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Research Article

Multiobjective Optimization of Copper Coil Blanking Based on Niche Genetic Algorithm

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The shear process of small batch and multivariety copper strip processing enterprises are the bottleneck of production, which often faces the contradiction between working efficiency (less tool changing) and yield (reducing geometric waste). The high yield of copper strip embryo is the core index of high yield and high benefit for enterprise. Less tool changing is a key step for high efficiency and fast product delivery in shear station. In this paper, we took the cutting production of the production management system as a research example in Hubei Lean High Precision Copper Strip Company when the system is developing. We used the penalty function to deal with the length floating constraint. Then, we established a multiobjective optimization model with the roll weight and the number of tool changing as the weights, which were calculated by an integrated weighting method. Three algorithms, namely, adaptive particle swarm optimization, niche genetic algorithm based on crowding, and niche genetic algorithm based on seed retention (NGA), were used to solve the problem. Through production examples, it was concluded that the solution solved by NGA has the highest utilization rate of the coil when the number of tool changing was as little as possible. This paper provides a new solution combining the efficiency and benefit for shear process in finished product delivery of copper strip processing enterprises.

1. Introduction

As the only dozens of small intermediate products in China, the copper strip processing enterprises mainly provide customized copper strip coil materials for downstream enterprises, which are involved in electronic communication, automobile industry, computer, construction, home appliances, and other industries, and the market demand is increasing [1]. After placing an order, the copper strip should go through casting, milling, blooming, intermediate rolling, trimming, pickling, shearing, and packaging before it can be shipped. A roll of material may be cutted and divided into dozens of specifications with hundreds of rolls according to the order, so the shear station is the bottleneck for enterprise product delivery. Such enterprise has the following characteristic: the typical small-batch and multivariety production mode. The yield is the basis to estimate the utilization level of copper, zinc, and silver materials in the processing process, and also the basic index to measure the competitive strength of the enterprise [2]. The production mode basically adopts $7*24$ hours. The copper coil blanking belongs to the linear cutting problem and the guillotine cutting problem in the layout problem of constrained rectangular parts [3]. According to the order, a roll of material may be cut and rolled into dozens of specifications, and hundreds of rolls. There are a large number of orders with variable lengths; in the cutting process, every change of knife will produce a new head and tail waste and occupy the running time of the machine; and the cutting and packing process often become the bottleneck of timely delivery of products.

For two-dimensional rectangular layout optimization problem, most of the research is sheet layout [4–6]. In reference [7], an optimized winding blanking algorithm based on an implicit enumeration method and dynamic programming algorithm is proposed, which only discusses a single rectangular piece and does not involve in the guillotine cutting constraint. The references [4, 5, 7] do not consider the length fluctuation, while the reference [6] considers the case of fixed width and variable length, and only considers the material utilization as a single target. On the optimization of the cutting process for reducing tool change times, references [8, 9] compared the number of blanking parts and maximized the use times of current blanking way, which has the thought of greedy algorithm. Reference [10] refers to the drawback of this algorithm. In the early stage, a large number of easily assembled rectangular pieces is used, and in the later stage, only rectangles that are difficult to assemble are left. All the above references are the solutions to the layout problem mainly aimed at the utilization rate of materials. All the schemes do not take into account the efficiency and benefit scheme and need the length of the layout to be fixed. It does not consider that copper strip processing enterprises need the optimization scheme with the length variation (tool changing and shearing), hours of work efficiency (tool changing times), and material utilization rate in shear station processing (tool changing and shearing) provided on a rolling basis in the 7∗24 working mode.

In the process of developing the production management system of Hubei Lean High Precision Copper Strip Company, the electronic weighing platform is successfully used to solve the problem of single coil weighing in the copper strip processing industry, which provided favorable support for the accurate single coil yield in the copper strip processing, and also provided the possibility for optimizing the efficiency and benefit of shear station and shear packing. Through the cutting data analysis of the company, this paper proposes that aiming at the two-dimensional shear blanking problem of copper strip coils with length fluctuation and tool change constraints, this paper first adopts a homogeneous block and implicit enumeration method [11] to determine all the researched blank layout, then establishes a multiobjective cost optimization model as the evaluation system of blanking scheme, and furthermore adopts the comprehensive weight method to calculate the weight of objective function. Finally, Niche Genetic Algorithm (NGA) based on seed retention is used to search blanking scheme. This paper not only puts forward the solution of shear station optimization solution but also provides the solution scheme.

