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Batch optimization of rectangular parts

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Abstract: In the field of modern industry, cutting material for industrial manufacturing essential basic process. In recent years, in order to meet the needs of national industrial development, the research on cutting has made rapid progress. Due to the different demands of different orders in the process of product production, and the cutting and cutting need to meet the constraints of "simultaneous cutting". Aiming at the common batch optimization problem of square parts, this paper mainly focuses on the two-dimensional three-stage shearing and cutting problem, aiming to minimize the use of original pieces and the lowest utilization rate of original pieces. By using genetic algorithm, product items or strip arrangement schemes are numbered to form chromosomes. Secondly, by initializing the population, evaluating the fitness of individuals in the population, selecting, crossing and other steps, Select the best layout solution. Finally, through the utilization rate of the original sheet, it is proved that the method proposed in this paper can effectively solve the typesetting problem of square parts, improve the utilization rate of raw materials, and improve the production flexibility to a certain extent.

1. Introduction

The manufacturing industry often encounters the problem of material segmentation, and square parts layout is the most common. Effective layout can not only improve the utilization rate of materials, but also simplify the cutting process [1]. The increase in the types of parts may improve the material utilization rate due to the combination of material cutting. The integration of multi-engineering and multi-task large-scale parts for centralized cutting can obtain better economy [2]. The problem of square layout is a resource optimization problem. The purpose of optimization is to rationally plan the layout of square parts on the board, so as to reduce the waste of the board in the blanking process and simplify the cutting process. According to the size and number of square parts in the same production batch, select the specification and number of the original sheet, optimize the blanking layout, and maximize the utilization rate of the original sheet. A good blanking scheme meets three requirements under the conditions of production capacity: first, it should maximize the utilization rate of raw materials, i.e. the minimum amount of raw materials; Secondly, different feeding methods are required as little as possible; Also meet the respective lead times for each part [3].

Blanking problems generally exist in the production process of glass, steel plate, wood, paper, clothing and ship industries. According to the dimensions of raw materials and parts, blanking problems can be divided into one-dimensional, two-dimensional and three-dimensional blanking problems. Among them, one-dimensional blanking problem refers to the blanking of profiles and bars, three-dimensional blanking problem refers to the length, width and height of raw materials and parts have specific requirements [4]. The two-dimensional blanking problem mainly refers to the blanking of the plate, and all kinds of blanking parts are cut from the plane raw materials, so that the utilization rate of materials is the highest. In terms of computational complexity theory, two-dimensional blanking problem belongs to a class of optimization problems with the highest complexity: NP-complete problems [5]. In the modern era of economic globalization, especially the cold development of the global steel industry affected by the COVID-19 pandemic, it is the only way for the current steel manufacturing industry to make reasonable and feasible cutting of existing raw materials and reduce production costs as far as possible, including raw materials, manpower and manufacturing time consumption, on the premise of meeting the demand of orders.

Therefore, improving the utilization rate of materials is the focus of current research. At present, the effective algorithms proposed by scholars at home and abroad can be roughly divided into two categories: one is heuristic algorithm, such as the knapsack algorithm proposed by Cao Ju [6], Huang Wenqi proposed a heuristic algorithm based on the idea of occupying points [7], Jia Zhixin proposed the lowest level emission algorithm.[8] All of them have achieved good results. Another kind of algorithm is mainly using modern intelligent algorithms, such as genetic algorithm, simulated annealing algorithm, ant algorithm, particle swarm algorithm and so on [9-10].

2. Assumptions of the model

1) Only consider the head-to-head cutting mode (straight cutting, cutting direction perpendicular to one edge of the plate, and ensure that each straight cutting plate can be separated into two pieces);

2) The number of cutting stages shall not exceed 3, and the direction of cutting is the same at the same stage and the number of cutting knives is not limited;

3) Layout method is accurate layout;

4) Assume that the original sheet has only one specification and sufficient quantity;

5) The layout plan does not take into account the effect of the width of the saw seam (i.e. the width of the slit cut).

6) The delivery time of all orders is the same without distinction.

