Automated Planning and Scheduling System for the Composite Component Manufacturing Workshop

Mei Zhongyi, Muhammad Younus, and Liu Yongjin

Abstract—**Aerospace manufacturing system is very intricate due to the extreme material and information flow. Management of these variables need automated planning and execution system. Commercially available software systems are highly expensive and are not designed for specific need. This paper describes a Manufacturing Execution System (MES) for the composite component manufacturing workshop of an aerospace enterprise. The production planning and scheduling is the core module of the MES that described in detail. The system shows the production planning and production scheduling have diverse effect on the workshop production. The significance of the automatic scheduling is emphasized. The characteristic of the composite component manufacturing and production scheduling is analyzed in detail. An improved genetic algorithm for automatic production scheduling is emphatically described. By improving some methods to the traditional genetic algorithm, the convergence rate of the improved genetic algorithm is increased. Three-layer structure is adopted to design and develop the system. Some practical manufacturing composite components are selected to verify the validity of the improved genetic algorithm and the developed system. The developed system has been applied in the composite component manufacturing workshop. The results show that working efficiency of the production planning and scheduling has been improved.**

Index Terms—**composite component, genetic algorithm, MES, production planning and scheduling.**

I. Introduction

In order to get the customer confidence, every manufacturing industry has to improve their product quality, reduce production cost, and minimum lead-time to deliver the part in time [1, 2]. The traditional manufacturing approach may not fulfill the contemporary digitalized manufacturing setup needs [3]. Therefore, sophisticated technologies and software solutions are implicated in the manufacturing industries to handle the frequent changes in the product and its demand. MES is one of the software solution used to bridge between production planning and equipment control system [4]. The production managements in aerospace enterprises are distinctly different from other enterprises. After receiving the production tasks in aerospace enterprises, the departments of production planning divide the production tasks into the component production plans at the beginning of the year. Then, the production plans are issued to the workshops. The workshops subdivide the production plans again and complete the production tasks. Most of the aerospace enterprises have been using Enterprise Resource Planning (ERP) systems currently. Matching material, predicting production capacity of the enterprise, and arranging main production plans may be done simultaneously after issuing production plan. Most of the enterprises do not have such kind of controlling and information management in the workshops. After the production plans are issued to the workshops, the information transferring is still implemented manually by using traditional paper bills. So it's difficult to keep the consistency between the workshop production and the enterprises production plans.

Due to the rapid development of the computer networking and internet technologies, the computerization pace in manufacturing and process industries are also accelerated. The automation level of these industries are constantly improved which led to a closed - loop flow of information at the plant level. The role of MES becomes more vital to link the two levels of the industries. MES has gradually been progressed to the presented intelligent integrated modular system [5, 6].

In recent years, a lot of enterprises have adopted Manufacturing Execution System (MES) to improve the level of information management in workshops. Cheng et al propose a systematic approach to develop an open, modularized, distributive, configurable, and integrated MES framework by using object-oriented technique [7]. In 2002, Chung Sheng-Leun et al present an integrated MES for Semi Conductor manufacturing on an open architecture [8]. In 2006, Walkden Michelle presents MES for a papermaking enterprise which composed of reliable delivery time, planning, and production invoicing [9]. In 2007, Qi ES et al analyze the characteristics of current shop floor's production planning and scheduling. The idea of researching on production planning and scheduling based on APS and MES integrated system is presented [10]. In 2008, Huang ZH et al

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implement the optimization control and management of the auto electronic parts enterprise production process [11]. In 2009, Cao Y et al introduce the scheduling optimization based on CAPP/PPC Integration. Three core modules, namely, operation planning, operation scheduling, and material tracing are presented [12]. In 2006, Zhilun Cheng et al introduced the framework for developing manufacturing execution system dedicated to iron and steel industry. Unified Modeling Language (UML) is used to specify the system model and components [13]. In 2008, Jiwei Hua et al adopted radio frequency identification (RFID) technology to obtain real-time production information which is applied in the MES [14]. In 2010, Mei Zhongyi et al presented a MES for the composite component manufacturing workshop of an aerospace enterprise. The algorithm of production planning and scheduling is emphatically introduced. The application of the production planning schedule system has radically changed the traditional manual production planning and scheduling manner and improved the work efficiency [15].

In 2004, Xiaoling Huang et al proposed a three layer integrated manufacturing system based on ERP/MES/PCS for an Ore dressing plant. This paper describes an effective and efficient controlling of information flow in closed loop architecture for an ore dressing plant. Most of the MES functionalities have been successfully implemented. Production cost control, production scheduling, production statistics & analysis, material flow control, equipment management, quality management, energy management and comprehensive inquiry functions are main module function of MES which are described in the paper [16]. In 2007, Jing Shaohong et al described MES architecture for a cement industry. They have described the various MES module functions for the cement industry to integrate the information data between PCS and ERP and optimize the production process. The paper describes the cement production process and its operation al characteristic analysis. A three layer manufacturing integration model for the cement industry has been described by explaining MES functionalities used in cement industry [17].

