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Study on Complex Products Job-shop Scheduling System Based on MES

SU Xiang[1] **SUN Hongxia** **LIAN Chunguang,** **YUE Xima**

Abstract: Various random disturbances that happen in the process of complex products (ship) production cannot feedback timely, and the plans of job-shop operation are too rough to instruct job-shop production. The purpose of this study is to solve the problems above, help the course of complex products (ship) job-shop production runs orderly and efficiently, and improve the job-shop on-site management level. In this paper, we proposed complex products job-shop scheduling system based on MES. The system adopts six-level, refined plan and scheduling mechanism. Its key part is the job-shop scheduling model with man-machine coordinated mechanism. What's more, an improved Genetic Algorithm based on TOC is proposed to make the optimized algorithm module of the system more scientific and effective.

Key words: Complex Products; MES; Job-shop Scheduling System; Man-machine Coordinated Mechanism; Genetic Algorithm

1. MANUFACTURING EXECUTIVE SYSTEM

1.1 The Key Issues on Manufacturing Executive System

The concept of Manufacturing execution system (referred to as MES) was advanced by the United States advanced manufacturing research institutions（AMR）introduced by in the 20th century to 90's. MES, as the implementation layer between the plan layer of manufacturing enterprises and the control layer. On the one hand, it will refine orders from ERP system further, and then send the manufacturing orders to Production job-shops. On the other hand, real-time information collected by the process control layer feedbacks back to the business management layer. The information is a basis for the preparation of production plans in future, and offers a useful reference for real-time dynamic job shop scheduling. If we Integrate enterprise resource planning and process control system together, the enterprise information integration system with ERP / MES / PCS as the core is formed.

We can see, MES is the bridge and bond between the enterprise resource planning systems and equipment control systems, which is the critical system which enables the enterprises realize agile and

[1] Department of Economic and Management, Jiangsu University of Science and Technology， Zhenjiang 212003,Jiangsu,China
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global optimization, which is the key of Construction and development of the ship-building industry information.

1.2 Information Integration of ERP / MES / PCS

MES architecture can be summarized as "a platform, two integrated, three supporting systems" [1]. The integrated Information Platform of the shipbuilding industry includes two major parts, the enterprise data integration platform and the application integration platform. The whole enterprise community will be integrated by database technology and related integration technology.

The integration between ERP and MES adopts the method of middleware integration. That is "integration of information content following the standard S95, Message Encapsulation Format applying XML technology, enterprise application integration using BizTalk server platform"[2]. The integration platform has stable performance and high reliability.

MES and PCS integrate by OPC technology. In the integrated process of information, MES doesn't consider the bottom of the details of the OPC technology. As long as MES follows the norms of OPCXML or OPCCOM / DCOM, OPC clients can easily access OPC servers. According to the actual situation at the scene and the needs of enterprise application, MES can realize the process of information integration of OPC server quickly.

Giving full play to two above-mentioned major integrated technologies, the basic framework of the job-shop scheduling system based on MES is set up, as shown in Figure 1.