3. Symbol specification (Table 1)

Table 1: Symbol specification table

meaning	meaning
Υ_{ij}	Represents the number of the i product in a certain sheet layout scheme
Q	Represents the sum of the arrangement modes of product items on the original sheet
m_j	Represents the number of the j plate
N	Represents the number of plates
c_i	Represents the total demand for each product
N	Represent a positive integer
y_j	Represents the number of plates consumed per batch
W	Represents the batch needed to complete all orders
g_j	Represents the area of each product item

4. Represents the width of the original sheet

Cutting blanking is essentially an optimization problem considering the sorting of blanking schemes, and cutting blanking needs to meet the constraints of "one size fits all", it must be optimized for the sorting of blanking schemes, through the reasonable sorting of product items on the plate. In the optimization process, it is necessary to minimize the use of the blanking sheet, so that the subwood can be concentrated in a few blanking schemes. According to these characteristics, the multi-objective optimization problem of cutting materials was transformed into a single-objective optimization problem for solving, and the optimization objective of the blanking problem was set to minimize the number of schemes, as follows:

$$\text{Objective function: min} \quad z = \sum_{j=1}^{Q} m_j \tag{1}$$

$$\text{s.t.} \quad i \cap j = \Phi \qquad 1 \le i, j \le Q \tag{2}$$

$$m_j \subset N \tag{3}$$

$$\sum_{j=1}^{Q} \gamma_{ij} m_j = c_i \qquad i = 1, 2, \cdots, n \tag{4}$$

$$\text{Demand just met} \tag{5}$$

Formula (1) is the objective of optimization, that is, it requires the least amount of original plates consumed. (2)-(5) are the constraint conditions, where: (2) represents that the arrangement modes i and j on any two plates are not overlapping; Formula (3) represents the use times of the original layout mode of the j plate as m_j, where m_j is the integer decision variable; (4) Formula represents the total number of product item i; Formula (5) indicates that the premise must be satisfied.

5. Algorithm design

The following is a brief introduction of some common algorithms to solve the rectangular strip layout problem.

1) The search algorithm based on the lowest horizontal line is one of the earliest and most widely used heuristic algorithms for solving rectangular strip layout problems. Bottom-up left-justified has two obvious disadvantages [11]: One is that some particular problems cannot be solved optimally; second, it is easy to produce the left side of the high result.

2) Heuristic recursive algorithm is a very effective algorithm proposed by Zhang Defu [12]. In this paper, a heuristic strategy is used for the product item discharge, and the recursive idea is used to divide the space, and the problem is decomposed into a set of layout problems and rectangular layout problems.

3) Branch and Bound recursive algorithm is based on the partition idea of solving strip layout problem recursively. Cui Yaodong [13] proposed an algorithm combining branch and bound method with recursion idea to solve rectangular strip layout problem. When the product item is discharged on the plate original, the branch and bound method is used to limit and constrain the product item emission, so as to improve the efficiency of recursive operation.