In 2007, a similar research has been carried out by Xioahong Wang et al for a cement industry. They have described the various MES module functions for the cement industry to integrate the information data and optimize the production process. Plan decomposition, quality management, job shop scheduling, material balance and inventory management, equipment running management, processes costing management, and other daily management are the module functions described for the cement industry. Relational database have been used for the database creation [18].

MES implementations are not restricted to the specific enterprise but it has been implemented even in small industries like SMT industries and knitting industries also to give automated manufacturing environment [19].

The composite component manufacturing workshop understudy is experiencing problems in inventory control, scheduling, material flow, equipment management, and real time data collection for decision making. It is extremely complicated to carry out any production statistics analysis on the available data for decision making because manual compilation of report involves several calculations. The real time data access and information sharing for further planning and rescheduling is unavailable resulting low productivity. A suitable MES has been developed to improve the traditional working efficiency and real time process monitoring of the products. This paper mainly presents the production planning and scheduling management of the developed MES, especially focus on the automatic scheduling algorithm.

II. The Function of Production Planning and Scheduling Management

MES is an important part of the enterprise information management system. The main functions of the developed MES for the composite component manufacturing workshop are production planning and scheduling management, and production process management. By real-time tracking the production process of the workshop, MES can harmonize all production activities. Some functions of the MES are managing material, equipment, and personnel in the composite component manufacturing workshop, and making all production resources most reasonable assignment. By integrating inventory management, personal management, file management, and other modules in the same system platform, MES improves the workshop production efficiency and management. The main function modules of the developed MES are shown in Fig.1.

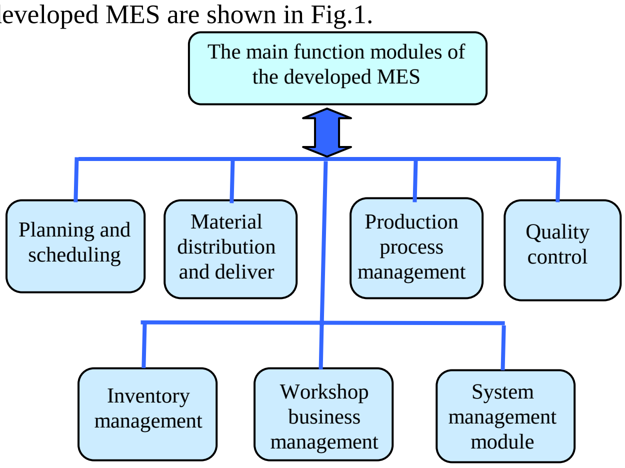


Figure 1. Main function module of the developed MES

The module of planning and scheduling management is the core module of the developed MES. It's the connecting tie between the Enterprise Resource Planning (ERP) system and the control system of the shop floor. The module of planning and scheduling management includes two aspects, namely, forming production planning and production scheduling. Production planning is mainly arranging product variety, product quality, production output, and production value which should be attained in the planning period. It's as the guidance to the workshop production. Production scheduling is the continue work of the production planning. It's the detailed execution process of the production planning. Based on the product variety, product quantity, and product delivery period planned by production planning, production scheduling makes up the detailed production tasks for every production unit in a determinate time period and puts the production planning into effect. Therefore, production planning and scheduling is the origination of the workshop production and the main line of the workshop process flow. Fig.2 shows the work content of production planning and scheduling in the composite component manufacturing workshop. The work flow of the production planning and scheduling is:

1) Importing the product process route from CAPP.
2) Determining the components that will be planned.
3) Working-out the planning task.
4) Arranging the planning task.
5) Querying the planning task.
6) Modifying the planning task.

The former three contents are forming the workshop production planning. The later three contents are called the workshop production scheduling.

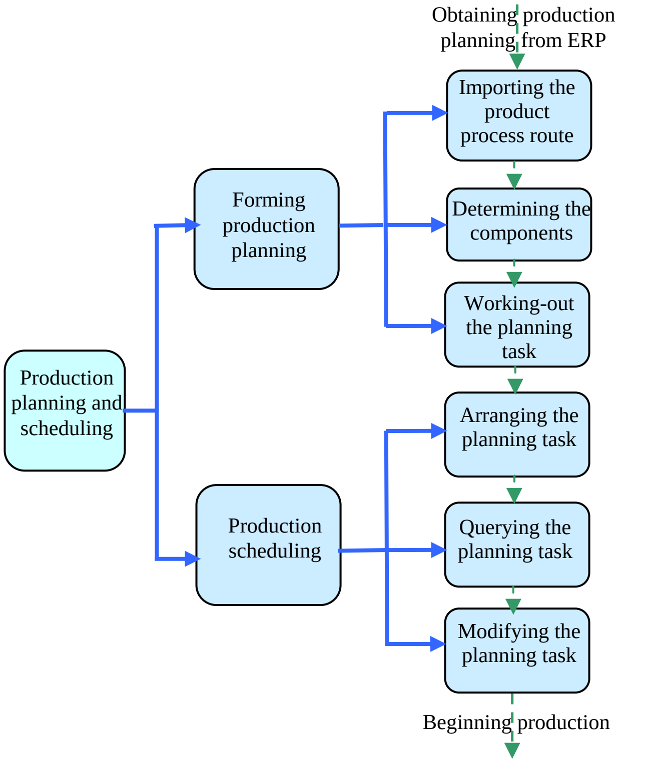


Figure 2. Work content of production planning and scheduling in the composite component manufacturing workshop

The workshop production planning is the subdivision of the enterprise production planning. According to the priority of the production, the workshop production planning can arrange appropriate production sequence of the orders which got from the enterprise production planning. The effect of workshop production scheduling is reasonably arranging production tasks to suitable production teams or workers at right time. The workshop production scheduling prepares all needed tools, materials, fixtures, and equipments in time. These will ensure the production tasks may be completed with high quality and right quantity.

