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Research on Production Scheduling Optimization of Prefabricated Components Based on Genetic Algorithm

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Abstract: The production of prefabricated components constitutes a crucial step in construction industrialization, where the scientificity and rationality of production scheduling can significantly influence project costs and progress. However, the prefabricated component manufacturing process commonly faces challenges including complex procedures, multiple resource constraints, extended cycles, and high costs. Furthermore, traditional scheduling approaches have become inadequate in meeting current demands for efficient and flexible production scheduling. This study aims to enhance prefabricated component production scheduling efficiency and reduce costs through innovative methodologies. After a careful study of the production process and its characteristics of prefabricated components, a mathematical model was successfully built to adapt to them. It is found that the optimization method based on genetic algorithm can significantly improve the production scheduling scheme of prefabricated components. Compared with conventional approaches, the proposed method effectively reduces production costs while shortening manufacturing cycles, thereby addressing the adaptability deficiencies of traditional scheduling methods in complex production environments.

Keywords: Prefabricated Components, Production Scheduling, Genetic Algorithm, Building Industry, Job Sequencing.

1. Introduction

At present, only some enterprises can be based on project demand, combined with their own production capacity and resources to develop prefabricated components production plan, most enterprises plan to develop a lack of precision and flexibility, changes in market demand, cost control and other situations to cope with insufficient. In the coordination of personnel, equipment, raw materials and other resources, most small and medium-sized enterprises have limited ability to coordinate resources, when the precast component production demand is large, often idle personnel or equipment utilization rate is low and other problems, these problems are in the absence of a set of appropriate management programs and staffing programs. In the field of model solving algorithms, heuristic algorithms such as Genetic Algorithm [1, 2], Non-dominated Sorting Genetic Algorithm III algorithm [3], and Simulated Annealing [4] have been used very frequently, which can help the production scheduling to optimize multiple objectives successfully and make the solving process more efficient.

Before 2000, the assembly building method was in the early stage of development, and the problems related to prefabricated component production scheduling had not attracted enough attention from researchers, who published only two papers between 1954 and 1998.Between 2000 and 2017, prefabricated component production scheduling gradually aroused the interest of researchers with the further popularization of the assembly building method, but the average annual number of publications was less than two, indicating that the prefabricated component production scheduling is a very important part of the development of prefabricated building methods. number was less than two, indicating that prefabricated component production scheduling research developed more slowly during this period. After 2018, prefabricated component production scheduling research developed strongly, with an average annual number of ten published literatures between 2018 and 2022 [5].

After analyzing the market, the research decided to use genetic algorithm to try to overcome these challenges. Genetic algorithm belongs to the intelligent optimization algorithm, which operates on the mechanism of natural selection and genetic variation, has outstanding global search instincts, and the convergence is quite good. Wang Dong [6], Wang Zhongyuan [7], Yao Gang [8] and so on want to improve the utilization of the die table by their own way, and a breakthrough has been made under their research. The code was written by genetic algorithm to continuously optimize the order of the workpieces on the die table, and gradually find out the order with the smallest total optimization time. In this thesis, the researchers used genetic algorithms to optimize the production process of prefabricated components, which greatly improved the ability of personnel to control the production progress and resource conditions in real time, and then implement reasonable scheduling arrangements.

2. Precast Production Scheduling

2.1. Current Status of Domestic Research

Many scholars have conducted in-depth research on the specific problems involved in prefabricated components production scheduling. Among them, some scholars take the emergency order insertion, which is easy to cause order perturbation, as an example, and build a two-layer scheduling optimization architecture covering job scheduling and production line selection to optimize the production scheduling with the help of genetic algorithms. PodolskiM and RejmentM et al. [9] focus on the theory of hybrid flow shop, and finally construct a prefabricated component production scheduling model. Li et al. [10] construct a prefabricated component production scheduling model by examining the actual situation of resource constraints within the prefabricated component production process.

