Modeling Production Scheduling Problem and Its Solution by Genetic Algorithm

Tinggui Chen

College of Computer Science & Information Engineering, Zhejiang Gongshang University, Hangzhou, P. R. China Email: ctgsimon@gmail.com

Guanglan Zhou

School of Business Administration, Zhejiang Gongshang University, Hangzhou, P. R. China Center for Studies of Modern Business, Zhejiang Gongshang University, Hangzhou, P. R. China Email: guanglanzhou@zjgsu.edu.cn (Corresponding author)

Abstract—Production cost and performance depend on the existing resource configuration and optimization, which play a fundamental role in occupying the dominant position in the aggressive market competition for the manufacturing enterprises. The existing resource configuration and optimization is implemented at workshop level of operation activity, and thus, it is of significance in strengthening the management and control at workshop level of operation activity. In this paper, the problem of production scheduling research background is analyzed and discussed. And then, it establishes the mathematic model of the problem to cope with the production scheduling problems with the characteristics of NP-hard via the genetic algorithm. Finally, it verifies the rationality and validity of the model and algorithm through the simulation experiment.

Index Terms—resource constraints, production scheduling problem, NP-hard problem, genetic algorithm

I. INTRODUCTION

There has been a more and more aggressive market competition, after China joining in the WTO. It is fundamental to occupy the predominant position in the aggressive competition for the manufacturing enterprises through reducing cost as well as ensuring the higher production capacity and efficiency in the workshop. In addition, an effective scheduling method has become foundation and core of advanced manufacturing technology practice. Accordingly, the research on the workshop production scheduling has important theoretical and practical value. Economic globalization leads to an increasingly aggressive market competition. For any one enterprise, the production cost and performance depend on the existing resource configuration and optimization, which play a fundamental role in occupying the dominant position in the aggressive market competition for the manufacturing enterprises. The existing resource configuration and optimization is implemented at workshop level of operation activity, and thus, it is of significance in strengthening the management and control at workshop level of operation activity. Therefore, workshop scheduling strategy has been one of the popular issues research in the

manufacturing industry, the study of which is of significance theoretical and practical value.

At present, the research on scheduling theory has been paid a overwhelming attention, and has made a great progress. However, it is still not mature enough. Among them, the research on complexity of scheduling problem has become a branch of applied mathematics with a strong engineering background. For instance, Reference [1] studies the effects of production loss during setup in dynamic production scheduling for process industries producing several products on non-identical flexible processors. The production scheduling problem is formulated as a mixed integer programming model and solved using primal and dual Lagrangian based procedures. Reference [2] presents analytical results concerning algorithms applied to off-line and on-line production scheduling problems, and presents algorithms for both types of problems concentrating on machines with limited availability and show how the solution quality of two simple scheduling rules can be guaranteed in terms of a worst-case analysis. Reference [3] studies the production scheduling problem for a two-stage flow shop in which there are options of outsourcing some operations to subcontractors, whereas the logistics issue between the subcontractor and the in-house shop further complicates the problem. The author presents models for different situations of outsourcings and develops optimization algorithms and conduct computational experiments to study the managerial insights for the models and the algorithms. Reference [4] develops and tests a short-run production scheduling model for process industry application. A preprocessing method based on coefficient reduction was modified to exploit the problem structure. This preprocessing tightens the problem prior to solution by a commercial branch-and-bound code. Additional computational studies found that this approach can process constraints having up to 80-110 variables. Reference [5] presents an information system supporting decision making in the area of production scheduling. The system relies on an interactive approach of problem solving which is known in the area of Artificial Intelligence under the name case-based reasoning. It tries to solve new problems using results from old solved problems. While iterative solution procedures try to tackle problems from the scratch, case-based reasoning takes advantage from analogies between cases. Additionally, it discusses the pros and cons of the approach. Reference [6] introduces one method which provides solution on assigning parts and allocating tools to optimize some predefined measures of productivity. The aim of this research is to develop a Machine Loading Sequencing Genetic Algorithm (MLSGA) model to improve the production efficiency by integrating a bin packing genetic algorithm model in an Ion Plating Cell (IPC), such that the entire system performance can be improved significantly. The proposed production scheduling system will take into account the quality of product and service, inventory holding cost, and machine utilization in Ion Plating.

In paralleled to aforementioned methods, there are additional computational intelligence solutions for the production scheduling problems. Reference [7] proposes the new Fundamental Tree Algorithm in optimizing production scheduling in surface mining. Reference [8] outlines the fundamental issues of the manufacturing design in a genetic algorithm formulation. Both simulation and comparison results indicate that this new scheduling scheme is an effective and efficient technique to tackle the problem. Reference [9] presents an artificial neural network (ANN) based real-time production scheduling expert system existing in a hierarchical integrated computer control/ production management system for some industrial processes with multiproduction-stages and discrete event operations. Reference [10] presents an algorithm based on Ant Colony Optimization paradigm to solve the joint production and maintenance scheduling problem. The aforementioned methods obtain the satisfactory performance in solving production scheduling problems.

This paper explains the background of production scheduling problem. Then, it establishes the model of the production scheduling problem, and describes the model and parameters systematically. Furthermore, it elaborates parameter design, operator realization relevant to the genetic algorithm. Finally, it verifies the proposed model and algorithm through the application of experiment.

