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# Balance Study of Clothing Single-piece Production Line Based on Dual-population Genetic Algorithm ⋆

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**Abstract**

Currently, line production is the mainstream production method for various clothing enterprises. Therefore, optimising and improving the production line plays a crucial role in promoting the development of manufacturing enterprises. To solve the problems of unbalanced operation time and low production line balance rate of each workstation of the garment sewing production line, a multi-objective optimisation mathematical model with the minimum smoothing index and the largest production line balance rate was established, and the dual-population genetic algorithm was designed in the MATLAB environment. The jeans (front piece) were used as an example to be simulated and verified in simulation software. Achieve load balancing at workstations, save production costs, and eliminate overproduction between jobs. The research results show that the smoothness index of the optimised production line has been reduced from 20.89 to 8.43, and the production line balance rate has been increased from 77.57% to 89.06%, which meets the requirements of enterprise process planning and can deliver on time. This verifies that the model proposed in this paper can effectively solve the production balance problem of a single clothing production line.

*Keywords*: Dual-population genetic algorithm; Balance optimisation; Garment sewing line; Simfactory software

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# 1 Introduction

In the fierce market competition environment, garment enterprises need to continuously reduce costs, shorten production cycles and improve production efficiency while ensuring quality to improve market competitiveness. One of the most important aspects is the issue of line balancing, which can lead to chaos in the production line cycle time. For a long time, the design and balance control of the production line in the garment production process have largely relied on the personal experience of the production technicians. However, the results of line orchestration using this empirical knowledge are often suboptimal, and it is difficult to ensure that each workstation can achieve the same production speed to achieve a true balance. There are often multiple optimisation goals in garment production. Staffing results based on the personal experience of production technicians often make it difficult to meet the actual needs of production. The development of intelligent algorithms can effectively solve this problem, but at present, the research on the balance of production lines is mainly concentrated in the manufacturing fields, such as machinery and electronics, and there are few studies on the balance of clothing sewing production lines. As a good approximation algorithm for global search, the two-population genetic algorithm has been successfully applied to solve the production line balance problem, and the approximate optimal solution can be reached faster.

Some scholars have used genetic algorithm [1, 2] and ant colony algorithm [3] to optimise the balance of the production line, which have been verified in Flexsim; Song Y [4-6] used Flexsim software to simulate the single-piece assembly line of T-shirts and silk cheongsams, and greatly improved the balance rate of the assembly line through the optimal combination of processes; Sun Y [7-8] established a simulation model of women's cotton clothing assembly line that is in good agreement with actual production. The simulation model of men's jacket assembly line was established and optimized, and the optimization of assembly line preparation efficiency and production efficiency were improved; Zhang Q [9] combined with the specific situation of bra sewing line management, applied genetic algorithm to optimize the process arrangement and equipment position, established the corresponding optimization model, and used MATLAB to implement it, and used virtual sewing line simulation software to test the feasibility and optimization effect of the established optimization model; Chen JC [10] proposed a grouping genetic algorithm for sewing threads of different labor skill levels in the garment industry, and evaluated the performance of the grouping genetic algorithm through the actual data and experimental design of garment factories; Bongomin O [11] using the method of position weight, taking a type of women's pants as the research object, by establishing two kinds of production lines with and without equipment constraints, the production balance rate was verified and concluded that the position weight method was more suitable for the assembly line setting with a small number of equipment and the same, and the application of virtual simulation technology to improve the production balance rate of the assembly line was put forward; Samattapapong N [12] used Flexsim virtual simulation technology to optimise the virtual simulation of a warehouse logistics production line, identified the bottlenecks of the production line after the simulation run, and verified the feasibility of Flexsim virtual simulation software in improving the efficiency of the production line through round-robin testing. Feasibility: Fattahi P and Zaman T [13, 14] performed equilibrium optimisation of the assembly line through intelligent algorithms; El-hawary IA [15] simulated the production line to produce multiple models simultaneously to find the maximum number of products that could be manufactured in the product mix with high quality and without wasting time; Xu YN [16] used the established model to simulate the T-shirt production line, explored the relationship between various balance indicators and the relationship between these indicators and production efficiency, analysed the accuracy, applicability and interchangeability of each balance index in the evaluation of production efficiency, and proposed a balance index that can be used to evaluate the assembly line preparation scheme.