2. Methodology

2.1. Problem Description. Considering the copper strip coil two-dimensional blanking problem with floating length and tool change as shown in Figure 1, with width W and the long enough length coil shear m specifications, the width of each specification is fixed. Length float in a certain range, the width sums of the finished small coil in every time tool changing should not be greater than the total coil width W. Within the constraints, the blanking goal is to use the least number of tools changing and require the shortest coil length with uniform width and thickness of the coil under the premise of cutting the required length of all products (the output requirements on the production schedule). The shortest length namely requires the least coil weight.

2.2. Mathematical Mode. Considering the complexity of the shearing, the following assumptions are made to effectively simplify the practical problems:

(1) The length of the coil is not limited, and the splicing waste is not considered. The width and thickness of the coil are fixed

(2) Each tool changes with shear specifications of at most two, at least one

(3) All the specifications needed to be sheared are only kept within the order quantity requirements, and the rest are scrap

(4) The sheared length of the finished product shall meet the requirements of the length of the finished product single coil

(5) The cutting mode is vertical one-cut, and the sheared length of the small coil in each blank layout scheme is the same (different lengths have the same effect with the same length).

The mathematical model is as follows:

$$\left\{ \min z_1 = \sum_{j=1}^{n} l_j x_j, \min z_2 = h, \right. \tag{1}$$

$$\text{S.T.} \begin{cases} \text{ALX} \geq B, \\ 0 \leq X \leq U, x_j \in \mathbb{N}, \\ P \leq L \leq Q. \end{cases} \tag{2}$$

Here, equation (1) is the objective function, n is the number of blank layout in the investigation, and h is the number of blank layout in the blanking, namely, the number of tool changes. Other symbols are defined as follows:

$L = [l_1, l_2, \cdots, l_n]^T$, and l_j denotes the cut length of a single coil in the j^{th} blank layout mode, $1 \leq \text{j} \leq \text{n}$, $P = [p_1, p_2, \cdots, p_n]^T$, and p_j denotes the lower limit length required for a single coil in the j^{th} blank layout mode, $1 \leq \text{j} \leq \text{n}$, $Q = [q_1, q_2, \cdots, q_n]^T, q_j$ denotes the upper limit length required for a single coil in the j^{th} blank layout mode, $1 \leq \text{j} \leq \text{n}$, $X = [x_1, x_2, \cdots, x_n]^T$, and x_j denotes the number of coil sheared by the j^{th} blank layout mode, $1 \leq j \leq n$, $U = [u_1, u_2, \cdots, u_n]^T$, and u_j denotes the upper limit number sheared by the j^{th} blank layout mode, $1 \leq j \leq n$, $B = [b_1, b_2, \cdots, b_m]^T$, and b_i denotes the total length required for the blank of the i^{th} width, $1 \leq i \leq m$

A: Among the matrix of m rows and n columns, a_{ij} denotes the number of the i^{th} blank in the j^{th} blank layout mode, $1 \leq i \leq m$, $1 \leq j \leq n$.

In equation (2), the first is the blank demand constraint, the second is the number constraint of coil sheared by blank

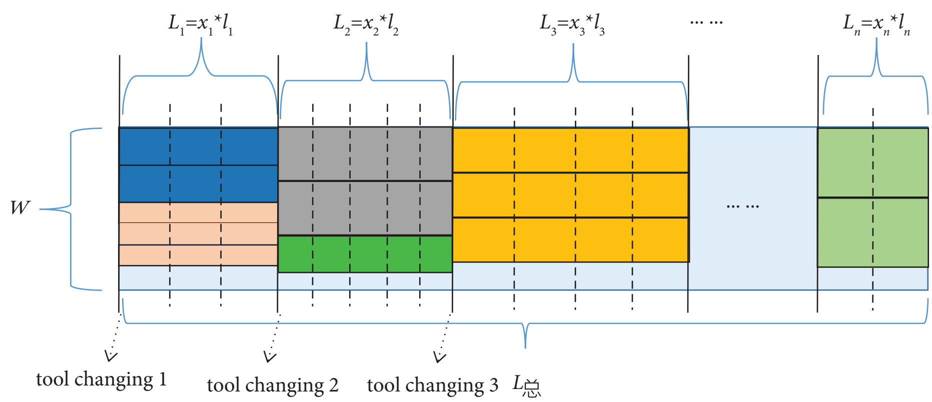

Figure 1: Blank layout diagram.

layout mode, and the third is the length constraint of a single coil sheared by blank layout mode.