In the research process of prefabricated components production scheduling, Yang et al [11] took the scheduling problem faced by a single production line as the entry point, dug deeper, extended outward, and successfully created a flow shop scheduling model adapted to the scenario of multiple prefabricated production lines. The model focuses on the complex scheduling situation when multiple production lines work together, breaks through the limitations of a single line, and provides a new solution to the problem of efficient deployment of multiple production lines in parallel operation in the industry, effectively filling the previous gap in the field of multi-line scheduling and fine management. The model takes the dynamic changes of prefabricated component types in the production process into consideration, and accurately captures their influence on the scheduling strategy. Story and other scholars [12] have successfully solved a series of representative workshop scheduling problems by using a comprehensive strategy that integrates mixed integer programming, pure integer programming, dynamic programming, and branch bounding, providing a powerful methodological support for the practice in this field. Giffler et al [13] systematically sorted out the cutting-edge theories and practices, and analyzed the technical paths and strategy orientations of production scheduling. In order to cope with the scheduling problem of replacement pipeline, Huang et al [14] constructed an improved parallel ant colony algorithm based on the principle of ant system, and designed a new heuristic information updating mechanism by combining with the characteristics of the pipeline problem.

In general, at present, the country has been involved in algorithm optimization, information management and multi-objective scheduling. Part of the research focuses on the development of prefabricated components production management information system, BIM, Internet of Things and other technologies are integrated with each other, focusing on the synergistic optimization of production efficiency, cost, quality and other objectives, building multi-objective optimization model, using the weighting method, particle swarm algorithm and other means of solving the problem, so as to formulate production scheduling solutions for the enterprise taking into account the benefits of various aspects, and to achieve the integration of the production process information and visual management, so that the production scheduling of the production of the production of the production line. Visualization management, so that production schedulers can control the production progress and resource conditions in real time, and then implement reasonable scheduling arrangements.

2.2. Production Scheduling Analysis

Table 1. Comparison of flow-through and stationary types

Comparison Program	flowing	stationary
Investment Comparison	high	Low
labor demand	Low	high
Level of labour force specialization	high	Low
production efficiency	high	Low
Feasibility of shaped components	difficult	applicable

As can be seen from Table 1, compared with the stationary production mode, the flow-through production mode has lower labor demand, higher labor specialization, and higher production efficiency. Therefore, the study chooses the production scheduling of prefabricated components in the flow-through production scenario. The production process of prefabricated components includes: firstly, formwork assembly to build a basic framework for subsequent processes; then, reinforcement bar tying to strengthen the internal support structure of the components; then, concrete pouring to give the main form of the components; after the completion of the pouring, steam curing to promote the concrete to reach the desired strength; after the completion of the curing, the mold dismantling is required to make the components to be completely separated from the molds; and finally, repairing and finishing of the precast components to ensure that their appearance is good. Finally, the prefabricated components are repaired and organized to ensure that their appearance and quality meet the standards and meet the requirements for use [15]. These steps are carried out sequentially until the completion of the entire production process, the specific process shown in Figure 1. Among them, steam curing can process prefabricated components on multiple mold tables at the same time, therefore, when writing the code, special attention is paid to the concurrent sequence of the fourth process.

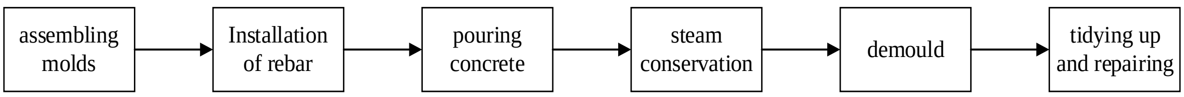

Figure 1. Prefabricated component production flow chart

As can be seen from

Figure 1 Figure 1, flow production means that there are n workpieces waiting to be processed, and these workpieces are to be processed sequentially in process 1, process 2, and up to process m. The following conditions are to be observed during the production process. In the production process, the following conditions need to be observed:

(1) Any workpiece in each machine will only run once, will not repeat the situation of running.

(2) With the exception of the steam conditioning process, each machine has the capacity to process only one workpiece at the same instant, and cannot take care of more than one.

(3) Any one workpiece will only be processed on one machine at an exact point in time, and will not be distributed among multiple machines at the same time.