However, the above-mentioned research usually only optimises the combination of the processes of the assembly line and verifies the optimisation effect of the assembly line through virtual simulation or optimises the algorithm for a certain goal and verifies the optimised production line in actual production and lacks the evaluation and analysis of the performance indicators in production. Based on the theory of dual-population genetic algorithm, this paper comprehensively considers the production characteristics such as process constraints and multiple optimisation objectives, explores the balance problem of clothing single-piece production line, completes the construction of single-piece production line balance optimisation model and the design of multi-objective optimisation algorithm to meet constraints, and uses Matlab software technology to verify the feasibility with examples, so that the intelligent optimisation algorithm can be further popularised and used in the field of garment manufacturing.

# 2 Method

## 2.1 Construction of the Balance Model of the Sewing Production Line

In this paper, the equilibrium model of the clothing single-piece assembly line is constructed from several aspects, such as model assumptions, parameter variable settings, constraints, and target functions. The goal is to optimise the allocation of equipment and personnel on the production line, improve the production equipment's utilisation rate, and reduce workers' idle time on the production line.

### 2.1.1 Model Assumptions and Parameter Variable Setting

Basic assumptions:

(1) The total production volume of clothing products, the operation time of each process and the processing sequence of the products are known;

(2) The type and quantity of equipment used in each process to meet the production needs are known;

(3) One worker is a station, and some equipment can only process unique work content;

(4) The work content that can be processed on the station comprises one or can also include two or more than two, and the set used by all the work contents operated by a worker is the station;

(5) When solving the two-population genetic algorithm, other constraints, such as the handling time of semi-finished products, are not considered for the time being.

(6) The operation level and proficiency of the worker to each operation process are roughly the same, and each worker can skillfully complete any process;

(7) The process cannot be split.

#### 2.1.2 Objective Functions

The production line balance rate is usually used to measure the quality of the balance state of the production process. It is generally expressed by the quantitative value of the percentage. The production line balance rate is generally expressed by P, and the higher the line balance rate, the higher the balance degree of the production line. The smoothness index (SI) is an index used to measure the degree of deviation between the time of each workstation and the beat of the production line. To improve the efficiency of the production line and reduce the idle time of workers on the production line, the production line equilibrium rate P and the equilibrium index SI are used as the objective function values, and the objective function values are expressed by F. $T_i$ represents the sum of the operation time of each process of workstation I, max $(T_i)$ represents the production cycle, and m represents the number of workstations. CT represents the cycle time of the production line, $T_i$ represents the sum of the working time of each process of workstation I, and m represents the number of workstations. The calculation is as follows.

$$\mathrm{P} = \frac{\sum_{i=1}^{m} T_i}{m \times \max(T_i)} \times 100\% \tag{1}$$

$$\mathrm{SI} = \frac{1}{m}\sqrt{\sum_{i=1}^{m}(\mathrm{CT} - T_i)^2} \tag{2}$$

$$\mathrm{F} = \min(W_1 \times \frac{1}{p} + W_2 \times \mathrm{SI}) \tag{3}$$

The jeans (front piece) production line is more urgent in improving the equilibrium index of the production line, so it is decided to take $W_1 = 0.2$ and $W_2 = 0.8$ in combination with the actual situation of the production line.

#### 2.1.3 Constraints

By understanding the above variables, the constraints for constructing the line balance model are as follows.

(1) The operation time of each working place does not exceed the production line beat, that is, $T_i \leqslant \mathrm{CT}$ formula: $T_i$ is the set of process operation time in the $i$ working place; CT is the theoretical cycle time of the production line.

(2) Each workplace's process should meet the process's priority relationship.

### 2.2 Dual-population Genetic Algorithm

Although the traditional genetic algorithm is simple and fast, it is easy to face some problems, such as non-standard coding and inaccurate coding representation. A single genetic algorithm coding cannot fully represent the constraints of the optimisation problem. Genetic algorithms are generally less efficient than other traditional optimisation methods; Genetic algorithms are prone to premature convergence, the most prominent of which is the problem of local optimal solution and limited search space. On the other hand, the two-population genetic algorithm expands the search space based on the traditional genetic algorithm, jumps out of the local optimal solution, and can operate in more than one population, which solves the problem of the local optimal solution and the limited search space of the traditional genetic algorithm. The flow of the two-population genetic algorithm is shown in Fig. 1.