3. Results

The blanking decision scheme design process is shown in Figure 2, according to the order and shear process requirements, and the blank layout mode and length range are calculated to provide the solution range for the blanking scheme. First, according to the order and shearing process requirements, the design of the scheduling method and the length range are obtained to provide a feasible solution range for the downgauging scheme. Second, the coding and decoding methods are designed according to the characteristics of the variables and the nonlinear constraints under the model are handled, then the design of the objective functions and the parameters under multiple objectives are carried out. Finally, the objective function is solved. For the solution of the objective function: the exact solution takes too long, the heuristic algorithm is not strong for the global search ability, the intelligent optimization algorithm has strong global search ability but also has "premature" and other problems. In order to solve the problem that the population of intelligent optimization algorithm converges prematurely and falls into local optimum. The authors in reference [8] adopted the adaptive particle swarm optimization algorithm (APSO) and designed an adaptive strategy for particle swarm optimization algorithm. The fitness of particles whose fitness is greater than the average fitness is summed and averaged, and the seeds whose fitness is higher than the average fitness (i.e., the seeds with premature convergence) are dynamically reduced their next generation inertia weight. The authors in reference [12] used the niche genetic algorithm based on deterministic crowding (DC) to calculate the Hamming distance between individuals in the population and compare similarities, so as to punish the worse one. The authors in reference [13] proposed the NGA algorithm, which means in the course of evolution the optimal individuals should be retained and evolve fully. Also, for the physical distribution of a population into different niche groups with their own evolution, to improve the ability of population evolution and population diversity to overcome the "premature," the algorithm has not been applied to blanking layout problem. By comparing the solutions of production examples, it is found that the NGA algorithm is more suitable for the blanking decision method than the other two algorithms in this paper.

3.1. Getting Blank Layout and Length Range. Because most of the cutting and packing (packaging) are parallel on the station, different specifications are to be packed in different boxes, to reduce the complexity of the operation, the one sheared specifications are at most two, at least one, and the end of the layout is the total width exhausted. Let the coil width W be set, the sheared blank width has m kinds of width: $M = \{w_1, w_2, \cdots, w_m\}$.

The layout method is shown in Figure 3. Figure 3(a) describes the specification with only one blank layout method, and equation (3) describes the coil number constraint of one specification, and α denotes the coil number of blank width. Figures 3(b) and 3(c) describe that the specifications have two kinds of blank layout scheme. Equation (4) describes the coil number constraint in two specifications, α denotes the coil number of the blank width w_1, and β denotes the coil number of the blank width w_2.

$$\begin{cases} 0 < \alpha w_1 \le W, \alpha \in \mathbb{N}^+, \\ W - \alpha w_1 < w_1, \alpha \in \mathbb{N}^+, \end{cases} \tag{3}$$

$$\begin{cases} 0 < \alpha w_1 + \beta w_2 \le W, \alpha, \beta \in \mathbb{N}^+, \\ W - (\alpha w_1 + \beta w_2) < \min(w_1, w_2), \alpha, \beta \in \mathbb{N}^+. \end{cases} \tag{4}$$

The length range of each blank layout method: $\mathrm{LB} = \{\mathrm{lb}_1, \mathrm{lb}_2, \cdots, \mathrm{lb}_\mathrm{n}\}$, $\mathrm{UB} = \{\mathrm{ub}_1, \mathrm{ub}_2, \cdots, \mathrm{ub}_\mathrm{n}\}$. LB stands for the lowest range, and UB stands for the highest range. The length range of the blank layout mode is the intersection length range of the two specifications:

$$u_j = \max\left(\mathrm{ceil}\left(\frac{b_1}{a_{1j} lb_j}\right), \mathrm{ceil}\left(\frac{b_2}{a_{2j} lb_j}\right)\right). \tag{5}$$

Let the j^{th} blank layout mode be sheared by the first and second type of blank, then the cutting times of the i^{th} blank layout mode u_j were calculated from equation (5). The *ceil*() function is the upward rounding function.