(4) Once the workpiece begins to process, the process is coherent and can not be interrupted, preempted to ensure the orderly processing.

(5) The workpiece in the machine spent on the operating time with certainty, not because of the scheduling order of the change in the length of time fluctuations, to ensure the stability of the production schedule.

(6) The order in which the machines are used is fixed [16].

Within a specific framework of constraints, by virtue of scientific and rational planning of the workpiece processing sequence, accurately determine the start time of the workpiece in each process can be opened for processing, as well as the end of the end of the processing time, so as to promote the total processing time as much as possible to minimize [17]. In this study, the article takes into account the constraints on the number of prefabricated component molds, and at the same time, considers the number of limitations on the steam maintenance process. On this basis, a mathematical model is constructed and a genetic algorithm is used to optimize production scheduling.

3. Genetic Algorithm and Mathematical Model

3.1. Genetic Algorithm

Genetic Algorithm (GA) is an algorithm created on the basis of Mendel's laws of heredity and Darwin's theory of survival of the fittest. It follows the evolutionary approach of nature and aims to search and find the optimal solution. It includes steps such as initializing the population, fitness assessment, selection and replication sessions, crossover step implementation, mutation action, population update, and termination condition verification. Initialization population is the random generation of a set of chromosomes constituting the original population during the initialization phase of the algorithm, where the number of chromosomes defines the size or magnitude of the population [18]. The quality of the chromosomes is optimized with the help of genetic operations such as selection, crossover, mutation, etc., which leads to the optimal solution of the problem [19]. Following the steps of genetic algorithm, the study incorporates it into the code.

3.2. Mathematical Modeling

Let one ordering of all artifacts be $\pi = (\sigma 1, \sigma 2, \sigma 3, ..., \sigma n)$, And if only one workpiece can be processed on a machine and only the corresponding process can be processed (e.g., machine 6 can only process process 6), the mathematical description is as follows (not taking into account the preparation time).

$$\pi^* = \arg\min\{f(\pi) = T_{\sigma n,m}\} \quad (2.1)$$

$$T_{\sigma 1,1} = t_{\sigma 1,1} \quad (2.2)$$

$$T_{\sigma j,1} = T_{\sigma j-1,1} + t_{\sigma j,1}, \; j = 2,...,n \quad (2.3)$$

$$T_{\sigma 1,i} = T_{\sigma 1,i-1} + t_{\sigma 1,i}, i = 2,...,m \quad (2.4)$$

$$T_{\sigma j,i} = \max\{T_{\sigma j-1,i}, T_{\sigma j,i-1}\} + t_{\sigma j,i}, \; j = 2,...,n; i = 2,...,m \quad (2.5)$$

$\arg\min\{\}$: The value of the independent variable when the expression reaches its maximum.

π : Workpiece Sorting;

j : Workpiece number;

i : Process number (machine number);

$T_{\sigma n,m}$: Finishing time of the m process of the n workpiece

$T_{\sigma j,i}$: Finishing time of the i process of the j workpiece

Equation (2.1) is the objective function who represents the π^* value taken when the expression $f(\pi)=T_{\sigma n,m}$ takes the minimum value. it is to find the sorting order of the artifacts in the prefabricated component production process when the minimum value of the maximum completion time occurs (the completion time is optimal as the number of iterations increases).

Equations (2.1-2.5) represent the constraints. Equation (2.2) indicates that the moment of final completion of the first workpiece on the first machine is equivalent to its actual machining duration on that machine; and then look at Equation (2.3), which indicates the point in time when a process is completely finished on the first machine, which needs to be obtained by adding the moment of the end of the previous process with the current workpiece's machining duration on this machine. And in equation (2.4), the time at which the i segment of workpiece 1 is fully processed on the corresponding machine needs to be obtained by adding the node of its completion on the previous machine as well as the length of processing time required for the current process.

