AN IMPROVED QUANTUM EVOLUTIONARY ALGORITHM FOR LARGE-SCALE MANUFACTURING WORKSHOP SCHEDULING PROBLEM

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ABSTRACT*: In the production process, there is a common problem with the sequencing of production plan and job control, namely the workshop scheduling problem, which has a non-negligible impact on the production efficiency, economic efficiency and long-term development of the enterprise. In order to improve the production efficiency of large-scale manufacturing workshops and reduce invalid processing procedures, this paper proposed an improved Quantum Evolutionary Algorithm (QEA) based on quantum algorithms and workshop scheduling related theories, and constructed graphical user interface (GUI) based on the proposed algorithm. The study found that quantum algorithms have higher accuracy and convergence speed in solving complex problems, and are more suitable for solving scheduling problems in large-scale manufacturing workshops; the improved QEA has the advantages of good global search ability, fast convergence speed, and can be combined with other algorithms more easily; in actual production scheduling, dynamic scheduling should be taken into consideration, and the proposed algorithm must be adjusted in time according to sudden situations. This study provided a theoretical basis for the scheduling and procedure adjustment and optimization of large-scale production workshops.*

KEYWORDS*: workshop scheduling; large-scale manufacturing; Quantum Evolution Algorithm (QEA); dynamic scheduling*

1 INTRODUCTION

Since the beginning of the 21st century, China's information technology has developed rapidly, and its economic development is among the best in the world. However, the development of China's manufacturing industry is relatively backward, manufacturing enterprises generally have shortcomings such as low management level, unsmooth communication, and slow respond to market changes, etc., resulting in that China’s manufacturing industry has low added value, its scale is large but the competency is weak (Pan, 2010; Qu and Zhang, 2012; Wang and Dai, 2017; Wu and Wu, 2017; Zhang and Li, 2013,). Therefore, upgrading and transforming the manufacturing industry with information technology has become the direction and focus of the manufacturing industry in China (Juybari and Hosseini, 2014, Qi et al., 2014).

At present, China's existing information management systems have achieved certain results in the management of human resource, materials, machines, goods, and money, but there’re still a series of problems with the application of the enterprise resource management systems (Qu and Zhang, 2012; Zhang et al., 2014). There is a disconnection between the automatic control systems and the management systems, which makes it difficult to collect data from the production workshops. The manufacturing execution systems can quickly respond to the unexpected situations in the workshops, thereby greatly improving the production efficiency of the enterprise (Liu, 2016; Gao et al., 2017; Song and Ye, 2010; Yang et al., 2014). However, both the two kinds of systems have certain defects in the production plan arrangement and scheduling modules, therefore, establishing a more efficient system to solve complex scheduling and planning problems has become a new research hotspot.

Large-scale manufacturing workshops have the characteristics of large production scale, complex processes, numerous products, and special equipment, which are the key points and difficulties in the research of workshop scheduling. This paper adopts QEA and data decomposition to solve large-scale workshop scheduling problems, it proposes a model for the large-scale workshop scheduling problems based on QEA and simulates and calculates the scheduling results under two dynamic scheduling conditions.

2 QUANTUM ALGORITHM AND WORKSHOP SCHEDULING THEORY

2.1 Large-scale manufacturing workshop scheduling

The workshop scheduling problems are generated from production planning and job sequence control; in the production process, the enterprise needs to clarify its annual, quarterly, and monthly production plans; then the production department prepares material demand plans for each workshop according to the total production plan; when the production orders are dispatched to the workshops, job scheduling starts to execute (Chung et al., 2011, Wang et al., 2017). In the actual production process, since there are various product types and the processing procedures for each type of product are different, it can easily cause conflicts to the production equipment, therefore, the enterprise has to solve the scheduling problem of production processes, assign the production tasks in stages, so as to maximize the production efficiency. The diversity of workshop scheduling problems is one of its characteristics, the algorithms and models constructed for different production requirements are different, and the obtained results vary greatly as well (Ding and Wang, 2013; Tang et al., 2015; Zhang et al., 2014,). At present, the classification of workshop scheduling problems is shown in Table 1.

Currently, there are two methods to solve large-scale workshop scheduling problems. The first is to decompose the problem into several sub-problems, and solve the sub-problems one by one to obtian the solution of the original problem; the second is to improve the original algorithm, so that it could find the optimal solution within the shortest time. The method adopted in this paper improved both the two methods at the same time to solve the large-scale workshop scheduling problem.