III. Integrating with Other Systems

The production planning and scheduling system is a subsystem of the MES. When applied in the composite component manufacturing workshop, it must exchange data with other system. The production planning and scheduling system imports main production plan of the enterprise from ERP. After completing the production schedules data collection and data statistic, the production planning and scheduling system returns these data and information to ERP. The production planning and scheduling system also needs to import production process route and BOM from CAPP and return production plan information to CAPP. This system needs to obtain material information and material inventory information from the MIS that belongs to the material management department.

Because the databases of all the systems are ORACLE, The integration between these systems is achieved by accessing the open view of each database. Integration relationship between the four systems is shown in Fig.3.

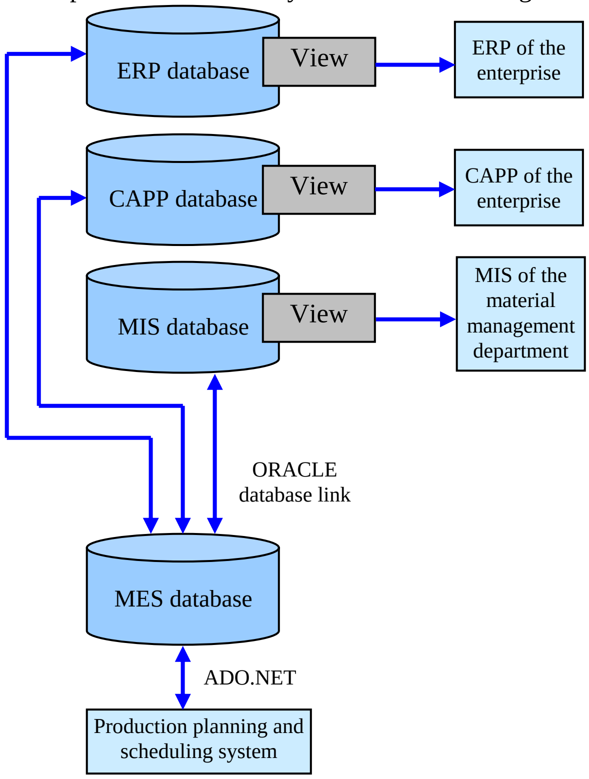


Figure 3. Integration relationship between four systems

IV. The Status of the Automatic Scheduling in the Production Planning and Scheduling

Production scheduling must consider a lot of factors, such as urgent order, production ability, the peak load of equipment, and delivery period. In actual production, these factors often restrict and conflict each other. It's impossible to satisfy all factors to the best. So production scheduling will synthetically consider all the factors and make the outcome of the scheduling most reasonably to the appointed workshop. The scheduling decides the utilizing efficiency of the equipments and the working efficiency of the workers. It also decides product cost and the overall production efficiency of the workshop. With the production scope enlarging and the production tasks increasing, the workshop production scheduling becomes more challenging. Traditional manual scheduling is difficult to satisfy the demand of the workshop production scheduling. Developing the automatic scheduling system is for replacing the traditional manual scheduling, realizing the optimization of the scheduling, and finally improving the workshop production efficiency. The status of the automatic scheduling in the production planning and scheduling is shown in Fig.4.

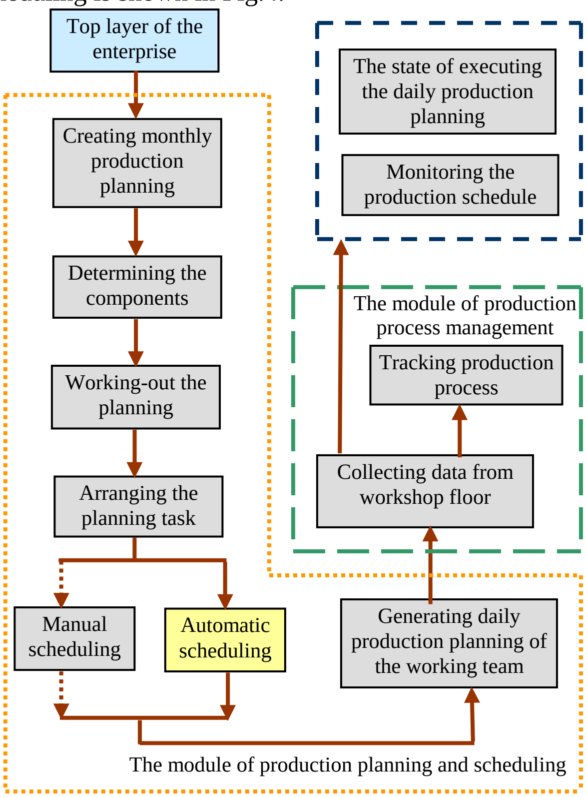


Figure 4. Status of the automatic scheduling in the production planning and scheduling

V. CHARACTERISTIC OF COMPOSITE COMPONENT PRODUCTION SCHEDULING

Aerospace composite component manufacturing workshop is differing from other component manufacturing enterprises. There are more working procedures. The working procedures of composite component manufacturing include three main portions, namely cloth cutting and lay up, curing and heat press for shaping, and painting and assembly. The production characteristic of these three working procedures is presented in Table Ⅰ.