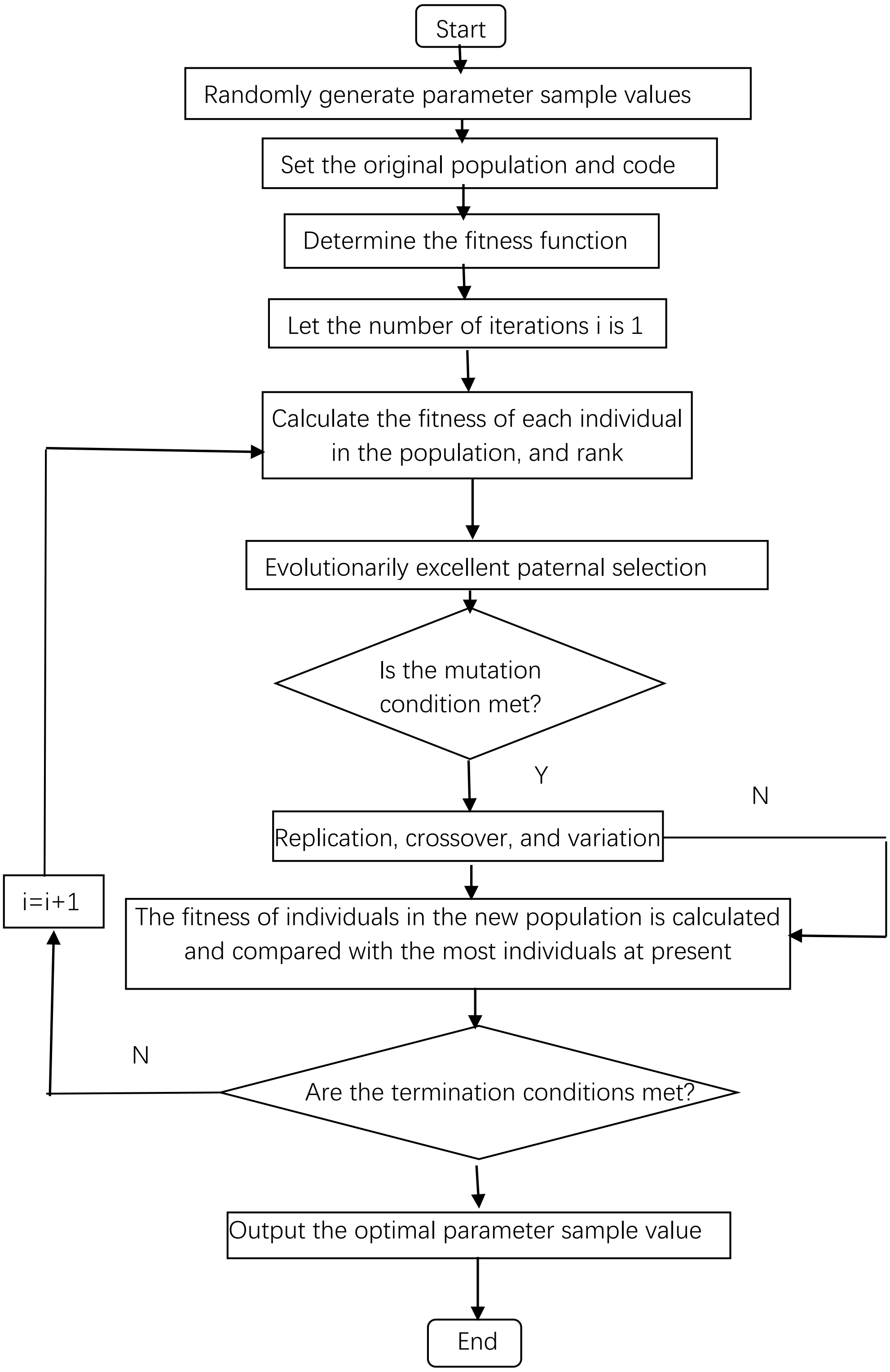

Figure 1: Flowchart of the overall process of genetic algorithm

4) Genetic Algorithms [14] (GA) is a kind of self-organizing and adaptive artificial intelligence technology inspired by Darwinian evolution—survival of the fittest. It simulates the process and mechanism of biological evolution in nature and solves problems. In essence, it is an efficient, parallel and global search method, which can automatically acquire and accumulate knowledge about search space in the search process, and control the search process adaptively to obtain the best solution. In

the genetic algorithm, a number of numerical codes, namely chromosomes, are generated randomly to form the initial population. A numerical evaluation is given to each individual through fitness function, and individuals with low fitness are eliminated, while individuals with high fitness are selected to participate in genetic manipulation. After genetic manipulation, the collection of individuals forms the next generation of new population. And then we move on to the next evolution of this new population.

Based on the logic of this paper, we choose genetic algorithm. The specific process is shown in Fig 1.

6. Case application

6.1 Problem analysis

In the square batch optimization problem, that is, the blanking optimization problem, the main research is how to reasonably arrange the position of the product on the plate, so as to establish a reasonable programming model. n square pieces of l_i*w_i with the original size of 2440*1220 (mm^2) are cut from m pieces. And I want m to be as small as possible without being able to cut n.

6.2 Problem solving

6.2.1 Preliminary data processing

Table 2: Preliminary data analysis

	Max length (m)	Min length (m)	Mean Length (m)	Max width(m)	Min Width (m)	Mean Width (m)	Area summation
dataC1	2.418	0.116	0.901	1.165	0.038	0.368	248.686
dataC2	2.433	0.112	0.921	1.198	0.038	0.341	246.700
dataC3	2.438	0.099	0.878	1.198	0.038	0.337	249.245
dataC44	2.438	0.111	0.831	1.151	0.038	0.342	243.660

