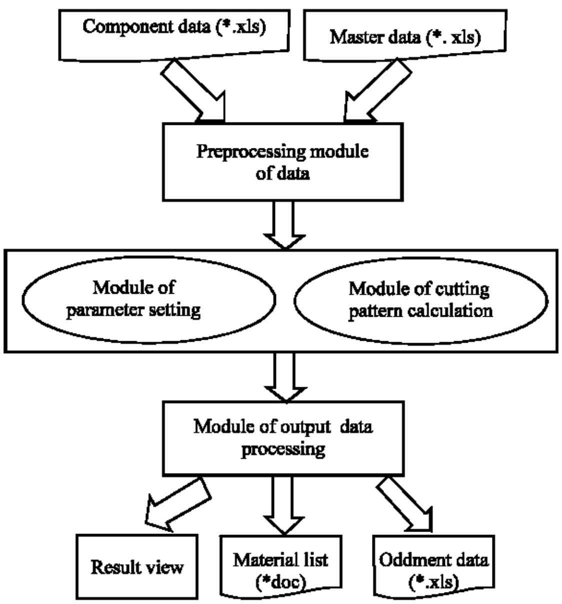

Fig. 5: System architecture

standardized file format (Excel). This process is no repetition of input dates, higher efficiency of cutting pattern and lower error rate; the finish of cutting pattern by calling algorithm module of cutting pattern after the preprocessing of input dates begins to output result such as result of cutting pattern, utilization rate, oddments and so on. System manages those results by journal files for inquiry and feedback in the future.

The architecture is shown in Fig. 5. The system used Chinese GUI which operates easily is designed by Microsoft Visual BASIC 6.0 which used for designing software of the GUI and developing integrated framework of system with an advantage of the capability of fast development. Different part of algorithms of system takes

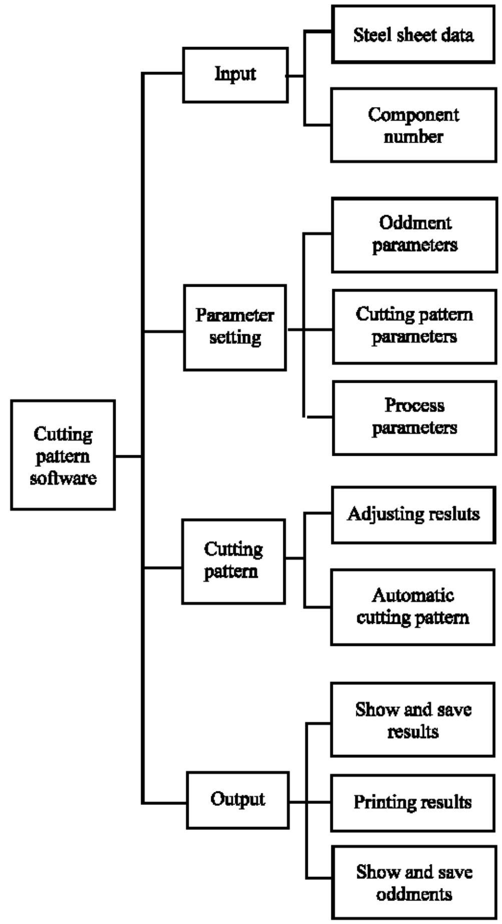

Fig. 6: Software architecture

the VC++ which improves solution efficiency of algorithm to program the single module and uses call technology of DLL. The DLL of algorithm module can use as a port of second development.

The software architecture of system is shown in Fig. 6 according to actual function of cutting pattern.

CONCLUSION

This system has been applied in the large-scale company of steel sheets in Hangzhou recently. The raw material utilization rate of cutting pattern of large steel sheets improved 1-2.5% by this system in trial operations, instead of by the artificial study work, and with great economic benefits considering huge steel costs. At the same time the work efficiency improved many times than before because of the realization of computer management.

It's efficient to use the optimized cutting pattern of steel components under the actual condition of multi-constraint in the system according to practice.

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