TABLE I. Characteristic of composite component manufacturing

Classify	Cloth cutting and lay up	Curing and heat press for shaping	Painting and assembly
The key working procedures	Cloth cutting and lay up	Curing and heat press (Necessary procedures)	Cementing and inspection (Optional procedures)
Process time	Process time is short except vacuumizing component	Curing and heat press needs nearly four hours	Process time of all procedures is short
Needed equipments	Numerical control equipments of cloth cutting and lay up	Curing stove and heat press pot	Most equipments are numerical control equipments

By comparing and analyzing, curing and heat press are the key procedures in the process of composite component manufacturing. Curing and heat press need more process time. All the composite component manufacturing must pass through curing and heat press procedure. There are a lot of working procedures in composite component manufacturing. So, it is more difficult to schedule for composite component manufacturing. The process flow of composite component manufacturing is shown in Fig.5.

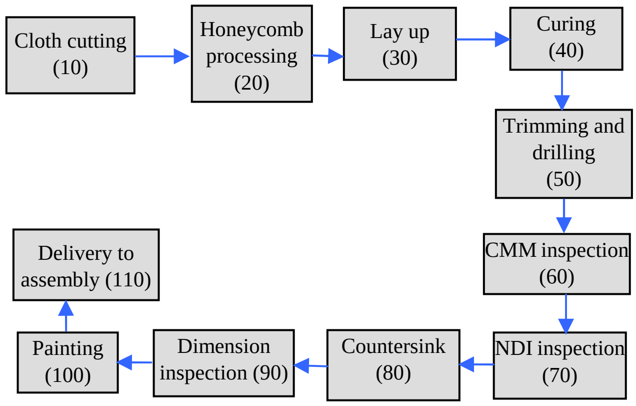


Figure 5. Process flow of composite component manufacturing

By investigating actual production of the composite component manufacturing workshop, there are some special characteristics in composite component manufacturing, as follows.

1) Manufacturing sequence of the composite component according to the production sequence which starts working from small procedure number to big procedure number.

2) Production processes of the composite components are generally same. The same production procedures of the different components have different process time.

3) Some components in the same batch of composite components can have the production priority.

4) Some production procedures of composite components are often finished manually. For example, lay up, honeycomb polishing, and trimming edge, etc.

On all accounts, production scheduling of composite component manufacturing workshop can be approximately regarded as scheduling problem of the flow shop. In flow shop, one production team can only finish one procedure of one component at one time. Before starting new procedure, the previous procedure must be finished.

In order to satisfy the demand of workshop production planning and scheduling, many optimal algorithms like Simulated Annealing, Genetic Algorithm, Tabu Search, and Neural Network are developed. This paper adopts improved genetic algorithm to complete automatic scheduling of the composite components manufacturing. Some improved methods are applied to the traditional genetic algorithm.

VI. THE WORK FLOW OF IMPROVED GENETIC ALGORITHM

To set up traditional genetic algorithm to the workshop production scheduling is required follow two steps. The first step is to input basic data about all machines and working teams, process procedures of the components, process time of every procedure, and required machine for every procedure. Second, the basic parameters of the genetic algorithm are assigned. These parameters include population genetic generations N, crossover probability Pc, mutation probability Pm, and so on. Based on above basic information and biology principle, the genetic algorithm can randomly create chromosome gene and subsequently generate initial population. By using selection operator, the individual with machine information is judged whether adapting environment. If it does not adapt environment, this individual will be discarded. Otherwise, this individual enters crossover phase. After the population suffers crossover, this population becomes the embryo of the next generation population. Afterward, this population is dealt with mutation operator and backward operator. It becomes the real next generation population. After the population undergo N times heredity, the chromosome gene becomes stable. Thereby, the best result can be obtained.

