Balancing of the national clothing production line based on the genetic taboo mixing algorithm

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ABSTRACT – REZUMAT

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In order to solve the problems of complicated process types, long production process arrangement time and low production efficiency of national clothing production, a national clothing production line is constructed based on a hanging assembly line. Firstly, the national clothing production line is thoroughly explored. Considering the constraints of the production line and the multi-objective optimisation, a mathematical model of balance optimisation is constructed. Secondly, the adaptive improvement of the genetic algorithm (GA) in coding and genetic operation is explored. On this basis, the tabu search algorithm is embedded into the GA framework, and the genetic tabu hybrid algorithm is proposed to realise the production balance of national clothing. MATLAB software is used to solve the problem of balancing the production line process arrangement. Finally, the Flexsim simulation software is used to simulate the actual production process to verify the intelligent arrangement results, and an application analysis is carried out with a Mongolian clothing with a national clothing characteristic manufacturing process as an example. The results show that the genetic tabu hybrid algorithm is suitable for solving the problem of process arrangement balance in the national clothing production line. The assembly line equilibrium index after intelligent automatic arrangement of the genetic tabu hybrid algorithm was 6.6, the maximum beat and the minimum beat difference Fmin was 19. The simulation model verifies that the stable operation time of each station accounts for more than 95%, and the simulation results show that the arrangement scheme is feasible.

Keywords: *national clothing, clothing production line, genetic taboo hybrid algorithm, Flexsim, simulation optimisation*

Echilibrarea liniei de producție a îmbrăcămintei cu specific național pe baza algoritmului de amestecare a tabuurilor genetice

Pentru a rezolva problemele legate de tipurile complicate de procese, timpul îndelungat de organizare a procesului de producție și eficiența scăzută a producției de îmbrăcăminte cu specific național, se construiește o linie de producție de îmbrăcăminte cu specific național bazată pe o linie de asamblare suspendată. În primul rând, linia de producție de îmbrăcăminte cu specific național este explorată în profunzime, luând în considerare constrângerile liniei de producție și optimizarea multi-obiectiv, se construiește modelul matematic de optimizare a echilibrului. În al doilea rând, este explorată îmbunătățirea adaptivă a algoritmului genetic (GA) în codare și operare genetică, pe această bază, algoritmul de căutare tabu este încorporat în cadrul GA și este propus algoritmul hibrid tabu genetic pentru a realiza echilibrul producției de îmbrăcăminte națională, utilizând software-ul MATLAB pentru a rezolva problema echilibrului aranjamentului procesului liniei de producție. În cele din urmă, software-ul de simulare Flexsim este utilizat pentru a simula procesul de producție real pentru a verifica rezultatele aranjamentului inteligent și este efectuată o analiză a aplicației cu un exemplu de îmbrăcăminte mongolă cu un proces de fabricație caracteristic îmbrăcămintei naționale. Rezultatele arată că algoritmul hibrid tabu genetic este potrivit pentru rezolvarea problemei echilibrului aranjamentului procesului în linia de producție a îmbrăcămintei cu specific național. Indicele de echilibru al liniei de asamblare după aranjarea automată inteligentă a algoritmului hibrid tabu genetic a fost de 6,6, diferența de bătăi maximă și minimă Fmin a fost de 19. Modelul de simulare verifică faptul că timpul de funcționare stabil al fiecărei stații reprezintă mai mult de 95%, iar rezultatele simulării arată că schema de aranjare este fezabilă.

Cuvinte-cheie*: îmbrăcăminte națională, linie de producție de îmbrăcăminte, algoritm hibrid tabu genetic, Flexsim, optimizare prin simulare*

INTRODUCTION

The deep integration of information technology and the manufacturing industry, promoting new industrialisation, and promoting the high-end and intelligent development of the manufacturing industry, is triggering far-reaching industrial changes. National clothing sewing has always been based on customisation. Under the direction of intelligent and efficient production, it has gradually formed a market demand situation with multiple varieties, small batches, high quality and short delivery time, which requires the production of national clothing enterprises to be more flexible and rapid. In enterprise clothing production, the most important thing is production efficiency; the production efficiency of clothing mainly depends on the balance of the process arrangement on the production line. In the research of clothing production, scholars have carried out theoretical, methodological and case application research on clothing production, but the study of clothing production mainly focuses on the clothing production lines construction based on the daily mass production of trousers, shirts and other relatively simple changes in style, it can not meet the production orders of national clothing manufacturing enterprises have the characteristics of small single quantity, changeable style and fast replacement, due to the complexity and variety of the production process of national clothing, the traditional manual arrangement method has the problems of long manual arrangement time and low arrangement efficiency, therefore, the balance problem of national clothing production line needs to be solved urgently. Thus, the objective of our research focuses on solving the problem of intelligent process arrangement balance of the national costume production line through intelligent algorithm and virtual simulation technology, improving the work efficiency of the national costume production line, adapting to the changes of production tasks and product structure, promoting the high-end, intelligent and green development of the national clothing manufacturing industry.