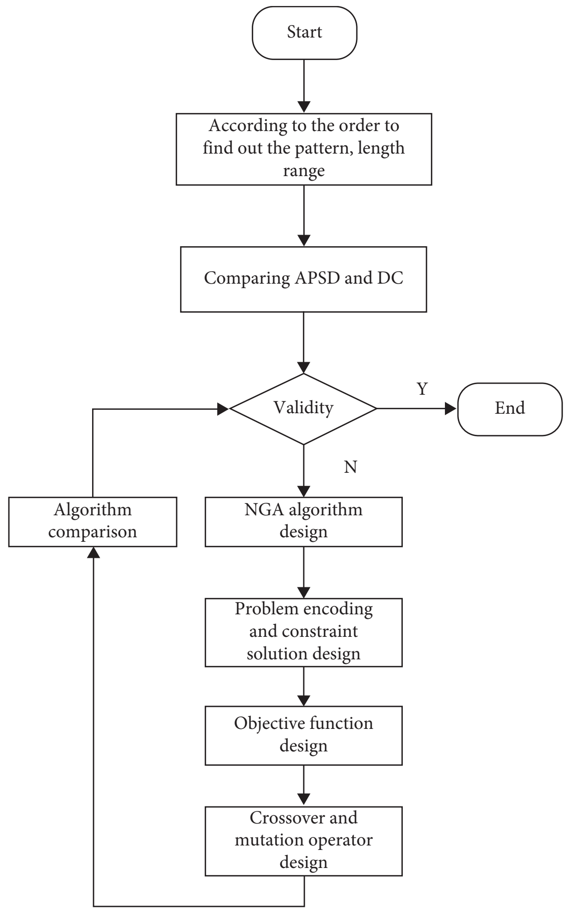

Figure 2: Blanking decision scheme design flow diagram.

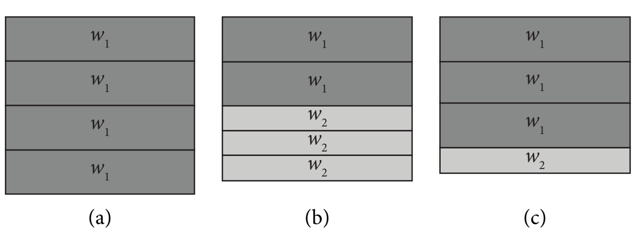

Figure 3: Blank layout method diagram.

3.2. *Niche Genetic Algorithm Design Based on Superior Seed Retention*

3.2.1. Problem Encoding. Encoding the problem is the key step to solving the problem in the niche genetic algorithm, the mathematical model described in section 2.2 has two decision variables, one is for a single coil length of each blank layout scheme, and the other is the shear number X of each blank layout scheme. There are two ways, one is L and X as a part of string genes, and the other is to take the product of L and X as a decision variable-the total length C of each blank layout. In the actual use of the first method, X must be an integer, and there will be restrictions on position and rounding in crossover and mutation, which will destroy the characteristics of genetic evolution. The second method C has no effect on a continuous variable in using crossover and mutation operator, but not all crossover and mutation seeds can satisfy the requirement of single coil length which is divided into several volumes of blank. Here using penalty function [14] to weed out them, penalty function processes the elementary function of nonlinear constraint more conveniently and flexibly.

In this paper, the decimal coding method is chosen which is based on the blank layout. The length of a chromosome is equal to the total number of blank layout n. Each chromosome represents a blank layout, where each number represents the total length sheared by the corresponding blank layout. A chromosome can be represented as $C = \{c_1, c_2, \cdots, c_n\}$, the total shear length of the j^{th} blank layout is $c_j\,(1 \le j \le n)$, so c_j should be satisfied with equations (6) and (7) at the same time.

$$0 \le c_j \le u_j \bullet ub_j, 1 \le j \le n, \tag{6}$$

$$\begin{cases} c_j = 0, \text{else}, \\ lb_j \le c_j/k \le ub_j, 1 \le j \le n, k \in \mathbb{N}^+. \end{cases} \tag{7}$$

Equation (6) describes the large feasible solution range of C, from which the initial population is randomly selected. Equation (7) describes the float constraint of a single coil length and the constraint with the integer number of the coil. If the system design does not meet the two constraints, penalty function *pf* will be generated, which will be added to the original objective function value. According to the comparison result of objective function value, seeds that do not meet the constraints will become inferior solutions and will be eliminated is the value of the penalty function which is generated by the j^{th}. F is the value of the objective function, $pf_i \gg f$.

Set the blank layout $A = \begin{bmatrix} 7 & 2 & 8 & 1 \\ 1 & 0 & 0 & 9 \\ 0 & 3 & 0 & 0 \end{bmatrix}$, $C = [\,1688 \;\; 2940 \;\; 0 \;\; 6000\,]$, $LB = [\,1685 \;\; 1467 \;\; 1467 \;\; 1490\,]$, $UB = [\,1690 \;\; 1477 \;\; 1480 \;\; 1573\,]$. The decoded single coil length of each blank layout $L = [\,1688 \;\; 1470 \;\; \forall \;\; 1500\,]$, the number of each blank layout $X = [\,1 \;\; 2 \;\; 0 \;\; 4\,]$, $\forall$ represents any number.