Equation (2-5) indicates: the end time of the i process of the j workpiece, to take into account the completion time of the i process of the previous workpiece and the completion node of the $i-1$ process of the j workpiece, and take the maximum value;

Example: As shown below, there are two templates, 1 and 2, whose processes 1 and 2 are done on machines $M1$ and $M2$, respectively, as shown in Figure 2:

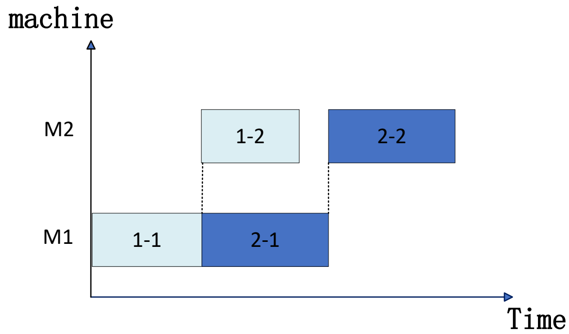

Figure 2. Schematic diagram of the work

In this figure, a color represents a workpiece. The figure presents the relationship between the completion times of the prefabricated workpieces in the formula, with 1-1 representing the first process of the first workpiece (or the first workpiece being machined on machine 1) and 2-1 representing the first process of the second workpiece. The completion time of the second process of the first workpiece (1-2) is equal to the sum of the processing time of the first process of the first workpiece (1-1) and the processing time of the second process of the first workpiece (1-2). And the completion time of 2-2 is equal to the maximum of the completion time of 1-2 and the completion time of 2-1 plus the processing time of 2-2.

4. Genetic Algorithm Design and Implementation

4.1. Encoding and Decoding

In prefabricated component processing, the process-based coding is used to organize the prefabricated component production process in a specific order to form a chromosomal coding string. In the decoding process, the encoding details are used to generate an executable dynamic scheduling strategy based on the required processing time and end time constraints of each process [20]. It should be noted that in genetic algorithms, a compliant chromosome actually symbolizes a solution that can be implemented, and in this paper, the coding means based on prefabricated components, the chromosome is presented in the prefabricated components production scheduling, the sequential numbering of the workpiece processing. In view of the role of coding in constructing the link between genotype and phenotype mapping, in the coding stage, we usually choose the production sequence of prefabricated parts production to code for it, as shown in Figure 3.

2	4	7	8	5	3	9	6	10	1

Figure 3. Schematic diagram of the encoding

This means that in the prefabricated components of the production process sequencing, the initial priority is the production of prefabricated components numbered 2, followed by arrangements for the production of prefabricated components numbered 4, and then in accordance with the established order, in order to promote the number of prefabricated components numbered 7, 8, 5, 3, 9, 6, 10 into the production process until the last turn to the production of prefabricated components numbered 1, so as to complete the round of the complete sequence of the arrangement of the production process.

4.2. Fitness Function

The fitness function is constructed based on our objective function for the production scheduling requirements when prefabricating components, and since our objective is the minimum value of the maximum completion time, we design the fitness function as: $F = 1/f(\pi)$

Where, F denotes the fitness value and $f(\pi)$ represents the completion time of each scenario of production scheduling.

4.3. Genetic Manipulation

Selection operation: A number of individuals are randomly selected from a population to compete and select the best adapted individuals to enter the next generation of the population to ensure the inheritance of the best individuals.

Crossover operation: The two-point crossover method is chosen to replace part of the paternal chromosome with a new crossover segment.

Mutation operation: Swap mutation method is chosen to randomly swap the position of two genes to increase the diversity of the population.

The following is the specific process:

(1) Randomly select two chromosomes as the parent and write the code with the help of MATLABR2016a software. And use the *randperm* function to generate two parent individuals. As shown in Figure 4.

Parent 1	9	8	4	5	6	7	1	3	2	10
Parent 2	8	7	1	2	3	9	5	4	6	10

Figure 4. Two parent individuals

(2) The selection operation usually selects the better individual based on the fitness function, here we assume that parent 1 and parent 2 are retained directly by the selection operation without elimination, generating the selection offspring. As shown in Figure 5.