Table 1. Classification of workshop scheduling

Classification standard	Category
Complexity of workshop environment	Single machine scheduling, multiple machines
	Single operation and flow operation
Properties of objective function	Single objective scheduling and multi-objective scheduling
Parameter properties	Deterministic scheduling and stochastic scheduling
Arrival of workpiece	Static scheduling, dynamic scheduling

Analytical target cascading (ATC) is a multi-disciplinary comprehensive optimization algorithm used to optimize hierarchical systems, it integrates many disciplines to optimize the scheme and find the optimal solution for the system, it is a new method for solving problems with decentralized and hierarchical structures. ATC generally decomposes a big target system into severaly subsystems, the subsystems at all hierarchies make their own decisions to obtain the optimal solutions, and the target system continuously makes optimization and adjustment according to the feedback results of the subsystems, and finally obtains the overall optimal solution. Fig. 1 is the structure of a typical ATC.

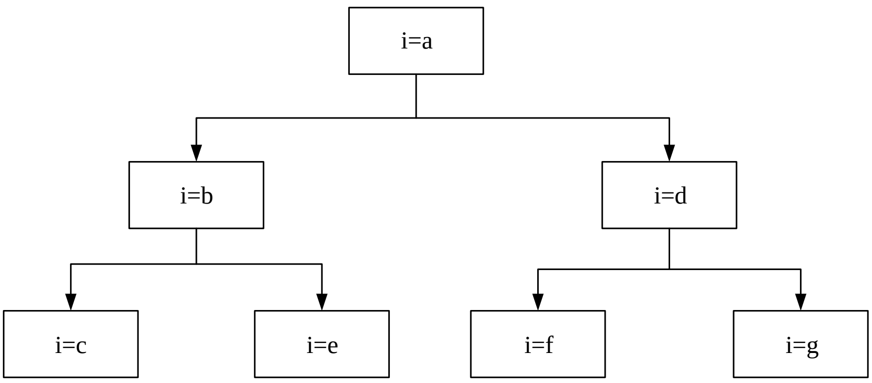

Fig. 1 Structure of ATC

In ATC structure, all elements have two modules: the first one is the system optimization design module, its function is to optimize and solve the sub-problems and obtain the optimal solutions of the sub-problems; the second one is the analysis module, its function is to obtain the optimal solution by analyzing the solution results of the overall system and inputting the response values and related parameters of each sub-problem into the model. The optimization principle for each element in the structure is shown as Fig. 2.

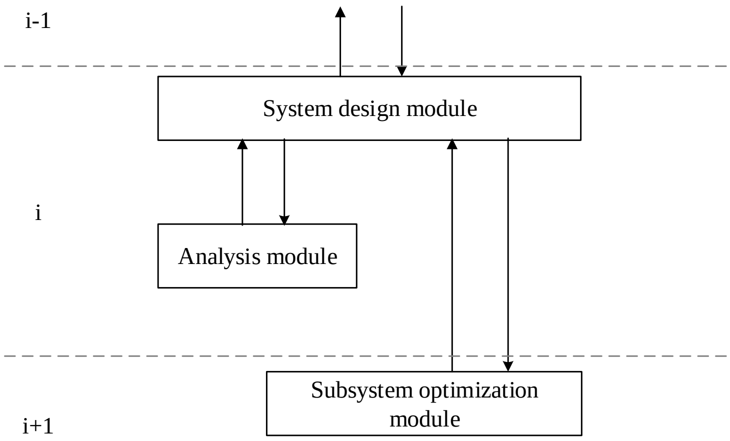

Fig. 2 Optimization of ATC

2.2 QEA

When optimizing and solving flexible workshop scheduling problems, reasonable optimization of the algorithms can greatly improve the convergence speed and accuracy, compared with other traditional algorithms, QEA has obvious advantages in accuracy, convergence speed, and solving complex problems. The research of QEA is still in the primary stage, integrating quantum computing, quantum information and operating mechanisms into the optimization of the algorithms can greatly improve its performance, its main advantages are manifested in concurrency, diverse population, strong global search ability, and higher probability of obtaining the global optimal solution, etc.