In this paper, the national clothing production line is constructed based on the hanging line. Firstly, the national clothing production line is deeply explored, and the mathematical model of the new national clothing production line is constructed by comprehensive consideration of the constraints of the production line and multiple optimisation objectives. Secondly, the genetic algorithm itself is designed to ensure the optimisation efficiency and the accuracy of the results. Although the genetic algorithm (GA) has invisible parallelism and global solution space search ability, it also has some problems, such as poor local search ability, premature convergence or slow convergence speed in practical applications. In this paper, in terms of gene coding and genetic operation, adaptive improvement is explored according to the characteristics of the process arrangement balance problem of the national clothing production line, so that it can be dynamically adjusted with the number of iterations to avoid premature convergence in the process. In the aspect of algorithm design, the tabu search algorithm is embedded into the GA framework, and the genetic tabu hybrid algorithm is proposed to improve the search ability of the feasible solution. The MATLAB software is used to realise the programming and operation of the algorithm, and the intelligent optimisation arrangement of the national clothing production line is realised. The arrangement results are verified by Flexsim virtual simulation technology, and a national costume is taken as an example to analyse and verify.

LITERATURE REVIEW

At present, scholars' research on the balance optimisation of garment production lines mainly adopts the application research of intelligent algorithms and virtual simulation technology. In the application research of intelligent algorithm, after giving the optimization goal of garment production line and the constraint condition of production line balance, scholars adopt [1] ranked positional weight technique [2], grouping genetic algorithm (GGA) [3], particle swarm algorithm [4, 5], improved ant colony algorithm [6], genetic algorithm [7], NSGA-II algorithm [8], quadratic-selection genetic algorithm [9] and other intelligent algorithms to build the balance optimization model of clothing production line. Through the comparison and application of different intelligent algorithms such as exhaustive search, simulated annealing and simulated annealing with greedy [10], greedy algorithm, tabu search algorithm and simulated annealing algorithm [11], the balance optimization of garment production line is studied [12], taking trousers, shirts and other daily wear as an example to solve the balance of production line process arrangement, through computer automatic process scheduling, the processing tasks are evenly distributed to each workstation [13] to achieve the purpose of improving the production efficiency of the garment assembly line and lean production[14]. In the application research of virtual simulation technology, scholars applied Em-plant [15], Arena [16], Flexsim [17], Plant Simulation [18], Anylogic [19] and other simulation software build simulation optimization models through virtual simulation technology, the simulation design of the garment production line is carried out to realize the production visualization and the re-optimization of the pipeline balance [20].

In addition, in the latest research, in the mixed production line research, Zheng [21] proposed garment intelligent production scheduling algorithm based on modularization, and the target tracking genetic algorithm was designed to set up the model, realized mixed assembly line rapid production of a variety of clothing; Sheng [22] proposed using fuzzy clustering of equivalence relation, the method of building module group of shirt processing components was achieved; Sheng [23] proposed a method for predicting module the man-hours based on BP neural network and optimizing and application of mixed-mode component module production scheduling; Tong [24] designed the non-dominate sorting genetic (NSGA-II), and applied to solve the production lines of multi-style clothing. In terms of flexible job scheduling, Liu [25] proposed a dynamic scheduling method for the garment sewing process based on deep reinforcement learning to realise real-time response to order dynamic problems; Ju [26] proposed a method of using machine learning to predict the clothing production line staff efficiency, which can provide a reference for the future national clothing production process arrangement.

MATHEMATICAL MODELLING OF A NATIONAL CLOTHING PRODUCTION LINE

The key to the production efficiency of the clothing production line lies in the processing load balance of each workstation in the clothing production line. As far as possible, to achieve the production synchronisation and production equalisation of each workstation in the assembly line, to ensure the continuity of production, and to improve the production efficiency of clothing.

Problem posing

In the process of working procedure arrangement, it is necessary to determine the operators of each process, that is, the operation process arranged by each workstation, and there are 2 situations in which each process works on the workstation: a certain process works on the workstation or does not work on the workstation. The decision variable in the model is “whether a process is working in a workstation”, and the purpose is to obtain the process scheduling scheme of the production line balance. The goal of assembly line balance in the garment production process mainly includes: (i) given the production line beat, minimise the number of workstations; (ii) given the number of workstations, minimise the production line beat; (iii) given the minimum number of workstations and the average beat, the workload of each workstation is balanced. In order to balance the load of each workstation, each process should be evenly distributed to each workstation as far as possible, so that the beat of each workstation tends to be synchronised. After the process arrangement is determined, the appropriate workers can be selected according to the actual situation.