3.2.2. Design Objective Function (Fitness Function). The cost loss associated with the blank layout scheme during the shearing process is mainly due to the geometric waste from the shear process (the lead and the tail from tool change, nonreusable surplus material) and the machine downtime cost caused by tool change. The cost of scrap is related to the processing process of the finished coil, and the copper strip brand. The cost of different coils is different.

$$G = \rho v = \rho l w \delta = \rho s \delta, \tag{8}$$

$$l = \lambda t, \tag{9}$$

where G represents the weight, ρ represents density, and v represents volume. l is the length, w is the width, s is the area, δ is the thickness of the coil, and λ represents the rotational speed of the recoiling machine (m/min). Equation (8) describes the calculation formula of copper strip weight, and equation (9) describes the calculation formula of the length sheared by the recoiling machine.

The objective weighting method is adopted to take the number of tool changes and coil weight as weights, and the objective function for assessing the cost loss is established as follows:

$$f = \gamma_1 \rho (S_1 - S_2)\delta + \gamma_2 \rho S_3 \delta = \gamma_1 \rho \left((l_1 + h l_d) w - S_2 \right)\delta + \gamma_2 \rho (h \lambda t w)\delta + \mathrm{PF}, \tag{10}$$

where γ_1 is the cost loss pen of waste, S_1 is the total area of the consumed coil, S_3 is the total area of the finished products normally produced by the machine during tool changing time, and γ_2 is the cost in the tool changing time. Not considering the lead and tail, l_1 is the total length of the sheared coil, h is the tool change times, t is the time for every tool change, and PF is the total value for the penalty function, $\mathrm{PF} = \sum_{j=1}^{n} pf_j$.

Equation (10) describes the relationship between cost loss, waste material, and tool changing times. The parameters determined by the blank layout mode are l_1 and h, and other parameters can be modified by the requirements of the production environment via the subjective weighting method. For example, the loss caused by tool changing times can be reduced for enough time and no urgent delivery. When the coil to be sheared is in short supply and the utilization rate needs to be further improved, the cost loss of scrap can be appropriately increased.

3.2.3. Composition of Niche Algorithm. Three individuals are randomly generated $x_i (1 \le i \le 3)$, the corresponding calculation is carried out by the fitness function $f(x)$. The smallest function value $\min_{1 \le i \le 3} f_i$ is selected and putted into the initial group. In this way, the required size E of the group is generated. According to the specific problems, the size of the niche population is fixed, which determines the efficiency of genetic evolution [13]. The niches are structured as follows: first, the radius of the niche σ, the maximum capacity $S_{\max}$, and the minimum capacity $S_{\min}$ of the niche are given.

In the n-dimensional space of the solution individuals, if $X_i = [\,X_{i1} \;\; X_{i2} \;\; \cdots \;\; X_{in}\,]$, $X_j = [\,X_{j1} \;\; X_{j2} \;\; \cdots \;\; X_{jn}\,]$,

$$d_{ij} = \left\| X_i - X_j \right\| = \sqrt{\sum_{k=1}^{n} \left(x_{ik} - x_{jk} \right)^2}, \, 1 \le i \ne j \le E. \tag{11}$$

Any element x_0 is chosen as the center of the group, and the distance d between the individual and other individuals is calculated, respectively. If $d \le \sigma$ and the number of individuals j is not greater than its maximum capacity $S_{\max}$, the individual x_i is classified as the first group. If $d \le \sigma$ and the number of individuals j is less than the capacity $S_{\min}$, the optimal individuals in the population are copied until the number of the population reaches the minimum capacity $S_{\min}$. The second niche group continues until all individuals are assigned to the corresponding group.

Second, the structure of niche pairs was constructed:

For each group, the individual fitness value is calculated and sorted by the size of the individual fitness value: $\{X_{i1}, X_{i2}, \cdots, X_{i\omega}\}$ (ω: the total number of individuals in the i^{th} group). The average fitness value of the population was calculated $\overline{f_i} = \sum_{k=1}^{\omega} f_{ik}/\omega$. Structure: $\Delta_{ij} = |\overline{f_i} - \overline{f_j}|$, $\min_{0<i,j\le p} \Delta_{ij}$. The correlation between the i^{th} group and the j^{th} group is established, which forms a niche pair. Using the niche pair, the individual with the largest function value is used to replace the individual with the smallest function value in another group, and the optimal individual is retained to participate in the evolution.