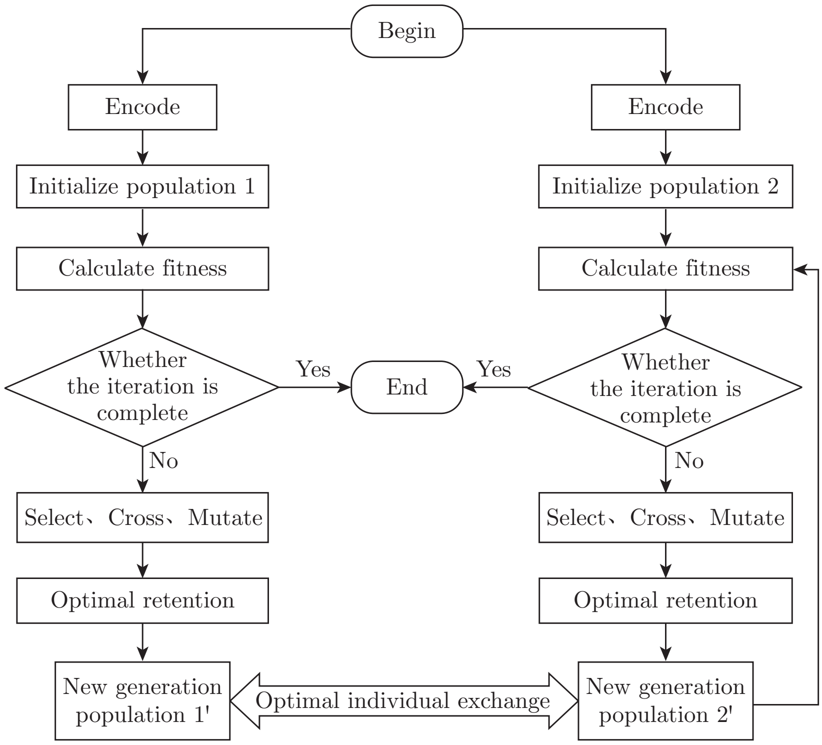


Fig. 1: Flow chart of the genetic algorithm of the two-population population

The specific steps are as follows:

(1) An initial population of m chromosomes (processes) is generated using real number coding;

(2) Calculate the fitness value of each chromosome in the initial population according to the objective function;

(3) Choose the method of roulette to choose chromosomes. The probability of each individual entering the next generation is equal to the proportion of its fitness value and the fitness value of the individual in the whole population. The higher the fitness value, the greater the probability of being selected, and the greater the probability of entering the next generation;

(4) Crossover and mutation of chromosomes. Crossover operation uses a two-point crossover method that is suitable for real encoding. Two intersections are randomly set in the coding strings of two individuals paired with each other, and part of the chromosomes between the two intersections are exchanged to obtain a new individual. The single-point mutation method is used for mutation operation. The chromosome fragments before the mutation points are directly copied to the offspring. A feasible chromosome fragment is regenerated using the population initialisation method after the mutation points to form a new individual.

(5) Repeat steps (2) $\sim$ (4) until the evolution is stopped when the termination condition is met.

# 3 Results

## 3.1 Data of the Production Line of the Front Sheet of Jeans

The data for the production line is sourced from Large-scale clothing production enterprises. This article conducts an example analysis of jeans (front panel) [17]. And the single-piece production line of jeans is arranged by the dual-population genetic algorithm, and the process and standard time are shown in Table 1. Table 2 shows the production line scheduling scheme of the optimised front workshop. A station can assign multiple processes. As seen from Table 1, there are 16 processes in the production process of this style of jeans (front piece). According to the nature of the operation, the operation time, the use of equipment, and the relationship between the priority of each process in the table, the total standard processing time T can be calculated as 453 s.

Suppose the total number of jeans (front pieces) ordered is 2 500 pieces, the actual number of materials is 2 624, and the production will be completed in 10 days. The effective working time is 8 h per day.