Model decision variables

Assume that a certain garment has a total of I processes (divided into minimum processes), and the process number is recorded as i, then i = 1, 2,..., I. The number of clothing workstations is set to J (one workstation represents one operator), which is arranged according to the order of garment processing and transmission in the production line, and the numbers are j = 1, 2,..., J respectively. X_{ij} indicates that the j-th workstation processes the i-th process; if “processing”, X_{ij} takes the value of 1, and if “not processing”, X_{ij} is 0. The definition of decision variables is shown in formula 1. Based on the value of X_{ij} in the obtained optimal solution, the membership relationship between process i and station j can be clarified, and the job scheduling scheme can be obtained.

$$X_{ij} = \begin{cases} 1, \ i \text{ works in } J \text{ place} \\ 0, \text{ opposite} \end{cases} \begin{pmatrix} i = 1,2,\ldots,I \\ j = 1,2,\ldots,J \end{pmatrix} \quad (1)$$

Constraint condition

The order batch of clothing products, the working time and processing equipment of each process and the production process flow are known. In the assembly line scheduling, it is necessary to consider or meet certain constraints, so that the final optimisation scheme is a balance of various factors. The following is a detailed description.

(1) Considering that the production workers’ operation proficiency and process quality requirements, classifying the non-separable process, and no longer splitting it, indicates that the process i is completed at a workstation.

(2) Considering the operation sequence of the process on the assembly line, setting the constraints of the preceding process, assuming that there are m tight preceding processes in the i-th process, which are denoted as $i_1, i_2, \ldots, i_m$, respectively, if there is no tight preceding process, then m is 0. It indicates that the preceding process of process i cannot be operated on the workstation behind process i, as shown in formula 2.

$$m = \begin{cases} i_1, i_2, \ldots, i_m, & i\text{-th preceding processes} \\ 0, & \text{no preceding processes} \end{cases} \quad (2)$$

(3) Considering the increase in floating time caused by changing equipment in the production process, a workstation is configured with up to 2 kinds of equipment, in which manual operation can be combined with any equipment.

(4) Supposing that the processing time of the i-th process is t_i, and the total operation time of the j-th workstation is T_j, see formula 3. SPT [5] refers to the theoretical average beat of the production line, the time it takes to produce a garment on a production line, see formula 4.

$$T_j = \textstyle\sum_{i=1}^{I} t_i \, X_{ij}, \ \ j = 1,2,\ldots,J \quad (3)$$

$$\text{SPT} = \frac{\sum_{i=1}^{I} t_i}{J}, \ \ j = 1,2,\ldots,J \quad (4)$$

The working time of each workstation is set within the beat limit [LPT, UPT] (LPT=2SPT–UPT, UPT=SPT/η) [27], where η is the arrangement efficiency, which indicates the coefficient of the degree of process balance. The closer η is to 1, the better the degree of production line synchronisation. In this paper, the arrangement efficiency (η) is set to 90%, and the arrangement efficiency formula 5.

$$\eta = \frac{\text{SPT}}{\text{SPT}_{max}} \times 100\% \quad (5)$$

For the process that the beat is too large or too small, multiple processes can be combined in a workstation, or the process can be split, and it is assigned to 2~3 workstations to work together, so that the working time of each workstation is within the beat limit.

Objective function

The equilibrium index SI and workstation maximum beat and minimum beat difference F_{min} are set as the objective function of the production line. The model solves the minimum value of SI and the minimum value of Fmin, see formulas 6 and 7.

$$SI = \frac{1}{J} \sqrt{\textstyle\sum_{j=1}^{J} (T_j - \text{SPT})^2} \quad (6)$$

$$F_{min} = \text{SPT}_{max} - \text{SPT}_{min} \quad (7)$$

PRODUCTION LINE BALANCE GENETIC TABU HYBRID ALGORITHM DESIGN

In this paper, the genetic tabu hybrid optimisation algorithm is used to establish a mathematical model