Table 3: Sorting results by area

item_id	item_material	item_num	item_order	length	width	s
111	YW10-0218S	1	order235	0.278	0.038	0.0106
309	YW10-0218S	1	order235	0.314	0.038	0.0119
591	YW10-0218S	1	order472	0.217	0.058	0.0126
286	YW10-0218S	1	order424	0.356	0.038	0.0135
275	YW10-0218S	1	order472	0.237	0.058	0.0137
469	YW10-0218S	1	order154	0.3185	0.0525	0.0167
194	YW10-0218S	1	order237	0.302	0.058	0.0175
623	YW10-0218S	1	order423	0.4985	0.038	0.0189
454	YW10-0218S	1	order174	0.362	0.058	0.0210
478	YW10-0218S	1	order156	0.362	0.058	0.0210
174	YW10-0218S	1	order250	0.577	0.038	0.0219
312	YW10-0218S	1	order121	0.38	0.058	0.0220
751	YW10-0218S	1	order450	0.382	0.058	0.0222
500	YW10-0218S	1	order469	0.482	0.048	0.0231
153	YW10-0218S	1	order474	0.399	0.058	0.231

A preliminary analysis of plate data set C was conducted, and the results were shown in Table 2.

By unifying the units of length and width of the products in each list in dataset C as (m), find the area of each square component as S. Sorted by product area, the results are shown in Table 3.

6.3 The validity and complexity analysis of the model

Effectiveness of genetic algorithm: 1. Genetic algorithm does not have too many mathematical requirements for the optimization problem solved. Due to its evolutionary characteristics, it does not need the intrinsic nature of the problem in the search process, and can handle any form of objective function and constraint, whether linear or non-linear, discrete or continuous. 2. The aergodic properties of evolutionary operators enable genetic algorithms to carry out probabilistic global search very effectively. 3. Genetic algorithm can provide great flexibility to construct domain-independent heuristics for various special problems, so as to ensure the effectiveness of the algorithm.

Complexity of genetic algorithm: Genetic algorithm is a double iteration, its time complexity is not more than n square genetic algorithm is a global optimization probabilistic algorithm. Space complexity: It is the extra storage space required by the program to run. General recursive algorithms will have o (n) space complexity. Simply put, recursive set calculation is usually repeated calls to the same method, recursion n times, it needs n space. Time complexity: The time taken by an algorithm is directly proportional to the number of statements executed in the algorithm. The algorithm with more statements executed takes more time. The number of statements executed in an algorithm is called statement frequency or time frequency.

The whole idea of this algorithm is genetic algorithm. The advantage of this algorithm is that it is easy to think about, but the disadvantage is that it is difficult to implement, especially in the face of large data sets need to consider many possible situations. The order of objects is very important when genetic algorithm is used to solve the model, which directly affects the result index. This algorithm is the most friendly to the primary goal, if the primary goal is used as the standard to measure the solution result, then the result can be perfect. However, it is not very friendly to the secondary goals and the later planning goals, and can only get the near optimal solution. The time complexity of the algorithm reaches o (n2), and the best case is o(n). The running time of the program on set C data is about 20 minutes.

6.4 Numerical result

The partial plate cutting of data set C is shown in Fig. 2.

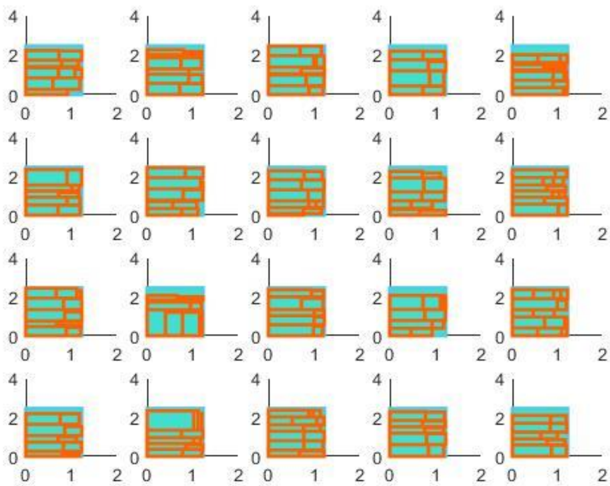

Figure 2: Sheet cutting diagram

Partial results of plate data set C are shown in Table 3.