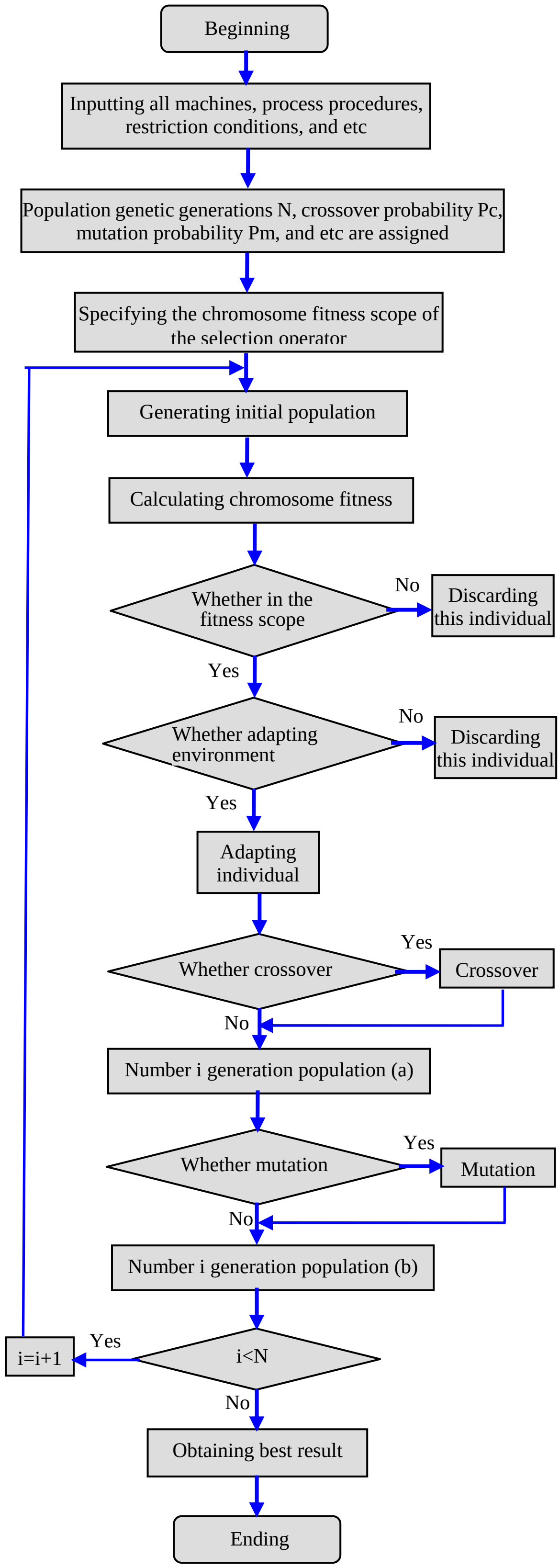


Figure 6. Work flow of improved genetic algorithm

When genetic algorithm is applied to the production scheduling of the composite workshop, based on the traditional genetic algorithm, some improved methods are adopted to adjust the convergence rate. For example, the suitable fitness scope is specified. Only the chromosome whose fitness satisfies the scope can enter into the selection operator. Otherwise, the chromosome whose fitness does not satisfy the scope will be discarded immediately. This is similar to the heredity of the biology population. The individual that does not adapt environment can not copulate and enter into next generation. This ensures that only relatively excellent individual can achieve the heredity and multiply the next generation. By using these methods, the convergence rate of this algorithm can be improved. Consequently, the influence of the bad individuals to the whole population can be eliminated. The work flow of improved genetic algorithm is shown in Fig.6.

VII. THE SOFTWARE TECHNOLOGY OF PRODUCTION PLANNING AND SCHEDULING SYSTEM

By using the core improved genetic algorithm, the production planning and scheduling system of the composite workshop has been developed. The system designing adopts three-layer structure which based on Web technology and browser/server (B/S) architecture. The developing languages are ASP.NET and C#. The application architecture of the system is divided into three layers that include user presentation layer, transaction logical layer, and data access layer. The architecture of the system is shown in Fig.7.

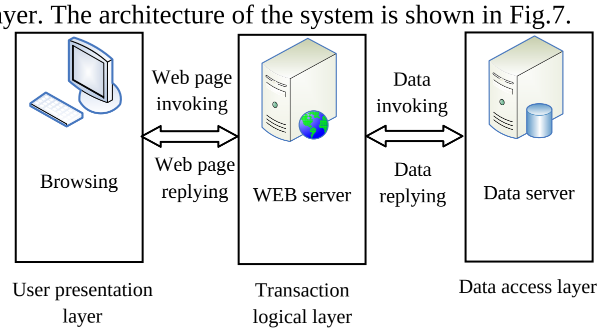


Figure 7. Architecture of the system

User presentation layer is the user interface of the system. This layer is used to implement human-computer interaction between the users and the developed system. Transaction logical layer is the core of the whole system. All the transaction rules and logical implementation are packaged in the logical groupware. Data access layer is used to access, store, and optimize data in database.

The client-side is the WEB browser of every computer. By using Internet or Intranet, The client-side can access the server at real time. All the transaction logical codes and data are saved in the server. So the central controlling of the system can be achieved.

VIII. APPLICATION OF IMPROVED GENETIC ALGORITHM

Some practical composite components of the workshop are selected to verify the validity of the improved genetic algorithm and the developed system. The parameter values of the improved genetic algorithm are specified, such as crossover probability Pc=0.9, mutation probability Pm=0.1, the individuals of the population is 300, the population genetic generations is 150. There are two orders and three composite components. The two orders are respectively named oreder1 and order2. The part numbers of the three composite components are respectively named 193Z1001-3, 193Z1001-4, and 193Z1002-3. Order1 includes three components and order2 includes two components, as presented in Table Ⅱ.