QEA also has the merits of simple principle, easy to implement in actual production, its application is not constrained by diversity, and it has good versatility, good global search ability, fast convergence speed, and easy to be combined with other algorithms, its calculation process is shown in Fig. 3.

The flow of QEA is mainly divided into 5 steps: first, randomly generate a population P(t) and encode any quantum in the population P_j={α_1, α_2, α_3, … α_m,}, m represents the length of the quantum; then observe the original population, determine the probability amplitude of each quantum, and convert all quantum codes into binary codes $R(t)$={β_1, β_2, β_3, … β_m,}, β_m is a binary string and it's also the observation value of the j-th population; after that, evaluate each individual in $R(t)$ according to the fitness function, retain the optimal individual in the population, judge whether the terminate condition is met, if yes then output the result, otherwise perform iteration and update, convert the quantum, and return to step 2 to continue the calculation.

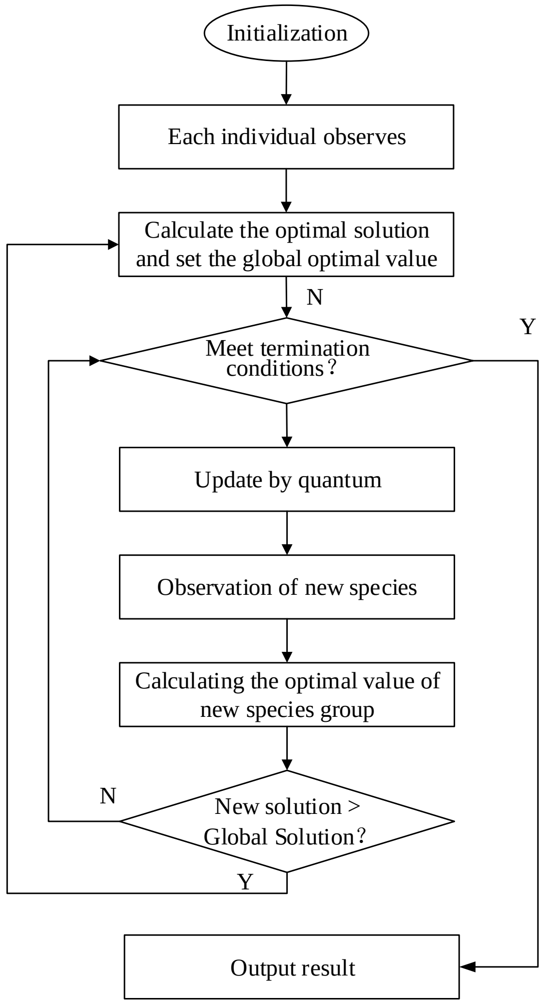

Fig. 3 QEA flow

3 QEA-BASED LARGE-SCALE WORKSHOP SCHEDULING PROBLEM

3.1 Construction of system interface

To understand the main modules of QEA and the production function of the workshop more intuitively, this paper used MATLAB to construct the GUI, the execution flow of the large-scale workshop scheduling modules of the quantum calculation system is shown in Fig. 4, by inputting basic parameters and information into the system, the related scheduling results and reports can be obtained.

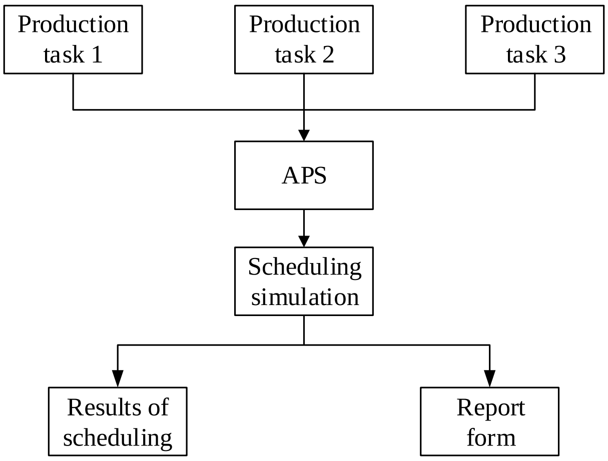

Fig. 4 Flow of workshop scheduling system

The modules and functions of the system are mainly divided into 3 parts: the system main interface, the production scheduling interface, and the dynamic insertion interface. The main interface of the system displays the 5 modules, including supply chain planning module, demand planning module, production scheduling module, transportation planning module, and the help module; the production scheduling interface includes dynamic scheduling and static scheduling, after scheduling parameters are input in the interface, the module can directly make schedules, after dynamic scheduling is completed, it can re-calculate the scheduling process. Based on the requirement of the study, we had only built interface for two working conditions: dynamic order insertion, and machine failure; the interface of dynamic order insertion is similar to the interface of production scheduling, a window of dynamic order insertion was added to the input port; the dynamic order insertion is divided into two methods: sequentially postponing insertion and mixed insertion, and the input and output ports of the two methods are the same.