3.2.4. Crossover and Mutation Operator Design. The dynamic adaptive technique is used to adjust the control parameters of genetic algorithm, so that the crossover and mutation operators can be adjusted randomly according to the actual situation of the population in the process of evolution. The method adopted is different from the scheme proposed in reference [15]. At the beginning of the population search, the specific method is to increase the crossover probability P_c and mutation probability P_m as much as possible to improve the global search ability and maintain the diversity of the population; when the population tends to converge, reducing P_c, P_m is improve the local search ability. The calculation formula is as follows:

$$P_{ic} = \begin{cases} P_{(i-1)c}/1.38, n = 10 \\ P_{(i-1)c}. \end{cases} \quad (12)$$

In other formula, n is the number of times that the same objective function value is searched continuously, and the mutation probability is the same as the calculation formula.

3.2.5. Algorithm Step

Step1. Parameter initialization: each production parameter is initialized as population size *ps*, evolution times *mg*, crossover probability P_c, mutation probability P_m, niche radius σ, niche maximum capacity $S_{\max}$, and minimum capacity $S_{\min}$. The algorithm in Section 2.1 is invoked to obtain the blank layout scheme combination A. The single coil length range *LB* and *UB* in each scheme, and the upper limit of the sheared number U;

Step 2. Use the rule of choosing one form three option to generate the initial population;

Step 3. Construct niche groups;

Step 4. Calculate the fitness value function and the average fitness value of each niche, rank each niche according to the fitness value, and construct the niche pair according to the average fitness value.

Step 5. Record and update the seed with the smallest objective function in the population, and calculate and retain the number of tool change, the coil utilization rate, and the length of used coil;

Step 6. Good operator replacement is performed for niche pairs;

Step 7. Selection, crossover, and mutation to the niche population and adjustment to crossover operator and mutation operator;

Step 8. Determine whether the termination conditions meet the convergence times and convergence rate requirements;

Step 9. If the conditions are met, the operation ends. Output the seeds of the record, otherwise continue to the iterative Steps 5–8.

4. Discussion

In order to solve the problem of tool changing times (hours of work efficiency) and yield (product benefit) in the processing with unfixed coil length, three groups of orders were randomly selected, which is solved by three intelligent algorithms to obtain the optimal solution.

The effectiveness of the blanking decision scheme was tested. The test data came from the actual production data of Hubei Lean High Precision Copper Strip and Plate Co. Ltd. The width and length requirements and the demands of each specification are shown in Tables 1 and 2. The upper limit of the length shown in Tables 1 and 2 is mainly calculated by the order requirement and the required weight range of the single roll.

The material used for blanking is *TP*2 copper strip, thickness $\delta = 0.1mm$, width $W = 410mm$, and density $\rho = 8.9\,t/m^3$. In order to facilitate the theoretical analysis of the algorithm, some parameters of the objective function give the corresponding experience value to the skilled shear workers, and financial-related statistical data as reference: cost loss parameter of coil scrap $\gamma_1 = 3000$yuan/ton, cost parameter when tool change $\gamma_2 = 6000$yuan/ton, length of lead and tail produced by each tool change $l_d = 20m$, time of each tool change $t = 30$ min, and speed of the coil $\lambda = 150m/$ min. In the actual production process, the length of the lead and tail range from 15 m to 30 m. Let us take the average length here. The time for each tool change varies from 15 min to 1 h, and it is also taken as the average tool change time here. The parameters given in the example are the actual working mode of three shifts for 24 hours in the production of the enterprise. With rolling material selection, cutting, production scheduling, and delivery order, each shift can take over the production. The waste cost loss, tool changing cost, lead, and tail length are all based on the assumptions of the actual situation in this simulation experiment. The size of this value may have a great impact on the calculation results. This paper mainly provides solutions to problems in the cutting process of copper strip, without further considering the impact of these values on the operating results. Furthermore, analysis of the data now generated can be made in the future to obtain further results.