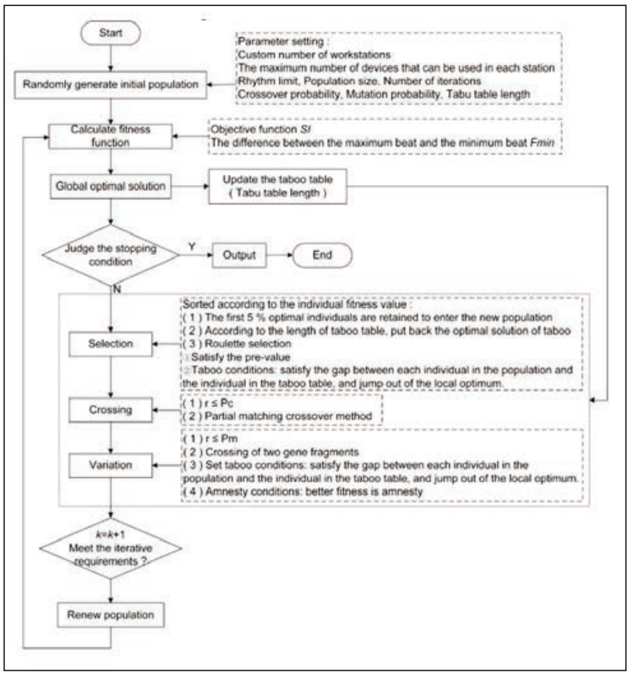

Fig. 1. Genetic tabu hybrid algorithm program flow chart

to intelligently optimise the national clothing production line. Because the genetic algorithm has strong global search ability through selection, crossover and mutation genetic operations, it is used as the main part of the algorithm, and the tabu search algorithm has strong local search ability through the tabu table and the amnesty criterion, which is used as an auxiliary algorithm. The flow chart of the genetic tabu hybrid algorithm is shown in figure 1. Finally, the MATLAB software is used to program and calculate the algorithm.

Step 1: Coding. In this paper, we select the real number coding method based on the process priority sequence.

Step 2: Formation the initial group and decoding. In this paper, the initial population is generated randomly, so that the initial population is evenly distributed throughout the solution space as much as possible, and a given number of individuals is selected to form the initial population *P* (*k*), *k* = 0.

(1) According to the process operation sequence, calculate the branch of the process table according to the previous process of the production process.

(2) According to the constraint conditions, the value range of the theoretical average beat SPT and the beat limit is calculated.

(3) Gene segments were generated according to the average beat SPT and job priority order, that is, the process sequences, and the *I* processes are assigned to *J* workstations in order, where the processing time of each workstation is $T_1, T_2, \ldots, T_J$.

(4) If the processing time of the *J*-th workstation is less than the beat lower limit LPT, the (*i*+1)-th process is added to this workstation, and then it is judged whether the processing time of the *J*-th workstation is within the beat limit [LPT, UPT] after adding the (*i*+1)-th process.

(4.1) If the (*i*+1)-th process is added and the processing time of the *J*-th workstation is within the beat limit [LPT, UPT], the (*i*+1)-th process is assigned to the *J*-th workstation.

(4.2) If the (*i*+1)-th procedure is added, and the processing time of the *J*-th workstation is less than the beat lower limit LPT, the (*i*+2)-th procedure is assigned to the *J*-th workstation until the constraint is satisfied.

(5) If the processing time of the *J*-th workstation is greater than the rhythm upper limit UPT, the process on this workplace is assigned to the (*J*+1)-th workstation, and then it is judged whether the processing time meets the beat limit [LPT, UPT] range, and then go back to Step (3).

(6) Repeat the above allocation process until all processes in the chromosome are allocated.

Step 3: Evaluation of adaptation degree. The fitness function is the objective function. According to the fitness function, the adaptation degree of each individual in the current generation is calculated, and sorted in order of fitness values from smallest to largest, the smaller the better. The first individual after sorting is the optimal individual of the current generation.

Step 4: Update the global optimal solution. Find the optimal solution in the non-taboo neighbourhood, compare the optimal individual of the current generation with the global optimal solution, and update the global optimal solution.

Step 5: Determine whether to meet the termination condition. If satisfied, the output results; otherwise, turn to step 7.

Step 6: Update the taboo list. Update the optimal individual of the current generation to the taboo table.

Step 7: Selecting operation. Using the roulette wheel selection method to select chromosomes, the selection probability of the individual can be expressed as shown in formula 8, where *i* represents the individual, f_i represents the fitness value, and *POP* represents the population size.

$$p_i = \frac{f_i}{\sum_{i=1}^{pop} f_i} \tag{8}$$

Step 8: Crossover operation. For each individual, if the random number $r \le P_c$ (P_c is the crossover probability), the chromosome is crossed. For the balance problem of the sewing production line, the crossover operation adopts a partially matched crossover method. The partially matched crossover method ensures that the genes of each chromosome appear only once, avoiding gene duplication. The schematic diagram of crossover operation is shown in figure 2.

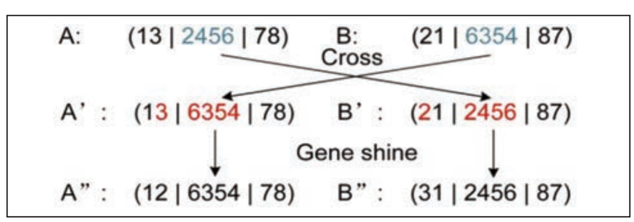

Fig. 2. Crossover operation diagram

A” : (12 | 6354 | 78)

↓ Change process position

A* : (12 | 4356 | 78)

Fig. 3. Mutation operation diagram

Step 9: Variation operation. The mutation operation is based on the new individual obtained by the crossover operation. For each individual, if the random number $r \leq P_m$ (P_m is the mutation probability), the chromosome is mutated; otherwise, consider the next chromosome. The mutation operation diagram is shown in figure 3.