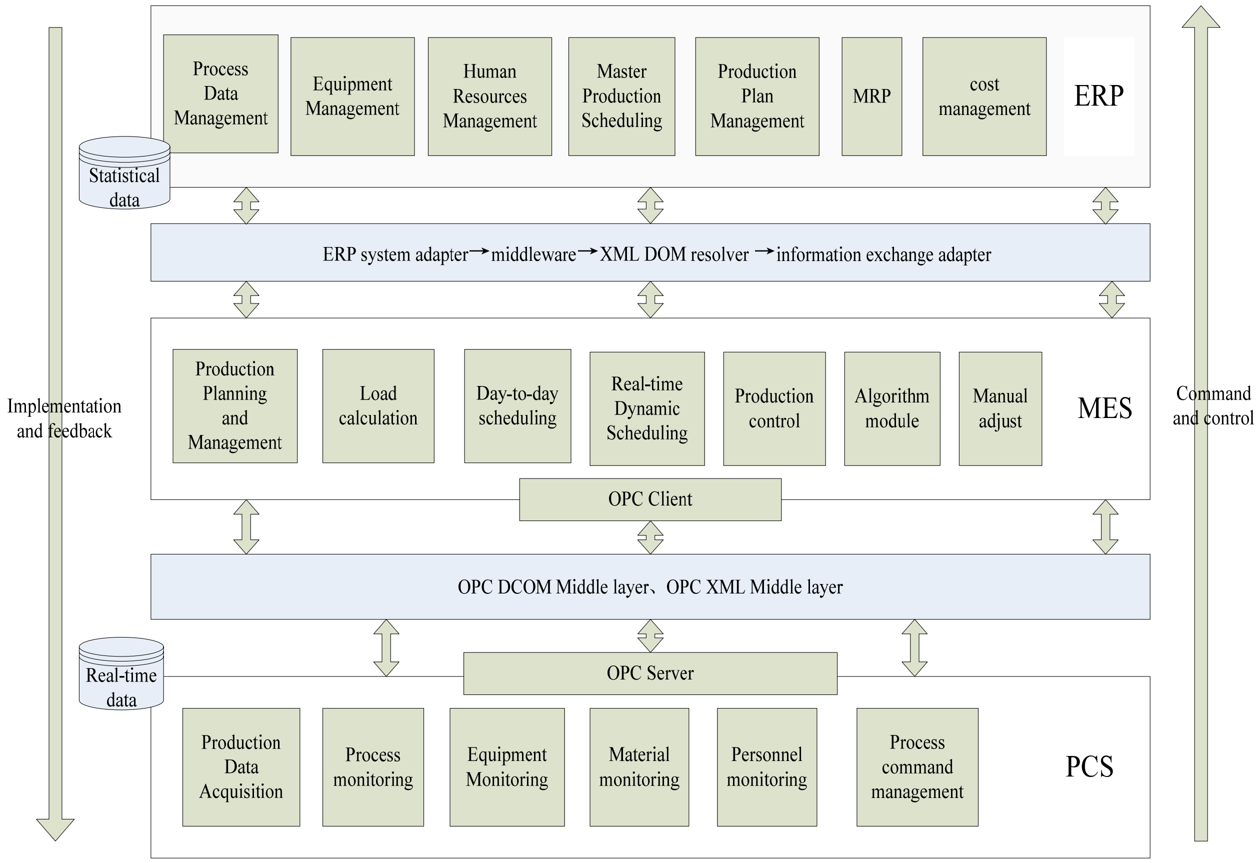

Fig.1. The Basic Framework of the Job-shop Scheduling System Based on MES

2. COMPLEX PRODUCTS JOB-SHOP SCHEDULING SYSTEM BASED ON MES DESIGN

A job-shop scheduling system based on MES consists of the production plan layer, the work scheduling layer and the operations control layer. The manufacturing process goes on smoothly as planned by establishing a reasonable process level production planning, optimizing scheduling and monitoring the production status. This section uses shipbuilding enterprise as an example to explain it.

2.1 Description of workflow in shipbuilding enterprise job-shop

Firstly, processing plant receives the production plan ERP orders. According to production capacity, inventory information, as well as fixed working hours, workers prepare operations scheduling, and then distribute it to production units to implement. The production units control the implementation of production plans, and feedback the production and resources to managers. Finally, production departments reschedule production plan. Production units monitor the implementation of production plans, and also generate reports of production analysis, and feedback critical information to ERP[3]. The flow or progress of specific production planning and scheduling or control is shown in figure 2.