In this paper, the simulation experiment was run on MATLAB R2017b. The modified niche algorithm (NGA) set the population size as 1000, the maximum number of iterations 100, the independent operation 5, and the radius of niche 10sum (UB)/len. The average maximum distance of a single gene was 10 times, *len* is the gene string length, the maximum capacity is 200, and the minimum capacity is 150. With the establishment of population size, the number of iterations, the number of runs, and the value of niche radius mainly considering the running time and the effect basically reflecting the optimization of the algorithm, with multiple run-in data, this study is mainly to obtain better solutions. As the data of the production management system become more and more complete and the scheduling data become more and more accurate, more accurate relevant parameters can be obtained. The three algorithms APSO, DC, and NGA are compared under the same population/particle swarm, iteration times, and objective function. The calculated blanking results are shown in Table 3. Since the running time of each algorithm is similar and has little impact on production scheduling, no comparison will be made here.

Table 1: Group 1 order.

Number	Width (mm)	Lower limit of a single coil length (m)	Upper limit of a single coil length (m)	Total demand length (m)
1	41	1685	1713	19803
2	58	1467	1573	13565
3	83	1467	1579	3384
4	100	1490	1690	21280
5	203	1618	1745	7249
6	260	1459	1628	5089

Table 2: Group 2 order.

Number	Width (mm)	Lower limit of a single coil length (m)	Upper limit of a single coil length (m)	Total demand length (m)
1	31	1498	1525	8643
2	40	1340	1534	34560
3	75	1400	1500	56180
4	145	1467	1579	5678
5	184	1490	1631	21280
6	200	1518	1645	6327
7	312	1476	1628	3345

Table 3: Blanking result.

Experiment number	Group 1			Group 2		
	APSO	DC	NGA	APSO	DC	NGA
1	66501	55679	45287	106190	82592	64675
2	45553	63886	55598	104200	64675	65679
3	54814	55246	45287	79773	88914	64675
4	54000	64864	45841	76587	85798	57415
5	54814	55536	45693	104200	76918	64675
Mean of the objective function/yuan	55136.4	59042.2	47541.2	94190	79779.4	63423.8
Mean number of tool changes	5	5.4	4.2	8.2	7.2	5.8
Mean value of coil utilization	75.66%	75.78%	74.68%	72.49%	79.91%	84.64%
Mean value of using length (m)	22057.4	21925.4	22303.6	43734.8	39569.8	37229
Mean value of working hours (h)	3.4	4.0	3.6	7.2	8.1	6.8
Mean value of running time (s)	1615	80	45	3018	112	66
Number of optional blank layout modes	21	21	21	34	34	34

Table 3 shows the comparison results with the NGA algorithm, APSO algorithm, and DC algorithm. In the first example, for the number of tool change, NGA < APSO < DC; for the length of coil used, DC < APSO < NGA; and for the value of objective function, NGA << APSO < DC. In the second example, for the number of tool change, NGA < DC < APSO; for the length of coil used, NGA < DC < APSO; and for the value of objective function, NGA << DC < APSO. Single example comparison: the tool change and cost loss of the blanking scheme sought by NGA are the least; comparison with the first and second group of examples: the gap of the search results between APSO, DC, and NGA is widened. NGA is more suitable for the situation with more blank layout methods and higher computational complexity.

Table 4 shows the optimal blanking scheme of the second group order examples calculated by the NGA algorithm. In the first group, the number of tool change is 4, the actual length of the coil is 21960 m, and the coil utilization rate is 75.55%. The number of tool change in the second group is 5, the actual length of the coil is 38940 m, and the coil utilization rate is 80.87%. It can be seen from the calculation examples that there is a large gap between the actual length of the coil material. This calculation example does not consider the number of the final order or the actual length of the material with embryo. If the problem is actually turned into a backpack problem, under the condition of a certain number of orders with a limited length of material, how the highest yield with the least number of tool changing can be achieved? Therefore, the data are settled by current staff

Table 4: Blanking scheme.

Example	Number	Cutting times	Cutting length	1 blank (with number)	2 blank (with number)
1	1	2	1685	(41, 7)	(100, 1)
	2	5	1467	(58, 2)	(260, 1)
	3	6	1618	(100, 2)	(203, 1)
	4	1	1467	(83, 4)	—
2	1	6	1504	(31, 1)	(184, 2)
	2	10	1413.2	(40, 2)	(75, 4)
	3	3	1512.6	(40, 2)	(312, 1)
	4	4	1576	(31, 1)	(184, 2)
	5	3	1614.3	(184, 1)	(200, 1)