3.2 Dynamic scheduling

In the actual production process, the problem of dynamic scheduling is quite common. It's hard to keep the production system always operating in a fixed and unchanging state, and in the actual production process, unpredictable situations happen all the time, such as machine failure, returned orders, rush orders, etc.; so the scheduling scheme needs to be adjusted in time, and the optimal scheme needs to be re-calculated, so as to maximize the resource utilization rate and the profit of the enterprise. Therefore, in the actual production scheduling process, it's necessary to take dynamic scheduling into consideration, and adjust the scheme according to the sudden situations. The specific process is shown in Fig. 5.

It can be seen from Fig. 5, after receiving the changed information, dynamic scheduling would make corrections and updates based on the original scheduling; the system can perceive the changes in the production environment, and then adjust the production status and re-arrange the production scheduling process. This paper mainly studies the dynamic production scheduling under two working conditions of rush-order insertion and machine failure. The solution to this problem is generally divided into two situations: the first is to prioritize the urgent order, process the rush-order first and the original order later; the second is to pack the two kinds of orders and process them together, with one processing procedure as an example, the original production process is shown in Fig. 6.

Suppose a new order is inserted at moment 20 of the processing time, the inserted order is $\{P_1, P_2\}$, which contains 6 procedures, the completed procedures are $\{M_{11}, M_{12}, M_{13}\}$, the ongoing procedures are $\{M_{21}, M_{22}\}$, and the rest procedures are unfinished procedures; when re-arranging the subsequent unfinished procedures and inserting the newly generated procedures, the ongoing procedures are considered as finished procedures; the re-arranged scheme meets the constraints of the order completion time and the maximum completion time of the equipment, the re-arranged scheme is shown in Fig. 7.

Assume at moment 20 of the processing time, machine failure occurs, and the scheduling of the original state needs to be re-arranged, the completed procedures are $\{M_{11}, M_{21}, M_{31}\}$, the ongoing no-failure procedure is $\{M_{21}\}$, the ongoing failure procedure is $\{M_{12}\}$, the rest procedures are unfinished procedures, the ongoing no-failure procedure is considered as the finished procedure, and the ongoing failure procedure is considered as the unfinished procedure, all unfinished procedures are re-arranged; the procedures of the new products are also processed under the constraints of the order completion time and the maximum completion time of the equipment, the rescheduling result is shown in Fig. 8.