Table 1: Standard timetable for jeans sewing process (front piece) [17]

| Process number | Process name | Operation time (s) | Immediate predecessor activity |
|---|---|---|---|
| 1 | Shrunken pants-front panel (2 pieces) | 30 | 0 |
| 2 | Three-wire lock front crotch, under fly, top fly, pocket opening | 31 | 1 |
| 3 | Shrink bag lining | 30 | 0 |
| 4 | Stitch watch pocket ribbon | 8 | 3 |
| 5 | Attach the watch bag to the bag lining, stitching the ribbon | 35 | 4 |
| 6 | Attach the pocket to the garment | 23 | 5 |
| 7 | Stitching front bag bottom | 23 | 6 |
| 8 | Make a front curved pocket opening | 33 | 2, 7 |
| 9 | Stitching front pocket opening | 31 | 8 |
| 10 | Single needle stitching front pocket opening (middle single thread) | 33 | 9 |
| 11 | Sealing the front pocket edge | 31 | 10 |
| 12 | Stitching the end of the underfly | 15 | 0 |
| 13 | Attach the zipper to the placket | 18 | 12 |
| 14 | Attach placket on the left front body | 28 | 13, 11 |
| 15 | Double-stitched front placket | 28 | 14 |
| 16 | Stitching under the fly and front crotch hidden line and front crotch | 56 | 15 |

Table 2: Production line scheduling scheme before optimisation [17]

| The station code | Processing operations | Operation time (s) |
|---|---|---|
| a | 1, 2 | 61 |
| b | 3, 4, 5 | 73 |
| c | 6, 7 | 46 |
| d | 8, 9 | 64 |
| e | 10, 11 | 64 |
| f | 12, 13, 14 | 61 |
| g | 15 | 28 |
| h | 16 | 56 |

## 3.2 Parameter Setting of Dual-population Genetic Algorithm

Set the number of initial populations 1 and 2 to 200 in the program. The crossover probability of initial population 1 was $PC_1 = 0.8$, and the mutation probability $PM_1 = 0.1$, while the crossover probability of initial population 2 was $PC_2 = 0.6$, the mutation probability $PM_2 = 0.05$, and the number of iterations was 200.

The number of workstations selected is 6, 7, 8 and 9, respectively, to simulate and optimise the jeans (front piece) production line. The results of the program operation are obtained, and the production line arrangement scheme of different stations is obtained according to the operation results after optimisation. As shown in Table 3.

Table 3: Production line scheduling scheme with different numbers of workstations after optimisation

| Station code | The number of stations is 6 | | The number of stations is 7 | | The number of stations is 8 | | The number of stations is 9 | |
|---|---|---|---|---|---|---|---|---|
| | Processing operations | Operation time (s) | Processing operations | Operation time (s) | Processing operations | Operation time (s) | Processing operations | Operation time (s) |
| a | 1, 3, 12 | 75 | 3, 4, 5 | 73 | 1, 3 | 60 | 1, 3 | 60 |
| b | 2, 4, 5 | 74 | 6, 12, 1 | 68 | 2, 4, 12 | 54 | 4, 5 | 43 |
| c | 6, 7, 8 | 79 | 2, 13, 7 | 72 | 5, 6 | 58 | 2, 6 | 54 |
| d | 9, 10 | 64 | 8, 9 | 64 | 7, 8 | 56 | 7, 8 | 56 |
| e | 11, 13, 14 | 77 | 10, 11 | 64 | 9, 10 | 64 | 9, 12 | 46 |
| f | 15, 16 | 84 | 14, 15 | 56 | 11, 13 | 49 | 10 | 33 |
| g | – | – | 16 | 56 | 14, 15 | 56 | 11, 13 | 49 |
| h | – | – | – | – | 16 | 56 | 14, 15 | 56 |
| i | – | – | – | – | – | – | 16 | 56 |

### 3.3 Verification of Algorithm Effectiveness

In this paper, a garment sewing production simulation system is constructed in the Simfactory software environment, and the average utilisation rate of workers, average efficiency, wage cost, equipment utilisation, and completion days are collected and analysed. The feasibility of the output scheme and the effectiveness of the double-population genetic algorithm was verified by simulating the production line arrangement scheme with different station numbers output by the program. In Simfactory, the width is set to 15%, and the worker's proficiency in completing each process is 0.85. Table 5 shows the simulation results of pipelines with different workplace layouts.