Table 3: Processing results of plate data set C

Original material	Original sequence number	productid	Product x coordinate	Product y coordinate	Product length in the x direction	Length of product in y direction
ZQB-0218S	26	30204	0.871	0	0.058	2.001
ZQB-0218S	63	30205	0	0	0.3525	1.339
ZQB-0218S	55	30206	0	0	0.517	2.147
ZQB-0218S	16	30207	0	0.711	1.1795	0.702
ZQB-0218S	39	30208	0.579	0	0.558	1.998
ZQB-0218S	43	30209	1.042	1.5175	0.17	0.568
ZQB-0218S	23	30210	0	0.3505	0.769	0.358
ZQB-0218S	63	30211	0.877	0	0.0925	0.343
ZQB-0218S	38	30213	0	0	0.63	2.348
ZQB-0218S	31	30214	0.63	0	0.558	2.348
ZQB-0218S	87	30215	0.812	0	0.368	1.568
ZQB-0218S	20	30216	0	0.308	0.878	0.478
ZQB-0218S	52	30217	1.181	0.387	0.038	0.925
ZQB-0218S	74	30218	1.1575	0.0925	0.058	2.161
ZQB-0218S	80	30219	0.847	1.2315	0.373	0.461
ZQB-0218S	7	30220	0.898	0.753	0.245	0.439
ZQB-0218S	35	30221	0	0	0.942	0.392
ZQB-0218S	82	30222	0	0	0.4	1.3205
ZQB-0218S	64	30223	0.711	0	0.508	0.289
ZQB-0218S	66	30224	1.116	0	0.098	2.078

6.5 Further analysis

During the processing of data set C, there are no restrictions on orders, and the same order can be in different batches. On this basis, further constraints were added to establish a mixed integer programming model. Therefore, all orders in another set of sheet data set D were grouped, and then each batch was arranged independently. In order to meet the order requirements and related constraints, the consumption of sheet original was minimized. The requirements are as follows:

1) If and only if each order appears in one lot;

2) Only items of the same material in each batch can use the same sheet original for layout;

3) To ensure the rapid flow of processing links, the total number of items in each batch should not exceed the limit value;

4) Due to the limited capacity of the factory, the total area of each batch item shall not exceed the limited value;

6.6 New problem solving

6.6.1 Preliminary data processing

Table 4: Preliminary data analysis

	Max length	Min length	Mean length	Max width	Min width	Mean width	Total area
dataD1	2.438	0.098	0.890	1.198	0.038	0.354	8865.813
dataD2	2.438	0.048	0.864	1.198	0.037	0.350	5735.887
dataD3	2.439	0.099	0.865	1.198	0.038	0.352	5756.364
dataD4	2.438	0.098	0.884	1.198	0.038	0.350	6043.318

Data set D is preliminarily analyzed, and the results are shown in Table 4:

Unify the units of length and width of the products in each list in the data set D as (m) and find the area of each square component as S. Sorted by product area, the results are shown in Table 5.

Table 5: Sorting results by area

item_id	item_material	item_num	item_order	Length(m)	Width (m)	$S(m^2)$
33403	NBSY-0218S	1	order362	0.146	0.038	0.0055
1460	YW8-0218S	1	order394	0.147	0.038	0.0056
8995	FMB-0218S	1	order82	0.156	0.038	0.0059
9890	FMB-0218S	1	order82	0.156	0.038	0.0059
28016	XMJQ-0218S	1	order125	0.126	0.048	0.0060
28121	XMJQ-0218S	1	order125	0.126	0.048	0.0060
29718	XMJQ-0218S	1	order125	0.126	0.048	0.0060
32342	XMJQ-0218S	1	order125	0.126	0.048	0.0060
3985	QKQ-0218S	1	order296	0.131	0.048	0.0063
4032	QKQ-0218S	1	order305	0.131	0.048	0.0063
4560	QKQ-0218S	1	order295	0.131	0.048	0.0063
5104	QKQ-0218S	1	order295	0.131	0.048	0.0063
5287	QKQ-0218S	1	order295	0.131	0.048	0.0063
5568	QKQ-0218S	1	order296	0.131	0.048	0.0063
5657	QKQ-0218S	1	order295	0.131	0.048	0.0063

6.6.2 Establish the optimization model

Order group batch, the material in each batch is required to be the same, according to statistical analysis, there are 220 material orders in the data set, the batch should be greater than or equal to 220.

$$\text{Objective function: min} \quad z = \sum_{j=1}^{W} y_j \tag{6}$$

$$\text{s.t.} \quad M_j < 1000 \qquad 220 \le j \le W \tag{7}$$

$$g_i < 250 \qquad 1 \le i \le 1000 \tag{8}$$

$$j = [220, 221 \ldots, W] \tag{9}$$

$$\text{Demand just met} \tag{10}$$

Where y_i represents the number of plates consumed in the order of batch j. The model of the initial problem is adopted to obtain the optimal layout result. Mi represents the number of product items in batch j, g_i represents the area occupied by product items in plate i,

6.7 Model validity and complexity analysis

The time complexity (also known as time complexity) T (n) of an algorithm is the time consumed by the algorithm and a function of the size n of the problem solved by the algorithm. When the size n of the problem approaches infinity, the order of magnitude (order) of the time complexity T (n) is called the asymptotic time complexity of the algorithm. The time complexity of an algorithm depends not only on the size of the problem, but also on the initial state of the input instance. The time complexity of the algorithm reaches o (n2), and the best case is o (n). The running time of the program on D sets of data is about 20 minutes.