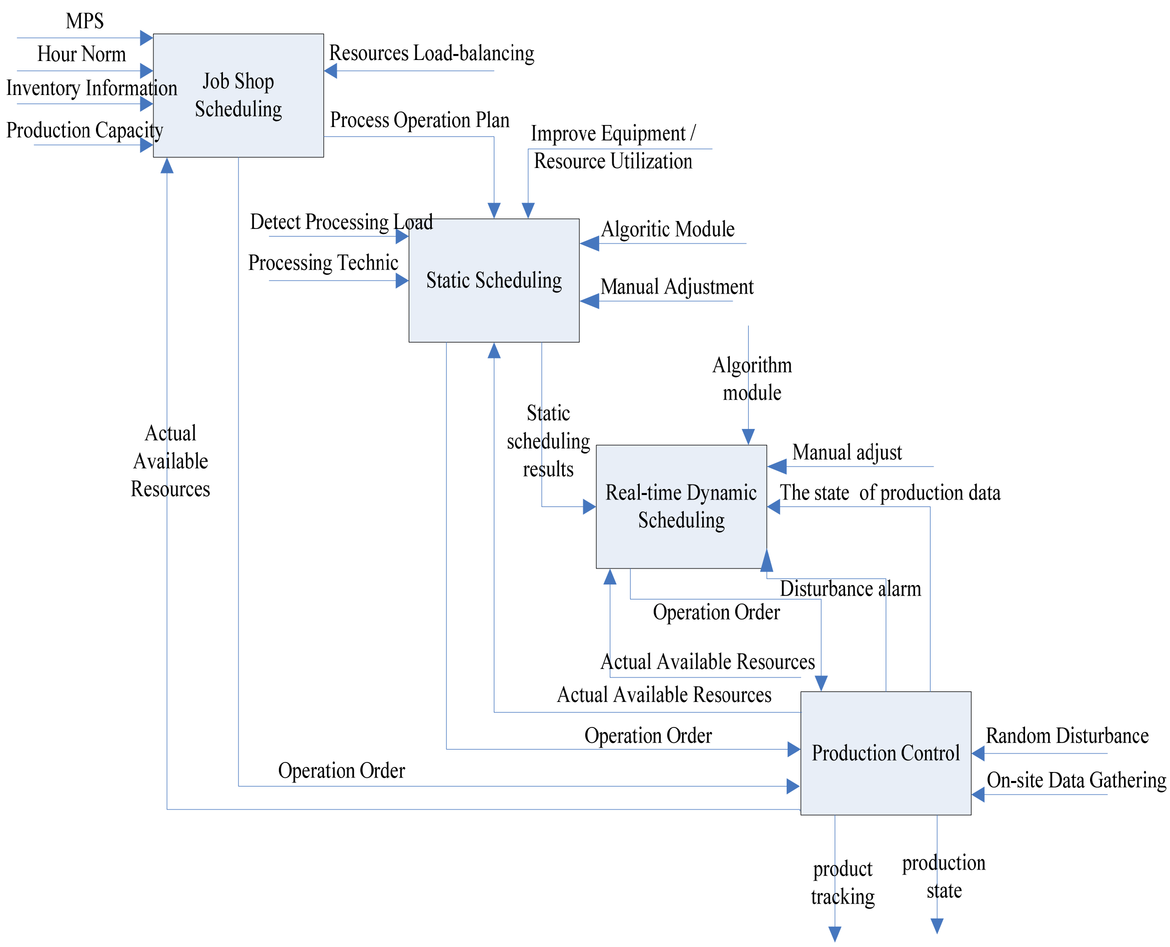

Fig.2. The flow or progress of specific production planning and scheduling or control

2.2 Job-shop scheduling system analysis and design

By analyzing the shipbuilding enterprise job-shop production and management processes，Job-shop Scheduling system mainly includes four aspects of demand.

1st. Provide data import, export and management functions.

2nd. Establish process-level production planning.

3rd. Provide production scheduling information, scheduling Gantts and results reports. emergencies can be scheduled timely.

4th. Track and manage the production process.

By analyzing the functional requirements for the job-shop, this paper proposes a six-level planning and scheduling mechanism.

1st. Process-level operations planning establishing module

The module generates process-level operational plans, that is, detailed plans. It provides scheduling function based on the designated priority, attributes, characteristics, methods, scheduling functions related to production units. Determine the specific use of a variety of manufacturing facilities in the required programs, and the types and quantities of processing workpiece within Daily / classes. The process-level operations planning are production implementation plans based on the limited capacity. Its purpose is to arrange a reasonable sequence, to compress auxiliary time of the production process to the maximum, to establish specific process-level operations planning [4].

2nd. Capacity planning module

Production needs and production line equipment in key operational capabilities, Production needs and production line equipment in key operational capabilities,

This module can reflect the requirements of facilities resources and provide surplus production capacity of every kind of product, by comparing plant capacity requirements with capabilities of critical operating assemblies in the production line.