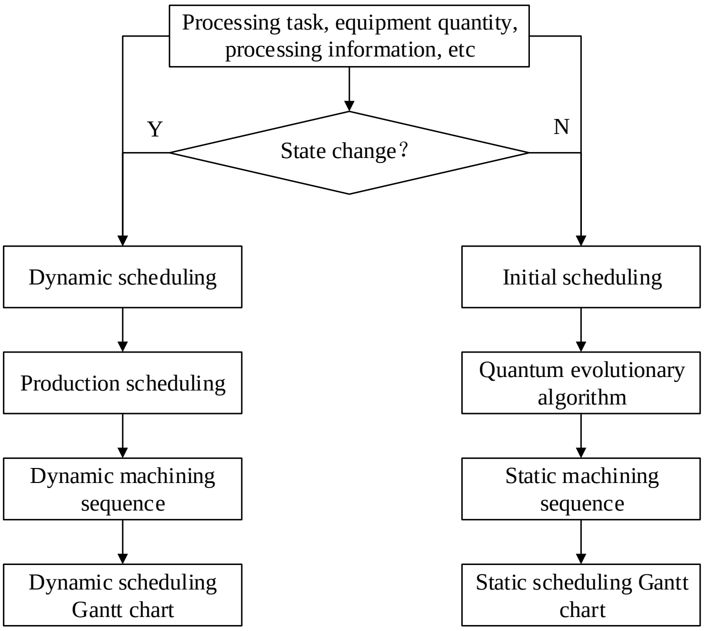

Fig. 5 Flow of dynamic scheduling

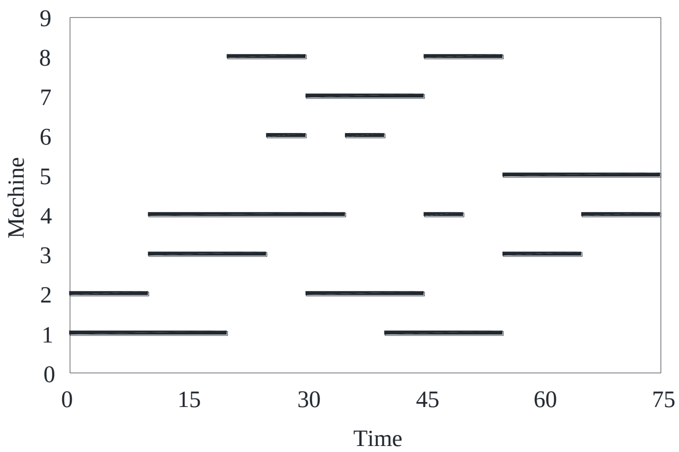

Fig. 6 Normal processing state

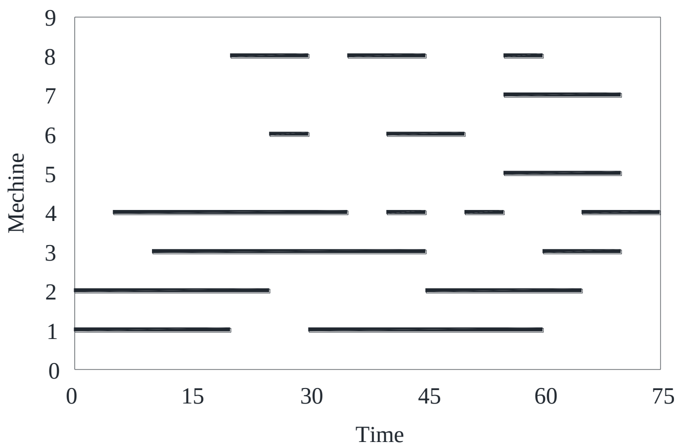

Fig. 7 Rescheduling result of rush-order insertion

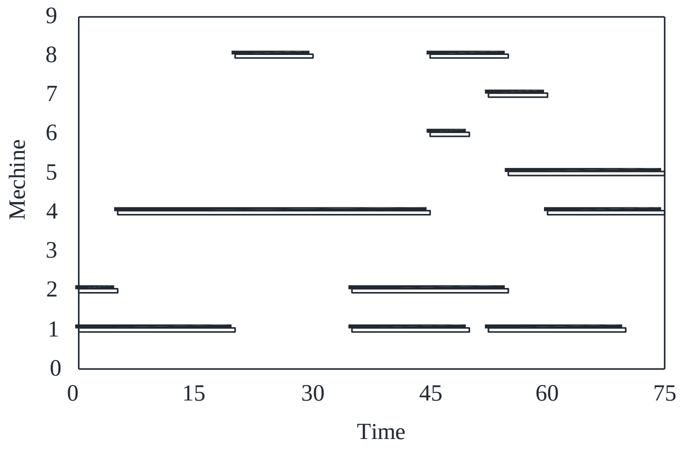

Fig. 8 Rescheduling result of machine failure

4 CONCLUSIONS

For large-scale manufacturing enterprises, the workshop production scheduling optimization is a problem that needs to be solved urgently. Combining with ATC and existing optimization algorithms, this paper proposed an improved QEA to solve the optimization problem of hierarchical systems. The main conclusions are as follows:

(1) The improved QEA greatly improved the performance of the existing algorithms, it had been optimized in terms of concurrency, population diversity, global search ability, and the probability of obtaining the global optimal solution.

(2) This study adopted MATLAB to build GUI, so as to more intuitively show the main modules of QEA and the production function of the workshop, and thereby improving the fitness of the optimization algorithm and the system.

(3) In the actual production scheduling process, it’s necessary to take the dynamic scheduling problem into consideration, the improved QEA system can make timely adjustments according to the sudden situations in the production process, thereby ensuring the continuous scheduling of large-scale manufacturing workshops.

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