Select Descendant 1	9	8	4	5	6	7	1	3	2	10
Select Descendant 2	8	7	1	2	3	9	5	4	6	10

Figure 5. Two select offspring

(3) The two-point crossover method was used to generate random numbers using randi function. If the numbers 3 and 7 are generated, it means that the numbers in the middle of position 3 to position 7, i.e., the numbers in positions 4-6, are crossovers, based on which two children are generated. As shown in Figure 6.

9	8	4	2	3	9	1	3	2	10
8	7	1	5	6	7	5	4	6	10

Figure 6. Two cross children to be modified

(4) and construct cross-segment mapping relationships, as shown in Figure 7.

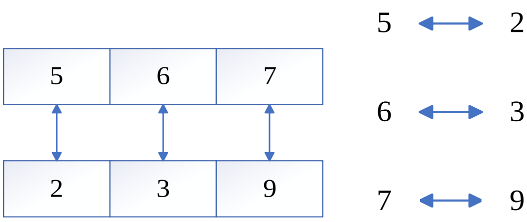

Figure 7. Mapping of intersecting segments

(5) Obviously, the elements in the non-crossing segment conflict with the elements in the crossing segment, which is corrected using the partial match crossing PMX method (replace the element in the non-crossing segment that conflicts with the crossing segment with the one that is mapped by that element in the crossing segment, e.g., 9 in the non-crossing segment of Crossing Subgeneration 1 conflicts with 9 in the crossing segment and 9 in the crossing segment maps to an element in Crossing Subgeneration 2 as 7. Therefore, replace 9 in the non-crossing segment with 7. and so on.) The two crossover children are constructed. As shown in Figure 8.

Cross child 1	7	8	4	2	3	9	1	6	5	10
Cross child 2	8	9	1	5	6	7	2	4	3	10

Figure 8. Two crossover children

(6) Mutation process: generate random numbers by *randi* function.

Perform mutation on crossover child 1: Assuming that the generated results are 3 and 7, find the element on position 3 as 4, and the element on position 7 as 1. Swap the elements to generate mutation child 1.

Perform a variation on cross child 2: Assuming the generation results are 2 and 8, find the result on position 2 as 9 and the result on position 8 as 4. Swap the elements to generate variant child 2. As shown in Figure 9.

Variant offspring 1	7	8	1	2	3	9	4	6	5	10
Variant offspring 2	8	4	1	5	6	7	2	9	3	10

Figure 9. Two variant offspring

4.4. Partial Adoption of Means to Prevent Local Optimization

Dynamically adjusting the mutation probability: during the operation of the algorithm, if a more optimal solution is not found for many consecutive generations, the mutation probability will be increased appropriately. When a more optimal solution is found, the mutation probability will be lowered so that the algorithm can focus more on the current search area.

Tournament selection: First, determine the parameter: fitness. Use a *randi* function to randomly select individuals from the population to participate in the "tournament" and compare their fitness. Using a for loop, the individual with the best fitness in each loop is selected as the parent of the next generation.

Improve crossover, keep the elite: use a for loop to let the parents of each generation perform crossover operation, and then use the if function to determine whether the new child is an elite child. Then put the optimal individual of each generation to the last position of the child generation to prevent the optimal individual from being lost because of the crossover operation.

5. Case Analysis

The real production data of a precast manufacturer is used as a case study for in-depth investigation. This enterprise is engaged in the production of a variety of prefabricated components, equipped with a number of production lines, its production process is complicated, and it needs to cope with a number of orders with different delivery deadlines. The company's production-related parameters and order details are substituted into the constructed mathematical model and genetic algorithm to solve the problem. After a number of iterations, the genetic algorithm successfully produced an optimized production scheduling solution.

In this case, the number of steam curing kilns is determined as 6. The study constructed a genetic algorithm computational model based on the MATLAB simulation experimental platform, and realized the iterative optimization process of the algorithm through programming. The algorithm parameters are configured as follows: the population size is 200, the total number of evolutionary iterations is 1000, the gene crossover rate is 0.7, and the chromosome variation rate is 0.05. The processing time of each process is shown in Table 2 Processing time for each process. which will be used as an important input parameter for the calculation of the objective function. After 1000 iterations to solve the process is completed, the result is obtained as 45 hours.