## 4 Discussion

Table 2 and Table 4 show that the production line's balance rate before optimisation was 77.57%, and the smoothness index was 20.89, indicating a very low preparation efficiency. Under the goal of minimising the smoothness index and maximising the production line balance rate, the balance rate of the production line with 6 workstations is 90.47%, and the smoothness index is 10.44. The balance rate of the production line with 7 workstations is 89.04%, and the smoothness index is 9.69; The balance rate of the production line with 8 workstations is 89.06%, and the smoothness index is 8.43; The production line with 9 workstations has a balance rate of 85% and a smoothness index of 12.56. The production line balance rate of the optimised production line layout scheme has significantly increased, the smoothness index has significantly decreased, and the optimisation effect is significant. The production line with 8 workstations has the minimum objective function value, the optimal solution under the optimisation objective.

Table 4: Optimized line balancing results for different workstation counts

| Serial number | Number of stations | Cycle time (s) | Production line balance rate (%) | Equilibrium index | Objective function value |
|---|---|---|---|---|---|
| 1 | 6 | 76 | 90.47 | 10.44 | 8.53 |
| 2 | 7 | 65 | 89.04 | 9.69 | 7.93 |
| 3 | 8 | 57 | 89.06 | 8.43 | 6.92 |
| 4 | 9 | 51 | 85 | 12.56 | 10.21 |

As can be seen from Table 5, when the number of workstations is 6, the production line balance rate is the highest, and the wage cost is the lowest, but the delivery time is 9 days; 9 workstations have the shortest lead time and the highest average equipment utilisation, but the highest wage costs. Enterprises can choose the solution with the shortest delivery time, the plan with the lowest wage cost, or the plan with the highest production line balance rate according to the situation. The errors between the production line balance rate value in the simulation results and the line balance rate value in the program operation results are 0.94 percentage points, 2.85 percentage points, 0.08 percentage points and 1.51 percentage points, respectively. Relatively consistent. The error may be due to a worker proficiency level that is not 1 and a wide amplifier is added to the simulation.

Table 5: Simulation results of different workstations of the production line after optimisation

| Number of workstations | Average worker use (%) | Average efficiency (%) | Wage cost (RMB) | Average equipment use (%) | Equipment usage cost | Days to completion | Production line balance rate (%) |
|---|---|---|---|---|---|---|---|
| 6 | 88.11 | 88.14 | 13253.98 | 43.59 | 365.66 | 9 | 91.41 |
| 7 | 79.86 | 77.53 | 13293.17 | 46.39 | 343.75 | 9 | 86.19 |
| 8 | 84.36 | 84.12 | 13422.69 | 47.81 | 323.11 | 8 | 88.98 |
| 9 | 78.68 | 76.65 | 13449.65 | 50.37 | 306.72 | 7 | 83.49 |

Among the methods used in production line balance optimisation, mathematical model methods such as integer programming are more suitable for solving small-scale problems [18]. The simulation method is too computational and difficult to find and solve when solving the problem of complex model construction. Intelligent algorithms, such as genetic algorithms, have certain advantages in solving complex multi-objective problems and obtaining global optimal solutions. However, the single-population genetic algorithm's convergence speed is too fast, leading to the premature end of convergence and falling into the local optimum [19]. However, the improved genetic algorithm based on double population expands the search range, which is a good solution for solving the problem of falling into the local optimum. The evaluation and analysis of the production performance indicators will help enterprises choose the appropriate production line arrangement plan.

# 5 Conclusion

(1) The balance rate of the production line before optimisation was 77.57%, and the smoothing index was 20.89. The optimised production line's balance rate with 8 workstations is 89.06%, the smoothing index is 8.43, and the minimum objective function value is 6.92, which is the optimal scheme under the optimisation target.

(2) This paper completes the multi-objective optimization of production line balance rate maximization and equilibrium index minimisation. It verifies the production line orchestration scheme output by comparing the production line balance rate obtained by simulation with the program output. It also provides a number of evaluation indicators for enterprises to choose according to their needs.

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