3rd. Release quantity each time every day module

The module helps production planners distribute processed products in the production line more accurately every day or class.

4th. Day production scheduling module

Limited resource scheduling engine in the module produces detailed machine scheduling plans. In addition, according to different purposes for each operation, the system will provide specific analytical results.

5th. Dynamic operation scheduling module

The module helps critical production operations carry out partial re-scheduling and optimization. It can also regenerate detailed machine scheduling tables, when the latest work-in-process will be considered and machine status and emergency orders are calculated. It helps supervisors in production lines respond to emergencies, at the same time it effectively optimizes the resource structure.

6th. Real-time monitoring of production module

This module issues production orders to production teams to carry out, and monitor practical situation of operative plans. Finally, it generates the report on production progress tracking, random perturbation alerts, completion statistics, which provide the basis for production planning and scheduling.

3. MAN-MACHINE COOPERATION MODEL OF JOB-SHOP SCHEDULING CONSTRUCTION AND SCHEDULING ALGORITHM OPTIMIZATION

For the core function module of the complex products (ship) job-shop scheduling system, scheduling module, a flexible man-machine cooperation model of job-shop scheduling is constructed, and multi-channel flexible approach is provided. Compared to a previous single form of scheduling, the efficiency of the work scheduling is improved to a large extent.

At the same time, the practicality of algorithm module is enhanced by improving the standard genetic algorithm.

3.1 Man-machine cooperation model of job-shop scheduling construction

Using general scheduling algorithm model is difficult to solve complex job scheduling problem of complex product (ship) job-shop. So, combined artificial intelligence methods with genetic optimization algorithm, this paper constructs man-machine cooperation model of job-shop scheduling. For static job-shop scheduling problems, better scheduling can be obtained through automated scheduling algorithm module. For complex dynamic scheduling problems, the initial feasible scheduling scheme is obtained through expert intelligent job-shop scheduling module. And then, according to inappropriate places of the initial scheduling scheme, Dispatchers decide whether a second manual adjust is needed, which can make up for the disadvantage of auto-scheduling algorithm. According to those two channels of job-shop scheduling, the corresponding job-shop scheduling model is established, as shown in figure 3[5-6].

3.2 Improved genetic scheduling algorithm based on TOC designing

For the scheduling algorithm module of job-shop scheduling process mode, Improved Genetic Scheduling Algorithm based on TOC is put forward.

Through improving Standard Genetic Algorithm (SGA) and making Theory of Constraints (TOC) guide the direction of convergence, the improved Genetic Algorithm avoids the premature convergence and random walk, and fasts searching speed.