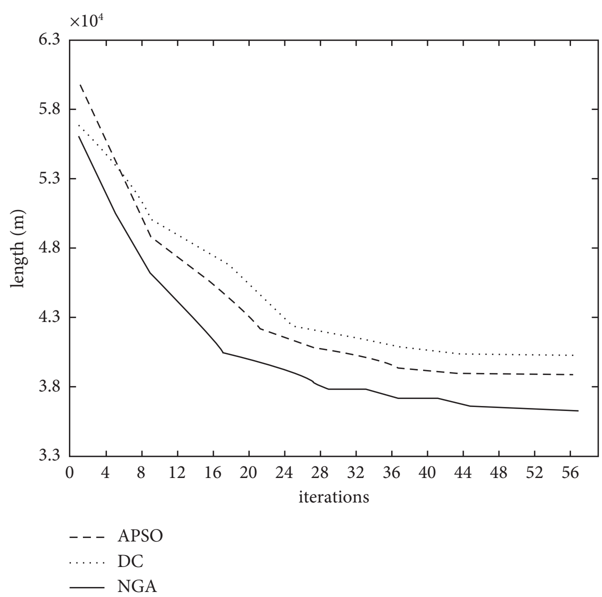

Figure 4: Convergence curves of three algorithms.

based on experience cutting further research which can be done in the future. At present, the shear embryo selection is manual selection. This optimal scheme is calculated and determined by the parameters of subjective weight given by the example. In the actual production process, different schemes can be selected according to the different evaluation requirements. The scheme selected here is only for theoretical research. The actual situation is far more complicated than the current example.

Table 4 shows the comparison results between the NGA algorithm, APSO algorithm, and DC algorithm. Compared with the single group of examples, the objective function of the scheme found by the NGA is that the total length of the coil used is the lowest, the number of tool changing and the hours of work used are less (the scheme found by the first group of the APSO algorithm takes the least hours of work with the lowest utilization rate of the coil), and the running time is the shortest. Compared with the examples in group 1 and group 2, the running time of the APSO algorithm doubles with the increase of the layout complexity, while the running time of DC and NGA algorithms increases slightly, which indicates that DC and NGA algorithms have stronger fitness for the examples with high complexity. Figure 4 describes the convergence curve after averaging the data of the 5 iterations of the 3 algorithms in the second group of orders. It can be seen from the curve that the NGA has the highest search efficiency in the early stage, and the DC algorithm is the fast one entering into convergence in the later stage, followed by the APSO algorithm, and the NGA has the slowest convergence, which indicates that the global search ability and local search ability of the NGA algorithm are stronger than those of the APSO algorithm and DC algorithm.

5. Conclusions

The delivery process of copper strip products is allowed to have errors with the order quantity (according to the specification weight delivery). The size of the error needs to be discussed with the distributor. Therefore, before delivering products, how to determine the production mode is important, which provide possible ways to improve the yield with the order quantity (weight) given to the customer. Try to avoid the need to cut again before packing or waste the cutted product. It is the focus of the whole research that plans the shear scheduling problem in advance for carrying out mathematical model and arriving at an algorithm solution. So, in this paper, we have studied the multiobjective two-dimensional shear blanking problem for the copper coil with floating lengths and developed a blanking model with the optimization objective of reducing tool changing times while increasing the overall yield. In view of the characteristics of the problem, the method of reducing discrete variables is used to optimize the coding scheme, and the penalty function is introduced to deal with the constraint of copper coil length fluctuation, and then combined with the comprehensive weight method. The objective function of evaluating the cost loss caused by the blank layout scheme is established to solve the decision problem of multiobjective blanking. The simulation experiments were conducted to compare the NGA algorithm adopted in this paper with two algorithms proposed in the references. The results have shown that the blanking scheme produced by the NGA algorithm has fewer tool changes, less cost loss, and can maintain a higher optimization ability under more complex blank layout conditions. This paper have also provided a solution with certain reference value in terms of ideas and methods to deal with coil blanking problem with multi-objective and complex constraints. In addition, considering the work mode of three shifts in 24 hours the objective function evaluation system is established, and each shift can take over production. Other production environments, such as rolling production scheduling and timing quantitative production scheduling, can be accepted as long as the impact of tool changing times on production time will not delay the delivery time. It is not necessary to maintain the least tool changing times, which can be further studied according to its objective function and the choice of blanking scheme. In the next step, we can consider selecting all the embryos or ready to be completed embryos as resources and order product specification requirements, production efficiency (hours of work), production benefit, and so on, which are considered in a unified way to further liberate enterprise productivity.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

Di He and Xuebing Li are co-first authors of this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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