Table 2. Processing time for each process

number	assembling molds/h	reinforcement installation/h	pouring concrete/h	steam conservation/h	demould/h	tidying up and repairing/h
1	1.8	1.9	2.3	13	2.3	0.5
2	1.7	1.8	2.5	13	2.4	0.4
3	2.0	2.4	2.6	13	2.7	0.5
4	1.9	2.2	3.0	13	3.0	0.5
5	2.6	2.7	2.8	13	3.1	0.4
6	2.3	2.8	2.9	13	3.0	0.5
7	1.4	1.6	2.1	13	1.8	0.5
8	1.7	1.7	2.0	13	1.9	0.5
9	1.5	1.3	1.9	13	1.8	0.4
10	1.4	1.6	1.1	13	1.7	0.5
11	1.2	1.7	1.0	13	1.6	0.5
12	1.1	1.5	0.9	13	1.4	0.5

Substitute the data into the code to get the final completion time of 45 hours. As shown in Figure 10 and Figure 11.

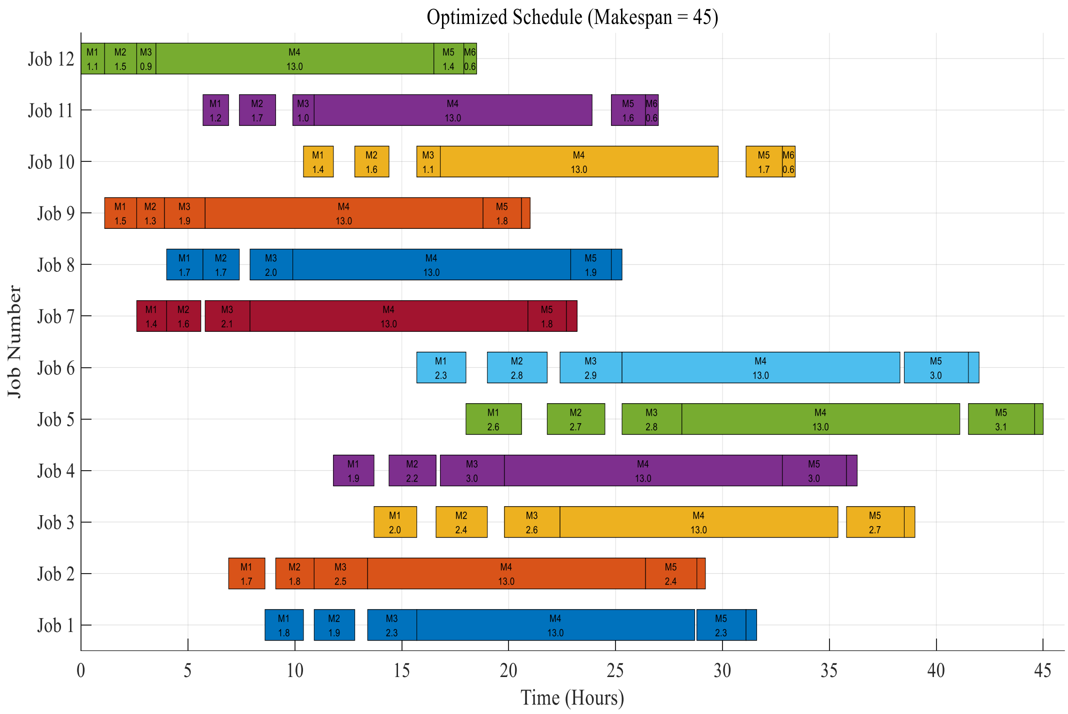

Figure 10. Gantt chart for production scheduling

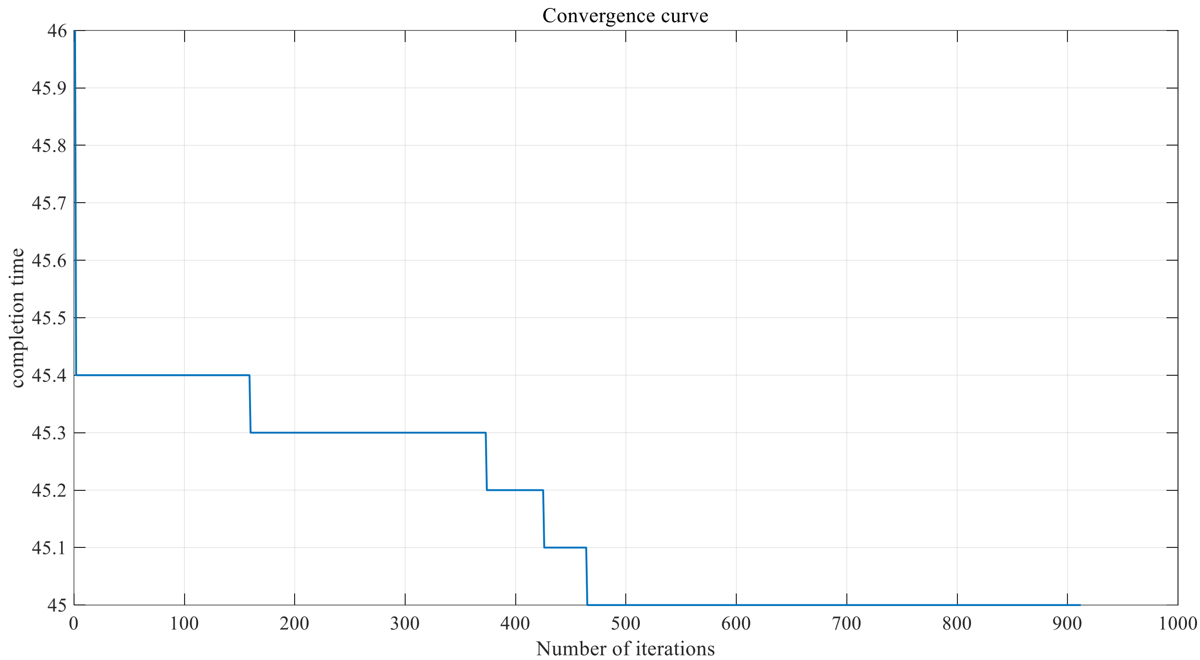

Figure 11. Convergence curves

In the production scheduling Gantt chart, each small square corresponding to each workpiece represents a process for that workpiece. For example, the first square M1-1.4 corresponding to workpiece 7 indicates that workpiece 7 is processed on machine M1 for the first process in 1.4 hours. From the Gantt chart, it can be seen that when the completion time is optimized to 45 hours, the workpieces are processed in the following order: 12-9-7-8-11-2-1-10-4-3-6-5. The intervals of white space in the processes of each workpiece are waiting times. For example, in workpiece 7, workpiece 7 is processed on machine M2 and does not go directly to machine M3, but waits to see a period of time before starting processing. This is because the machining time of the second process of workpiece 7 should be taken as the maximum value of the completion time of the first process of workpiece 7 and the completion time of the first process of workpiece 9, the previous workpiece of workpiece 7.

As can be seen from Figure 11, In the initial stage, the convergence curve flies down, which indicates that the process of finding the optimal solution is smooth. However, as the number of iterations increases, a local optimal solution appears in the middle, which keeps the curve smooth. In order to solve this problem, the code integrates various methods such as dynamic adjustment of variation probability, tournament selection, and elite retention as a way to avoid the algorithm from falling into the local optimal.

6. Conclusion

In this paper, the mathematical model of prefabricated components production scheduling is constructed, and the code is written to optimize prefabricated components production scheduling using genetic algorithm. By rationally planning the production sequence of precast components, efficiently scheduling the workpieces, significantly reducing the production cost, greatly improving the production efficiency, and successfully solving the scheduling problems in the precast component production process. The feasibility and effectiveness of the method is verified by actual cases, which provides a scientific and efficient production scheduling decision basis for precast component manufacturers. Future research can consider combining more actual production factors to further improve and refine the model, while exploring more efficient intelligent optimization algorithms or hybrid applications of multiple algorithms.

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