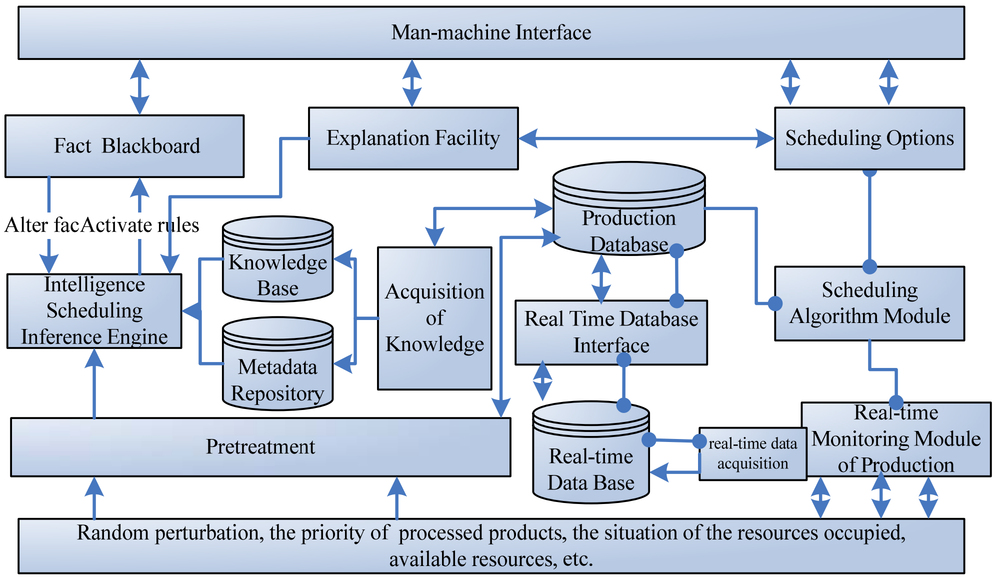

Fig.3. Job-shop Scheduling Process Model

3.2.1 Standard Genetic Algorithm improving

3.2.1.1 Chromosome code strategy

Combining workpiece number encoding method with machine allocation encoding method, genes in the same position of chromosomes produced put into a one-to-one relationship, as obtain feasible solution of scheduling problems. The method can solve the neglected question "many processes one machine" in No. workpiece coding. At the same time, it overcomes deficiencies that the machine allocation encoding does not take into account the precedence relationship between processes [7].

3.2.1.2 Control strategies of species diversity

During the initial evolution of groups, first of all, parent species are cached. And then the expected value of progeny species and parent species are calculated, and compare their expectations. If the expected value of progeny species is greater than parent species, the species evolve. If not, the species degenerate by the use of Simulated Annealing Algorithm. And then they cross and change. The next round of iterative calculation goes on until the iteration stops. It ensures species evolve in accordance with the rules of evolution.

According to species diversity control theory, the direction of species evolution should in step with high species average fitness and low species diversity, and the expected value (e) controls the direction of evolution. So the expected value (e) varies directly as F and inversely as H (N). According to above thinking, specific calculation steps of the expected value of the evolution of species are given below:

Step 1. Calculate the entropy of N chromosomes H (N).

$$H\left(N\right)=\frac{1}{M}\sum_{j=1}^{M}\sum_{i=1}^{S}\left(-p_{ij}\ln p_{ij}\right) \quad (1)$$

P_{ij} represents the probability that the workpiece i of N chromosomes appears in the jth gene place. S represents the total number of workpieces. M represents the number of genes of chromosomes.

Step 2. Calculate the average fitness value of species $\overline{F}$.

$$\overline{F}=\frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{M}F_{ij} \quad (2)$$

F_{ij} represents the fitness of the jth gene spaces in the ith chromosome.

Step 3. According to information entropy and the average fitness, the expected value (e) of the evolution of species is calculated. $e=\dfrac{\overline{F}}{1+H\left(N\right)}$ (3)

3.2.1.3 The strategy of the substitute and preservation of the best individual

Selection, crossover or mutation operation are likely to lose the optimal solution, so the optimal individual in each generation needs to find out and be saved in filters after each evolutionary cycle. And then the historical optimal individual in the filter replaces the worst individual of species After Parent species generate progeny species, which avoids optimal individual storm. The size of the filter is planned in advance. If the number of individuals is greater than the size of the size of the filter, the smallest fitness of the individual is moved and those nearest from other points are excluded.

3.2.1.4 The strategy of the infeasible solution conversion

The solution may be feasible or infeasible, because cross-matrix and cross-point are randomly selected. The new chromosome needs validity Check.

The recognition process of infeasible solutions is as follows:

Step 1. Read a gene of the chromosome, and know the workpiece number and the process number it represents.

Step 2. Compared start time of the process (st_{ij}) with finishing time of the previous process accomplished ($et_{i(j-1)}$), we will believe the solution is infeasible if (st_{ij}) is earlier than ($et_{i(j-1)}$).

Step 3. If the infeasible solution appears, the infeasible gene is put in the last or lowest in an orderings. The solution obtained by using this approach is the feasible solution which is more nearly resembles the parent.

(5) Parameter Adjustment Strategy

Ref. 8 analyzed the impact of every genetic operator on the algorithm, drew some important conclusions that the reasonable choice of selection probability, crossing probability (p_c) and mutation probability (P_m) is very beneficial to improve the fitness and enhance the diversity of species.