TABLE II. Components in the order

Order	Order1	Order2
The components in the order	193Z1001-3 193Z1001-4 193Z1002-3	193Z1001-3 193Z1001-4

All the three composite components have the same working procedures. But the process time of the same working procedure for different component is different. The working procedures and process time of the three composite components are presented in Table Ⅲ.

TABLE III. Working procedures and process time (hour) of the composite components

Working procedure number	Working procedure name	Working team number	Process time of 193Z1001-3	Process time of 193Z1001-4	Process time of 193Z1002-3
10	Cloth cutting	1	2	2.5	3
20	Honeycomb	2	2.5	2.5	2.5
30	Lay up	3	4.5	5	4.5
40	Curing	4	3.5	6.5	4
50	Trimming and drilling	5	0.5	1.5	1.5
60	CMM inspection	6	1.5	1.2	1.5
70	NDI inspection	7	1.5	2	1
80	Countersink	8	1	2	2.5
90	Dimension inspection	9	0.5	1	1.5
100	Painting	10	1	1.2	1.5
110	Delivery	11	0.5	0.5	0.5

Based on the improved genetic algorithm, the optimized process sequence of the composite components can be calculated. The starting time and end time of every procedure for the three components can be also obtained at the same time. The optimized process sequence, process time, starting time, and end time of the working procedures are presented in Table Ⅳ.

TABLE IV. The optimized process sequence, process time, starting time, and end time of the working procedures

ID	Working team number	order	component	Working procedure number	Process time (hour)	Starting time (hour)	End time (hour)
0	1	Order1	193Z1001-4	10	2.50	0	2.5
1	1	Order1	193Z1002-3	10	3	2.5	5.5
2	1	Order2	193Z1001-3	10	2	5.5	7.5
3	1	Order1	193Z1001-3	10	2	7.5	9.5
4	1	Order2	193Z1001-4	10	2.50	9.5	12
5	2	Order1	193Z1001-4	20	2.50	2.5	5
6	2	Order2	193Z1001-3	20	2.50	7.5	10
7	2	Order1	193Z1002-3	20	2.50	10	12.5
8	2	Order2	193Z1001-4	20	2.50	12.5	15
9	2	Order1	193Z1001-3	20	2.50	15	17.5
10	3	Order1	193Z1001-4	30	5	5	10
11	3	Order2	193Z1001-3	30	4.50	10	14.5
12	3	Order1	193Z1002-3	30	4.50	14.5	19
13	3	Order2	193Z1001-4	30	5	19	24
14	3	Order1	193Z1001-3	30	4.50	24	28.5
15	4	Order1	193Z1001-4	40	6.50	10	16.5
16	4	Order2	193Z1001-3	40	3.50	16.5	20
17	4	Order1	193Z1002-3	40	4	20	24
18	4	Order2	193Z1001-4	40	6.50	24	30.5
19	4	Order1	193Z1001-3	40	3.50	30.5	34
20	5	Order1	193Z1001-4	50	1.50	16.5	18
21	5	Order1	193Z1002-3	50	1.50	24	25.5
22	5	Order2	193Z1001-3	50	0.50	25.5	26
23	5	Order2	193Z1001-4	50	1.50	30.5	32
24	5	Order1	193Z1001-3	50	0.50	34	34.5
25	6	Order1	193Z1001-4	60	1.20	18	19.2
26	6	Order2	193Z1001-3	60	1.50	26	27.5
27	6	Order1	193Z1002-3	60	1.50	27.5	29
28	6	Order2	193Z1001-4	60	1.20	32	33.2
29	6	Order1	193Z1001-3	60	1.50	34.5	36
30	7	Order1	193Z1001-4	70	2	19.2	21.2
31	7	Order1	193Z1002-3	70	1	29	30
32	7	Order2	193Z1001-3	70	1.50	30	31.5
33	7	Order2	193Z1001-4	70	2	33.2	35.2
34	7	Order1	193Z1001-3	70	1.50	36	37.5
35	8	Order1	193Z1001-4	80	2	21.2	23.2
36	8	Order2	193Z1001-3	80	1	31.5	32.5
37	8	Order1	193Z1002-3	80	2.50	32.5	35
38	8	Order2	193Z1001-4	80	2	35.2	37.2
39	8	Order1	193Z1001-3	80	1	37.5	38.5
40	9	Order2	193Z1001-3	90	0.50	32.5	33
41	9	Order1	193Z1002-3	90	1.50	35	36.5
42	9	Order2	193Z1001-4	90	1	37.2	38.2
43	9	Order1	193Z1001-3	90	0.50	38.5	39
44	9	Order1	193Z1001-4	90	1	39	40
45	10	Order2	193Z1001-3	100	1	33	34
46	10	Order1	193Z1002-3	100	1.50	36.5	38
47	10	Order2	193Z1001-4	100	1.20	38.2	39.4
48	10	Order1	193Z1001-3	100	1	39.4	40.4
49	10	Order1	193Z1001-4	100	1.20	40.4	41.6
50	11	Order2	193Z1001-3	110	0.50	34	34.5
51	11	Order1	193Z1002-3	110	0.50	38	38.5
52	11	Order1	193Z1001-3	110	0.50	40.4	40.9
53	11	Order2	193Z1001-4	110	0.50	40.9	41.4
54	11	Order1	193Z1001-4	110	0.50	41.6	42.1

The result of the production scheduling is shown by using Gantt chart, as shown in Fig.8. It clearly shows there is no waiting time in working team 1, working team 3, and working team 4. There is only a little waiting time in working team 2. Because the process time of the later working teams is less than the process time of the former working teams, there is some waiting time in the later seven working teams.