Step 10: Update the population, go to step 3, and perform a round of iterations on the population $P(k)$. This time, the maximum number of iterations is used as the stopping condition.

EXAMPLE ANALYSIS OF PRODUCTION LINE BALANCE

Data preparation

In this paper, Mongolian clothing is used as an example to verify, and the clothing production data collected by field research is used as the original experimental data. The national clothing style is the Mongolian basic clothing, and the style diagram is shown in figure 4.

The national costume consists of 58 processes, of which the 58th process is the most time-consuming, 3945*s*, the 28th process is the most time-saving, 25*s*,

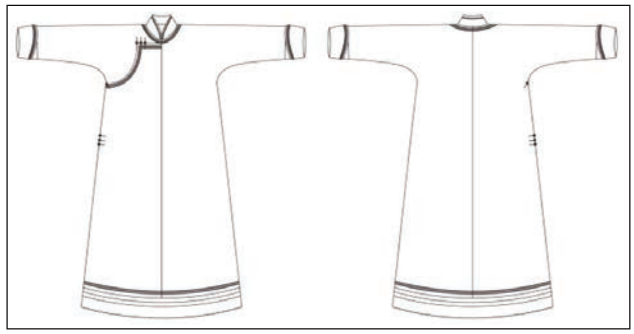

Fig. 4. Mongolian clothing style drawing

and the standard total processing time is 10807*s*. The national costume process flow chart is shown in figure 5.

It can be seen from figure 5 that the production sequence of each processing procedure of the national costume.

Application of a multi-objective national clothing production line balance algorithm

Assuming that the target daily output *Q* of the national clothing production line is 20 pieces per day, and the working time *T* is 8 hours per day, the theoretical average beat of the production line is calculated as follows:

$$SPT(t) = T/Q = 8 \times 60 \times 60/20 = 1440s \qquad (9)$$

The total processing time *T’* of the national costume is 10807*s*, and the minimum number of workstations is as follows:

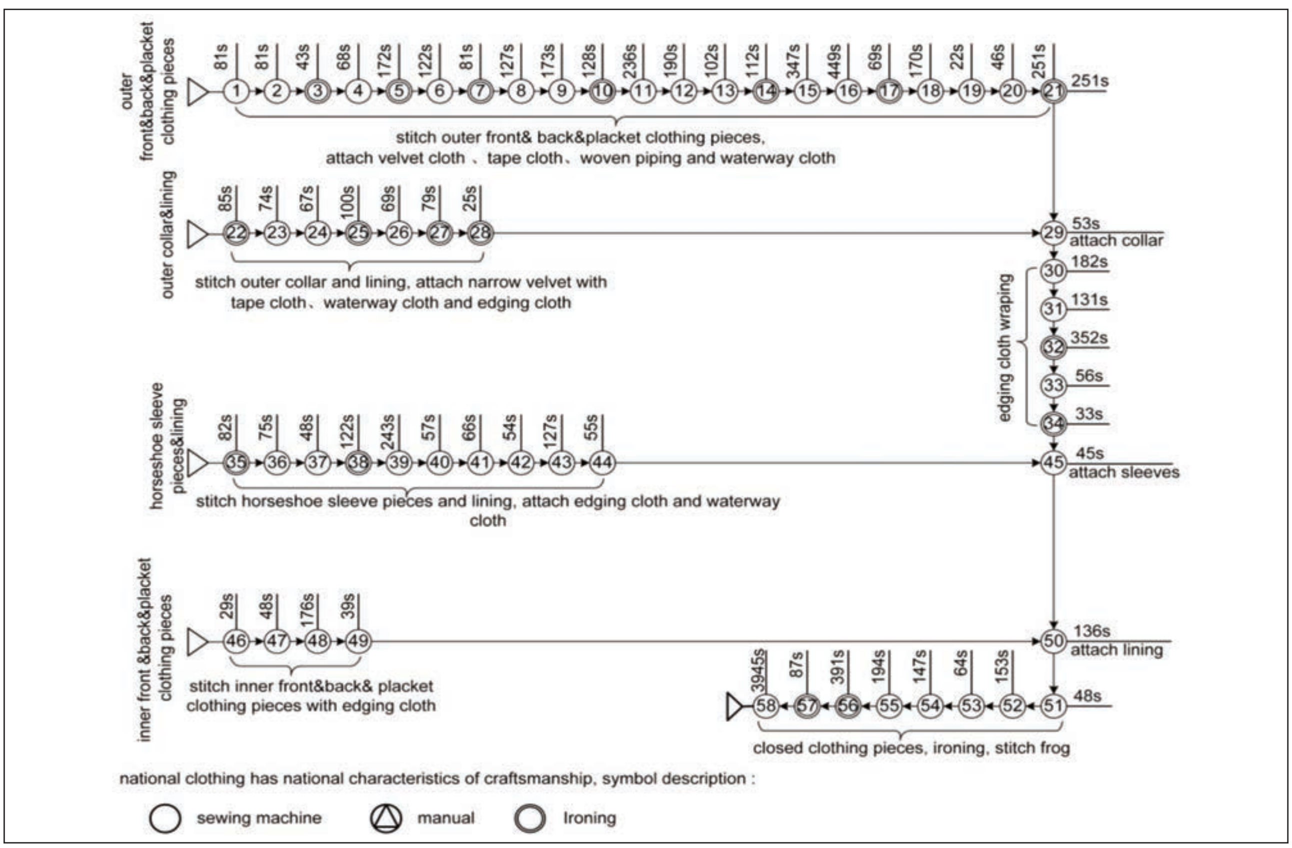

Fig. 5. The national costume process flow chart

$$W_{min} = T'/\mathrm{SPT}(t) + 1 = 10807/1440 + 1 = 8 \quad (10)$$

when the number of stations is 8, the average beat SPT can be obtained from formula 4, which is 1350*s*, the process arrangement efficiency η is 90%, and the rhythm boundary is:

$$\mathrm{UPT} = \mathrm{SPT}/90\% = 1500s$$

$$\mathrm{LPT} = 2\mathrm{SPT} - \mathrm{UPT} = 1200s$$

In this national clothing process arrangement operation parameters, the user-defined station numbers are set to 8, the population size is 100, the iteration times are 500, the crossover probability P_c is 0.9, the mutation probability P_m is 0.9, the tabu table length is 20, and the algorithm termination condition is that the number of iterations reaches the set value 500 times. Finally, the process arrangement scheme of the national clothing production line is output. The process arrangement result of the genetic tabu hybrid algorithm is shown in table 1.

Table 1

PIPELINING OF GENETIC TABU HYBRID ALGORITHM			
Station	**Process number**	**Beat (s)**	**Job nature**
1	1-8, 35-39	1345	P, T
2	9-14, 22-23, 46-48	1353	P, T
3	15-21	1354	P, T
4	24-34, 40-42, 49	1363	P, T
5	43-45, 50-56	1360	P, T
6	57, 58	1344	S, T
7	57, 58	1344	S, T
8	57, 58	1344	S, T
Total	-	10807	-

Result analysis

By analysing the different algorithms used by scholars to arrange the process of garment production line, it can be seen that ranked positional weight technique [2] took trousers as an example, when the constraints weren't considered, it had better production balance efficiency, the smoothness index was 5.71, when the constraints were considered, the production efficiency was low, which confirmed the invalidity of the ranked positional weight technique for the balance of complex production lines. The particle swarm algorithm [4] took trousers as an example; the equilibrium index was 16.5, and the compilation efficiency was 96.1%. The improved ant colony algorithm [6] took a shirt as an example, and focuses on the two factors of work-in-process transfer time and transfer path; the compilation efficiency was improved to 88.96% compared with the manual compilation efficiency. Exhaustive search, simulated annealing algorithm and simulated annealing algorithm with greed [10] took a polo-shirt production as an example, computational results affirmed that the simulated annealing algorithm performed well in terms of accuracy and running time, the balance efficiency was between 60% – 80%.

In this paper, combined with the actual production constraints of the factory, the constraints and objective functions are set, and the balance problem of the national clothing production line is solved by the genetic tabu hybrid algorithm. According to the output results of the genetic tabu hybrid algorithm program, combined with table 1, it can be seen that the operation time of each station is within the beat boundary (1200, 1500). The equilibrium index *SI* can be obtained from formula 6 is 6.6, and the compilation efficiency η can be obtained from formula 5 is 98%, and the maximum beat and minimum beat difference F_{min} can be obtained from formula 7 is 19, which meets the requirement that the compilation efficiency η is greater than 85% and can be put into production [21]. However, in order to predict the actual production situation of the national clothing production line in advance and predict the possible problems in the actual production, this paper uses Flexsim simulation software to further simulate the production.

VIRTUAL SIMULATION

Simulation modeling

Flexsim garment production line simulation mainly includes model layout, model logic and parameter setting. Flexsim software structure modelling is shown in figure 6. Parameter setting needs to set the parameters such as station production time, transmission quantity, processing quantity, transmission time, preheating time, running time and arrival time interval.