① The selection of selection probability

The individual is selected by comparison with fitness in a voluminous literature. This approach is slow rate of convergence and was liable to trap in local minimum value. Ref. 9 puts forward GASA based on entropy, which overcomes above defects to a large extent. Selection probability is chosen by

$$p_{si} = e^{-(H_i+\beta F_i)} / \sum_{i=1}^{N} e^{-(H_i+\beta F_i)}$$

Of which, $H_i = \sum_{j=1}^{M} -p_{ij} lnp_{ij}$ represents the entropy of the ith chromosome. F_i represents the fitness of the ith (No. i) individual. $\beta = (\alpha T_S)^{-1}$, α are the constants of Boltzmann. $\{T_s\}$ is the temperature control sequence approaching to 0.

② The selection of crossing probability and mutation probability

The following adaptive parameters are used to adjust dynamically crossover probability and mutation probability [10-11].

$$p_c = \begin{cases} 0.9 - \dfrac{0.3(F_{\max} - F_{\min})}{F_{\max} - F_{\min}} , & F \geq \overline{F} \\ 0.9 , & F p \overline{F} \end{cases}$$

$$p_m = \begin{cases} 0.1 - \dfrac{0.099(F_{\max} - F_{\min})}{F_{\max} - F_{\min}} , & F \geq \overline{F} \\ 0.9 , & F p \overline{F} \end{cases}$$

Of which, $F = \max(fitness(parent_1), fitness(parent_2))$

$Parent_1$ and $parent_2$ are alternatives or crossed objects.

$$\overline{F} = \frac{1}{N} \sum_{i=1}^{N} F_i$$

Within above-mentioned Adaptive Genetic Algorithm (AGA), crossing probability (P_c) and mutation probability (P_m) will automatically change as population fitness changes. When individuals within the population tend to be consistent or converge local optimal solution, adding the value of P_c and P_m overcome local optimal solution. When the fitness of individuals within the population scatters, reducing the value of P_c and P_m facilitates the survival of excellent individual. At the same time, the individuals whose fitness is higher than population average fitness should choose smaller values of P_c and P_m, which can protect the good solution. The individuals whose fitness is lower than population average fitness should choose larger values of P_c and P_m, which increases the speed of producing a new individual [12].

3.2.2 Arithmetical Statement

The detailed steps of improved Genetic Algorithm based on TOC are as follows:

Step 1. Find the bottleneck

The steps to find the bottleneck by listing the Processes load table are as follows.

(1) Find out all processes $\{O_{ij}\}$ of the processing equipment (M_i) in the processes set, and calculate the process time {Pm} of the equipment (Mi).

(2) Calculate the utilized time efficiently of every equipment, $\{\sum p_m\}$.

(3) Calculate the load rate of every kind of the equipment, $\{\sum p_m / k(m)\}$, of which $k(m)$ represents the number of the equipment (M).

(4) Comparing the load rate of every kind of equipments $\{\sum p_m / k(m)\}$, the equipment with maximum load rate is the bottleneck of this sorting.

Step 2. Processes dividing

In order to make the bottleneck obtain the highest resource utilization rate, processes before the bottleneck use the Pull Production Mode, while processes after the bottleneck adopt modes of the launch management, as illustrated in Fig. 4.

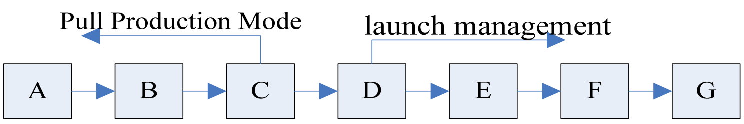

Fig. 4. Processes dividing

Step 3. Sorting processes before the bottleneck

For processes before the bottleneck, it obtains a proximate satisfying solution (S1) suing improved GA. This solution is obtained when processes in inverted, so we must convert it again and obtain the sequence (S2) before the pattern generation. Then the sequence (S2) is involved into the pattern (S3), to carry on the work of global optimization. In the latter GA operation, on the one hand we should not change the model S3, and on the other hand, we should not undermine the information about the implicit time point in S3.

Step 4. Global optimization

Global optimization is to make the processes without involving sorting insert into the pattern S3, and to optimize the pattern S3. Finally, we get a better basic feasible solution. Improved GA flow chart is shown as in the figure.