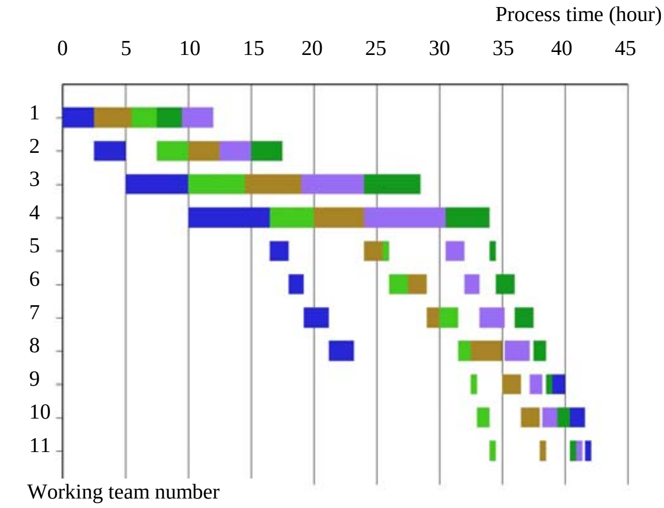


Figure 8. Result of the production scheduling

IX. SOFTWARE SOLUTION MAIN EDITORS

There are many interfaces/editors of this software. Some of them are described below.

A. Process Information Editor

Following Fig.9 presents a process information editor. Using this editor, we can enter all the process information of the composite component. It includes process number, process name, and working team number.

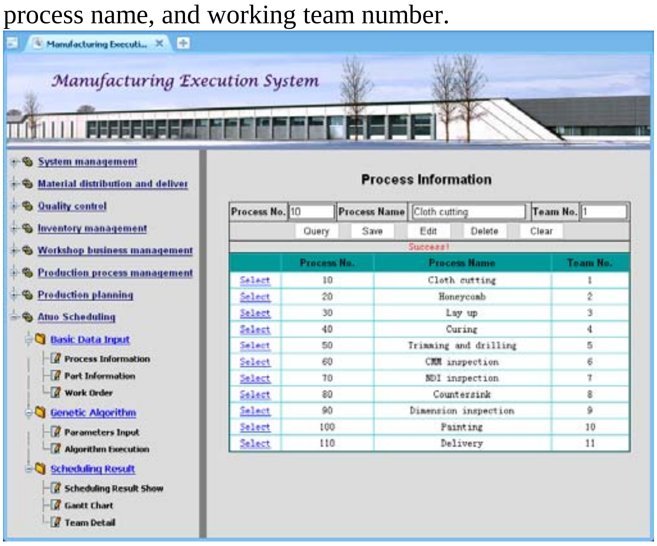


Figure 9. Process information editor

B. Part Information Editor

Part information editor provides detail information of the part including part number and the processes to be carried out to complete the part. Using this editor, part number, process number and name, team number, process time, and last process can be inputted. Fig.10 describes a part information editor.

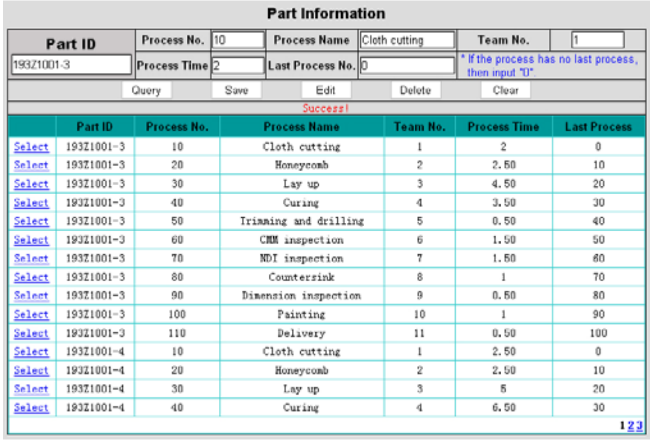


Figure 10. Part information editor

C. Work Order Information Editor

Work order information editor provides the detail information about the work order. Using this editor, work order number, work order name, completion date, and responsible person detail can be inputted. Based on the inputted order information, one order can be queried. In this editor, the composite components in this order can be also selected and issued to the work teams. Fig.11 shows a work order information editor.