Example verification

Supposing the number of orders is 100, the daily working time is 8 h, and the number of production line transfers is set to 10, the number of processing is set to constant 1, the transfer time is set to 0, and the preheating time is set to 10807s according to the processing time of a garment, it shows that the time of taking clothes is included in the working hours. Analysing the production factors, such as the operation status of each station and the daily production of orders.

According to the data in table 1, the model layout is set according to the actual station layout of the production line, and the direction of the transportation system is the transfer path of the work-in-process. The processing time of each station is mainly to set the processing time of the processor and run the garment production line model. The simulation results show that (figures 7 and 8 are the comparison diagrams of the optimal solution of the genetic tabu hybrid algorithm and the optimal solution of the genetic algorithm):

(1) The comparison of the operation and idle status of each station in the genetic tabu hybrid algorithm is shown in figure 7. The stable operation time of each station accounts for more than 95%, and there is no bottleneck station. The highest operating time accounted for 99.90%, and the lowest operating time accounted for 98.60%.

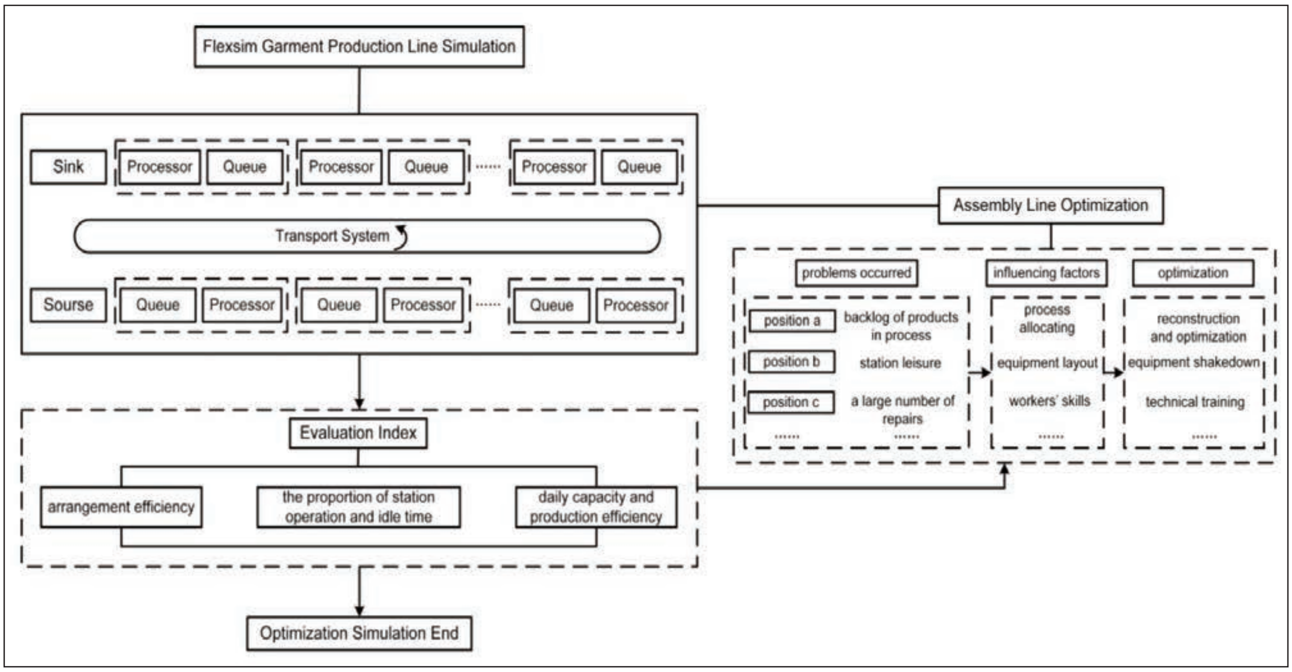

Fig. 6. Design diagram of clothing production simulation optimisation based on Flexsim software