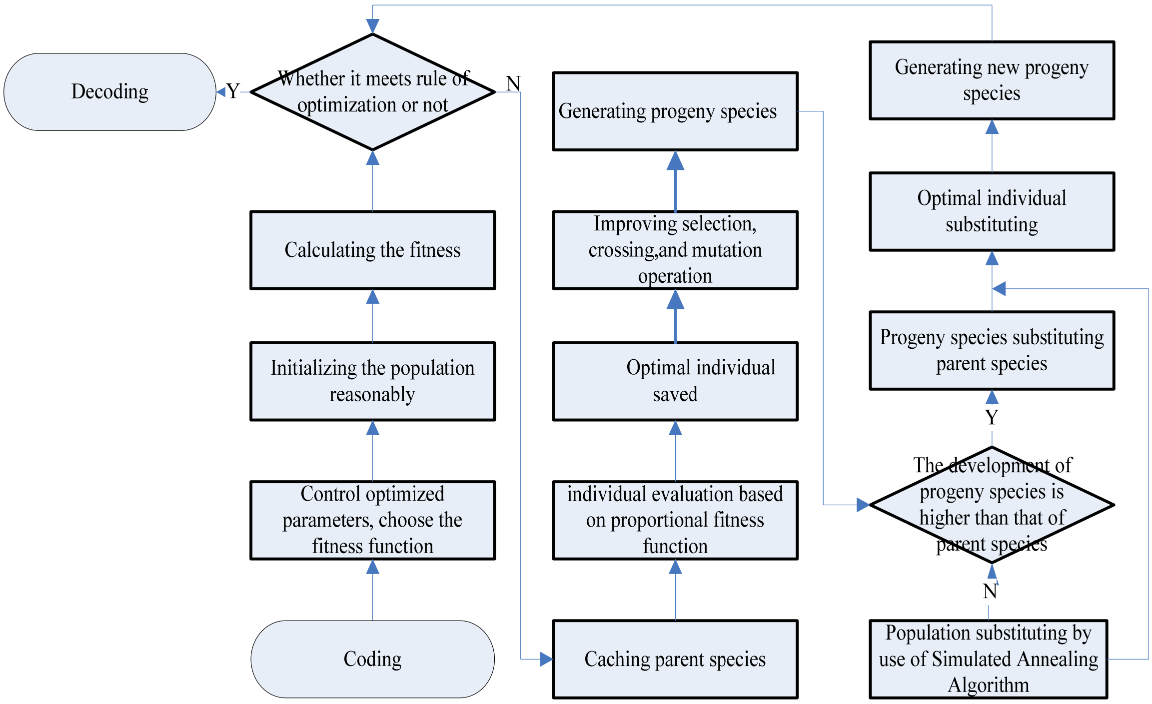

Fig.5. Improved GA flow chart

3.2.3 Algorithm feasibility analysis

Repetition tests were conducted for typical shop scheduling problems by using Visual C++ to realize SGA, improved GA, GA based on TOC and improved GA based on TOC. Because of restrictions on the number of words, this paper does not introduce specific examples. The experimental results show, When genetic algebra and population size s are relatively small values, obtained solutions take on randomicity by using standard genetic algorithm and improved genetic algorithm, and the quality of solutions may have a greater fluctuation. By comparison, the solutions in use of improved GA based on TOC ensure The quality and stability of the solution, and the total cost of the method is less.

In a complex product (the ship) job-shop, production processes are complex, so improved genetic algorithm based on TOC is better. It can search the satisfactory solution under less computational cost, and the quality of the solution is more stable.

4. CONCLUDING REMARKS

1st. This paper designs production scheduling system of the complex product job-shop. This system realizes the orderly operation of the production process, the optimized allocation of resources, less manufacturing time through properly planning, effectively scheduling, real-time control of the job-shop in the manufacturing process, improves on-site production management level, and ultimately helps improve the economic efficiency of enterprises.

2nd. For the functional module of scheduling, this paper constructs the flexible and human-machine cooperative job-shop scheduling model, which provides a flexible multi-channel scheduling approach.

3rd. For the algorithm module, this paper designs improved Genetic Algorithm based on TOC.

Through comparative analysis, resulting solution from the improved genetic algorithm based on TOC has better stability and less computational cost. The system is more appropriate for the complex products (ship) job-shop scheduling system implementation.

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