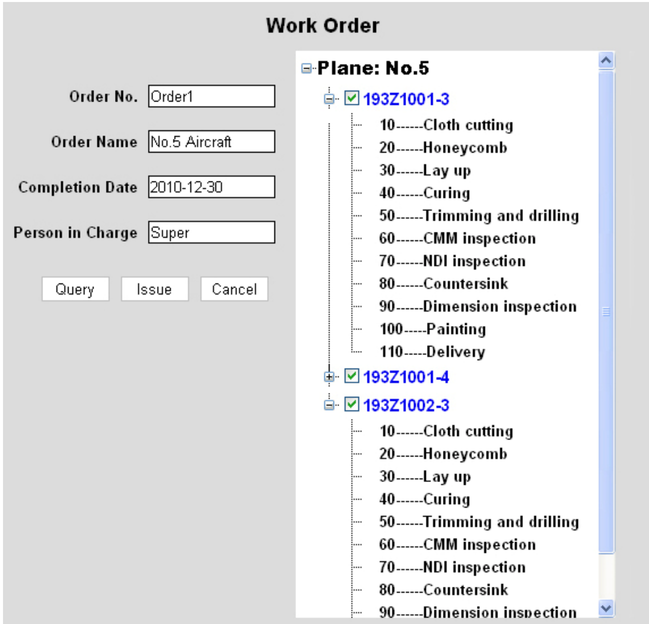


Figure 11. Work order information editor

D. Genetic Algorithm Information Editor

The genetic algorithm parameter editor is shown in Fig.12. Using genetic algorithm information editor, crossover probability, mutation probability, backward probability, number of individual, and number of generation data can be inputted in the scheduling system.

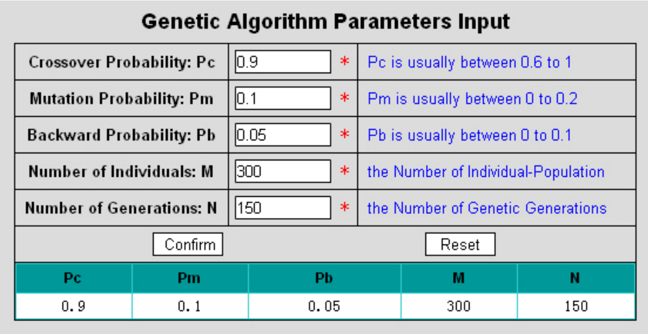
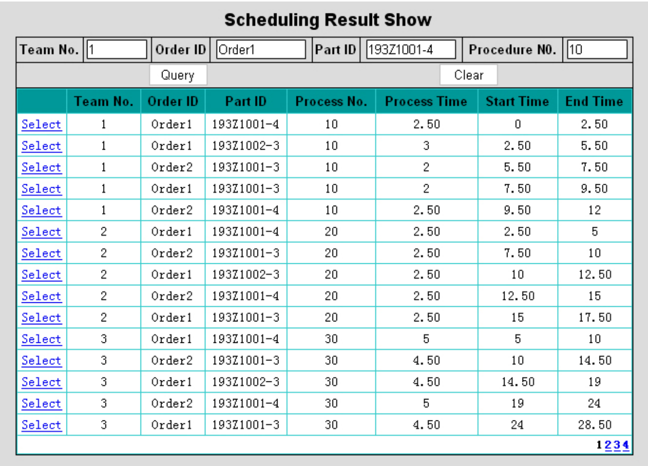


Figure 12. Genetic algorithm information editor

E. Scheduling Results Information showing Interface

Fig.13 presents the scheduling results information showing interface. Using this software interface, the optimized scheduling results are showed to the user. The scheduling results information include process sequence, process time, starting time of the working procedures, end time of the working procedures, and so on.


Scheduling Result Show

Team No. 1 | Order ID Order1 | Part ID 193Z1001-4 | Procedure NO. 10

Query | Clear

	Team No.	Order ID	Part ID	Process No.	Process Time	Start Time	End Time
Select	1	Order1	193Z1001-4	10	2.50	0	2.50
Select	1	Order1	193Z1002-3	10	3	2.50	5.50
Select	1	Order2	193Z1001-3	10	2	5.50	7.50
Select	1	Order1	193Z1001-3	10	2	7.50	9.50
Select	1	Order2	193Z1001-4	10	2.50	9.50	12
Select	2	Order1	193Z1001-4	20	2.50	2.50	5
Select	2	Order2	193Z1001-3	20	2.50	7.50	10
Select	2	Order1	193Z1002-3	20	2.50	10	12.50
Select	2	Order2	193Z1001-4	20	2.50	12.50	15
Select	2	Order1	193Z1001-3	20	2.50	15	17.50
Select	3	Order1	193Z1001-4	30	5	5	10
Select	3	Order2	193Z1001-3	30	4.50	10	14.50
Select	3	Order1	193Z1002-3	30	4.50	14.50	19
Select	3	Order2	193Z1001-4	30	5	19	24
Select	3	Order1	193Z1001-3	30	4.50	24	28.50

1 2 3 4

Figure 13. Scheduling results information showing interface

X. Conclusion

The improved genetic algorithm is implemented and applied in the production planning and scheduling of the composite manufacturing. By improving traditional genetic algorithm, the convergence rate of the algorithm is increased. The developed system has been applied in the composite component manufacturing workshop of an aerospace enterprise. The application of the production planning and scheduling system has radically changed the traditional manual production planning and scheduling manner and improved the work efficiency. By using this system, the real time monitoring and feeding back of the production activities are ensured. This information system has filled up the communication gap between ERP at the higher level and shop floor at the lower level. The production planning and scheduling system is an important part of the information system in an enterprise. It provides immense amount of information support to the entire enterprise.

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