6.8 Algorithm design

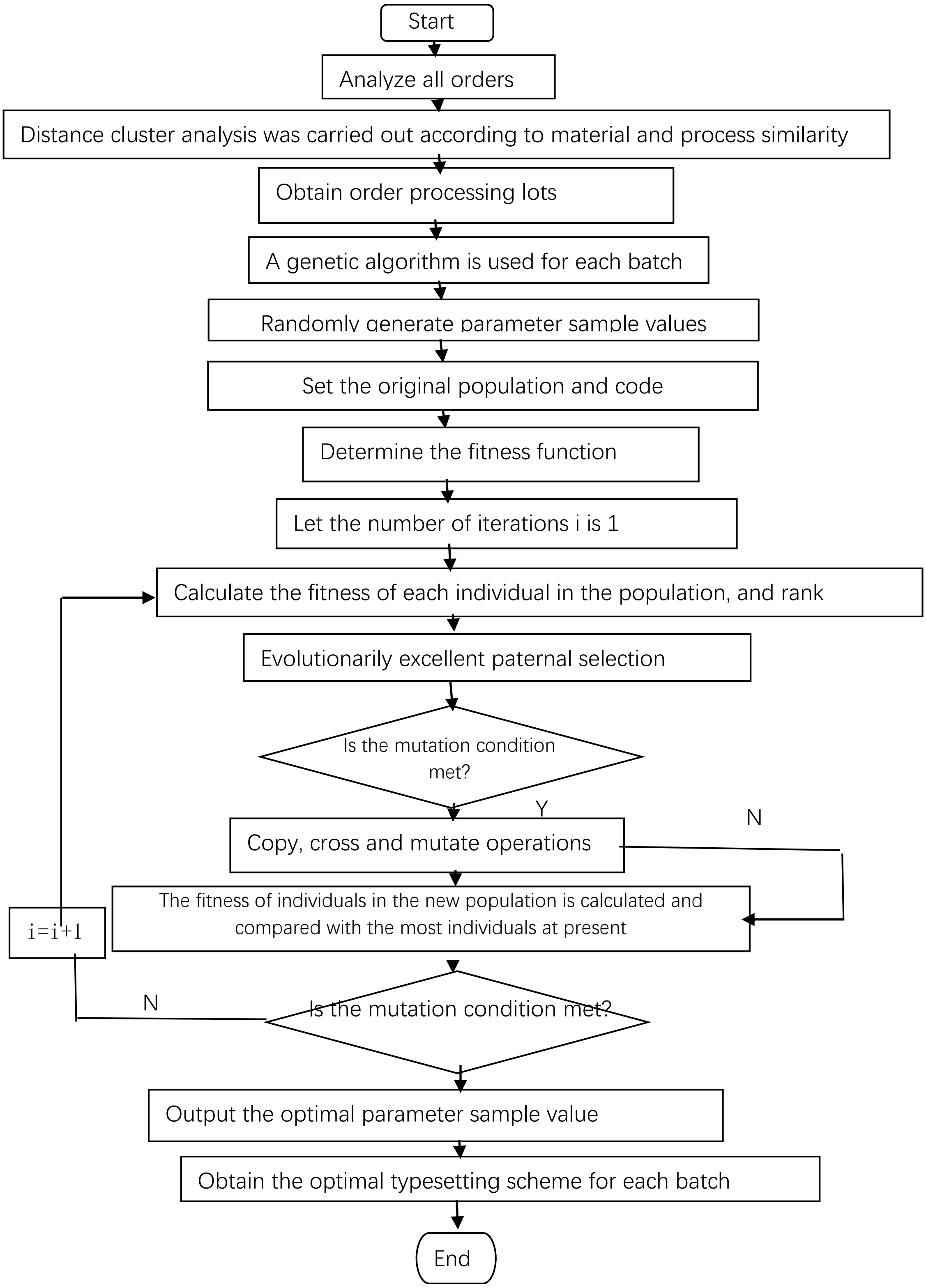

Figure 3: Flowchart of the overall process of genetic algorithm after further consideration

After the improvement of the basic algorithm in the previous step, the specific steps are shown in Fig. 3:

6.9 Result presentation

Product items in D1 are divided into 43 batches to complete, and some results are shown in Table 6.