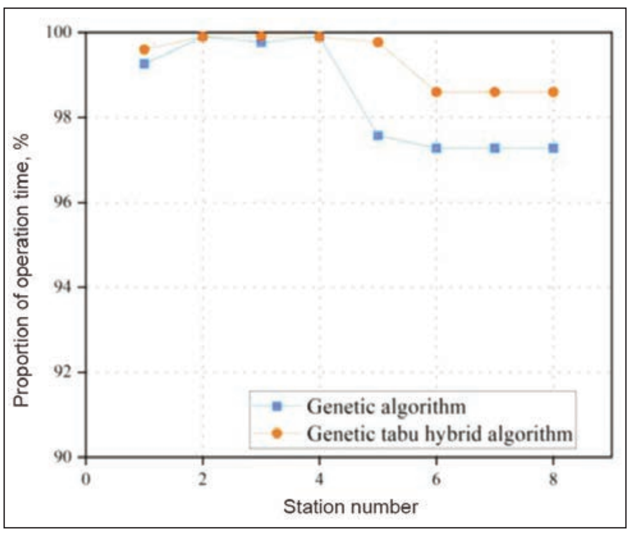

Fig. 7. Operation status table

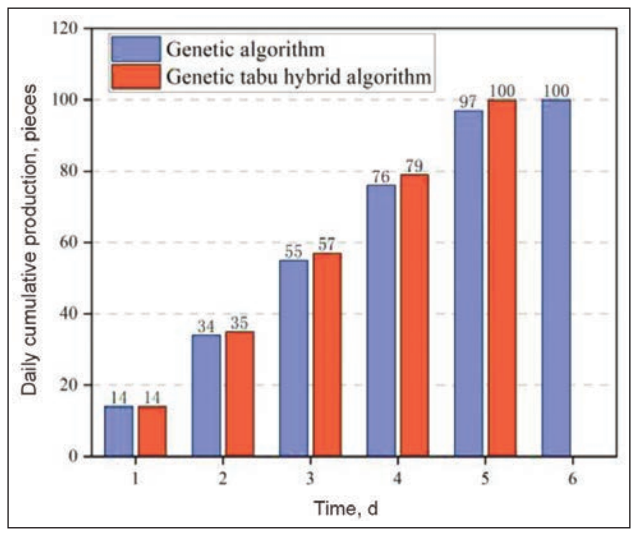

Fig. 8. Daily cumulation production table

(2) The cumulative production per order day of the genetic tabu hybrid algorithm is shown in figure 8, which takes 5 days to complete the order.

In summary, the simulation model of the national costume production line can observe the operation of the production line intuitively and clearly, and verify the feasibility of the production line arrangement scheme and the effectiveness of the algorithm.

RESULTS AND DISCUSSION

In this paper, aiming at the process arrangement problem of the national clothing production line, the intelligent arrangement of the national clothing production line is carried out by an intelligent algorithm and virtual simulation technology. Compared with the traditional manual arrangement method, the process arrangement speed is improved, and the compilation efficiency is high. The Flexsim software verifies the arrangement results in advance, which provides a theoretical reference for the promotion of intelligent manufacturing of national clothing.

In this paper, the genetic tabu hybrid algorithm is used to solve the balance problem of the national clothing production line. Theoretical calculation is carried out by evaluation index, the equilibrium index *SI* is 6.6, and the maximum beat and minimum beat difference F_{min} is 19. The computer is used instead of the manual to optimise the balance of the production line, which improves the speed of the process arrangement and efficiency. It meets the production orders of national clothing manufacturing enterprises with the characteristics of complex process, small single volume, changeable style and fast change.

In this paper, Flexsim software is used to simulate the operation of the production line of the intelligent scheduling scheme of the genetic tabu hybrid algorithm. It is assumed that the batch is 100 pieces, the daily working time is 8 hours, and the order needs 5 days to complete. This scheduling scheme has no bottleneck station, and the stable operation time of each station accounts for more than 95%. The feasibility of the production line scheduling scheme and the effectiveness of the algorithm are verified, which provides a reference for enterprises to arrange production.

CONCLUSION AND FUTURE RECOMMENDATIONS

In this paper, the national clothing production line is constructed based on the hanging assembly line. The national clothing production line is deeply explored, and the mathematical model of the new national clothing production line is constructed by considering the production line constraints and multi-optimisation objectives. The multi-objective genetic tabu hybrid algorithm is designed to minimise the equilibrium index and minimise the difference between the maximum beat and the minimum beat. The model is not only suitable for national clothing production, but also for other clothing production. It has good compatibility and meets the requirements of lean production. In the future:

- This mathematical model and virtual simulation technology are applied to mixed-style modular production layout optimisation. Combined with automatic equipment such as a template machine, production gestures are optimised to further improve the efficiency of multi-variety and small-batch production of national clothing.
- The production information management system (such as the MES system) and the hanging assembly line are connected. Through the production information management system, the production rhythm and rhythm trend map of each station in the production process are monitored in real time, and the production factors such as process, personnel, equipment, material transmission path and time on the hanging assembly line are timely and comprehensively guided to optimise the production. Through the digital twin, the virtual production line is constructed, and the real-time simulation optimisation strategy is deployed, so as to improve the national clothing production efficiency.
- At present, the process scheduling of garment production has shifted from traditional large-scale production to a flexible, dynamic scheduling mode driven by lean and digitisation. In the future, it is necessary for national clothing to further integrate intelligent technologies, such as recurrent neural network models, deep reinforcement learning, etc, combined with green technology, to achieve green production with energy saving and efficiency improvement.

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