Table 6: Further analysis results

Original material	Original sequence number	Product id	Product x coordinate	Product y coordinate	Product length in the x direction	Length of product in y direction
5-0218S	7	19	0	0	0.4945	0.4475
YW1-0218S	23	20	1.12	0.378	0.058	0.927
YW1-0218S	37	21	0.948	0.358	0.161	0.451
YW1-0218S	22	22	0.753	1.5518	0.378	0.53
YW1-0218S	14	23	1.1275	0	0.058	0.482
YW1-0218S	24	24	0	1.6741	0.703	0.269
YW1-0215S	24	25	0	1.983	0.803	0.449
YW1-0218S	34	26	1.178	1.758	0.038	0.326
YW1-0218S	19	27	0	0.558	0.699	0.327
YW1-0218S	16	28	0	0.8895	0.608	0.48
YW1-0218S	8	29	0	0	0.56	0.498
YW1-0218SD	7	30	0	0	0.971	0.557
YW1-0218S	52	31	0	0	0.841	0.594
YW1-0215S	9	32	0.936	0.512	0.1325	0.629
YW1-0218S	7	33	0.821	1.298	0.367	0.538
YW1-0218S	7	34	0.58	0	0.58	2.098
YW1-0218SD	2	35	1.152	0	0.058	1.803

7. Model evaluation

7.1 Model advantage

(1) In data processing, in addition to the hard restriction conditions in the actual situation, the material rate is also taken as a constraint condition, so as to meet the cutting requirements as far as possible.

(2) The model is easy to understand and operate, and the algorithm processing selects a relatively simple way to solve the cutting problem.

7.2 Model Shortcomings

(1) For the analysis of residual materials, some residual materials have not been compared with actual operations, so the accuracy of the algorithm needs to be improved.

(2) If the data is too large and the algorithm is not optimized enough, it may need to process more data, resulting in slow operation speed

8. Outlook

The problem of layout of rectangular parts is widespread in many trades of national economy. It is of great theoretical and practical value to study this problem. Genetic algorithm (GA) is a kind of bionic evolutionary computing technology. At present, there are many researches on this algorithm. It is of great practical value to study how to apply this algorithm to solve practical problems. The algorithm described in this paper is based on genetic algorithm. According to the characteristics of specific problems, the corresponding genetic operator is designed to solve the RSPP. This paper mainly completed the following work: (1) Combined with the requirements of some production processes and applications in special occasions, this paper adopted the phased shear layout scheme to solve the RSPP problem. (2) Design the corresponding genetic operator. According to the requirements of the layout scheme, the genetic manipulation was designed in layers and piles, which ensured the inheritance of good genes in the parent genes and accelerated the efficiency of calculation. In the process of chromosome decoding, the idea of heuristic is used to make the decoding process simple and easy to implement. According to these methods, the detailed steps of genetic algorithm to solve RSPP algorithm are given. (3) A rectangular strip layout system based on genetic algorithm is developed. Through a large number of experimental tests, the experimental results are compared with those of various algorithms, and the effectiveness of the proposed algorithm is verified from the aspects of material utilization rate and the simplicity of layout scheme. However, any algorithm has certain pertinence and is closely related to the specific application field, so it is very difficult to construct a general layout strategy that can achieve the best results in various situations. On the basis of the research in this paper, the following work can be further carried out: (1) Chromosome decoding is the most frequent operation in genetic algorithm, so it is an improvement direction of the algorithm in this paper to design more efficient computation or to seek some strategy that can reduce the computation frequency. (2) In the process of layout, the blank with similar size is divided into groups, which can not only reduce the scale of the problem in a disguised way, but also further simplify the layout results. The design of grouping strategy is also not completed in this paper. The problem of layout has influenced modern people's life closely since it was put forward. It is hoped that the work of this paper can play a role in introducing jade, and more peers will invest in this research, so that more good algorithms can play a greater role in solving layout problems.

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