II. MODELING PRODUCTION SCHEDULING PROBLEM

Production scheduling problem can be generally described as: n workpieces are processed on m machines, while one workpiece is processed through k procedures. Each machine at some time can only process some workpiece of some procedure, where the next procedures could only be processed after the completion of the previous procedures. Accordingly, the research on production scheduling problem includes the workpiece processing sequence, the processing time of each procedure, and equipment allocation. In the production scheduling problem description, the "machine" can refer to the machine, or sometimes to the operation workers. "Workpiece" can refer to one component, a batch of components, or anything else, which would be confirmed

at one specific circumstance. "Procedure" can refer to the operation and sequence of workpiece through some or all the machines. "Processing time" can refer the demand time of completing an operation. As the "machine", "workpiece" and other words are illustrative, all the terminology, concepts, and the problem on production scheduling are accessible and straightaway.

This paper studies the scheduling problem of single workpiece at the workshop. There usually requires 3 parameters to describe the procedure, i, j and k, where i denotes workpiece code, j denotes procedure number, k denotes that the machine code of j procedure at i finished workpiece. Therefore, (i,j,k) can denote that the procedure j of workpiece i is completed at machine k. Here we can use processing matrix D to explain the scheduling problem of single workpiece at the workshop, while processing time matrix T corresponds to processing matrix D accordingly. The related parameters are detailed as follows.

(i,j,k)—The procedure *j* of workpiece j_i processed at machine m_k ;

 P_{ij} —The process time of workpiece j_i processed at machine m_{kj} ;

 r_i — The arrival time of workpiece j_i , or ready time. It denotes that the workpiece enters into the workshop, which is the earliest time of starting process;

 d_i — The finished time duration of workpiece j_i ;

 a_i — Permitted retention time of workpiece j_i at whorkshop, which is the interval between the entering and expected finished time;

 w_{ij} The waiting time of workpiece j_i before the procedure j;

 c_i — The finished time of workpiece j_{i_i} which the final procedure of workpiece j_i is completed;

 C_{max} — The maximum finished time;

 S_k — The sum finished time of all worpieces of some scheduling k;

 S_{min} : The minimum time of sum process time;

Here, it selects the minimum time of sum process time as the objective function, i.e. $n/m/G/S_{min}$ model.

Suppose there are *m* machines, $M_1, M_2, ..., M_m$ and *n* workpieces, $J_1, J_2, ..., J_n$, the process time of procedure *j* of workpiece J_i is T_{ij} , which satisfy the following conditions:

1) One machine could process one workpiece at one time only.

2) Each workpiece can not be processed at multiple machines simultaneously.

3) Every part of the processing sequence of predetermined sequentially, the workpiece processing.

4) Each workpiece could be processed at each machine once only.

5) The interruption of workpiece being processed is not allowed.

6) The parallel processing mode is adopted, which is when the procedure is completed, the workpiece is immediately sent to the next procedure.

Let C(i,j) (i=1,2,...,n; j=1,2,...,m) be the machine number of procedure *j* of workpiece j_i . Let $E_{i,j,C(i,j)}$ be the completion time of procedure *j* of workpiece j_i . Let $B_{i,j,C(i,j)}$ be the start time of procedure j of workpiece j_i , where $E_{k,l,C(i,j)}$ is the completion time of procedure l of workpiece j_k before the workpiece j_i processed at machine C(i,j). Here, it selects the minimum time of longest completion time as the objective function, which is illustrated as:

$$P_i = \sum_{j=1}^m P_{ij} \tag{1}$$

$$a_i = d_i - r_i \tag{2}$$

$$w_i = \sum_{j=1}^m w_{ij} \tag{3}$$

$$c_i = r_i + \sum_{j=1}^{m} (w_{ij} + p_{ij}) = r_i + w_i + p_i$$
(4)

$$c_{\max} = \max_{k} \{c_i\} \tag{5}$$

$$S_k = \sum_{i=1}^n c_i \tag{6}$$

$$S_{\min} = \min_{k} \{s_k\}$$
(7)

$$E_{i,j,c(i,j)} > 0$$
 (8)

$$B_{i,j,c(i,j)} \ge 0 \tag{9}$$

$$E_{i,j,c(i,j)} = B_{i,j,c(i,j)} + T_i$$
(10)

$$B_{i,j,c(i,j)} = \max\{E_{i,j-1,c(i,j-1)}, E_{k,l,c(i,j)}\}$$
(11)

$$\min\{\sum E_{i,m,c(i,m)}\}, (i=1,2,\ldots,n)$$
(12)

III. GENETIC ALGORITHM FOR SOLVING PRODUCTION SCHEDULING PROBLEM

Genetic Algorithm is a simulation of Darwin biological theory of evolution by natural selection and genetic mechanism of the process of biological evolution calculation model, and is one random search method evolved from biological evolution (survival of the fittest genetic mechanism). Its main characteristic is that it copes with structural object directly, while there is no derivation and the continuity of function limit, which has inherent implicit parallelism and better ability of global searching. It uses the probability optimization method to automatically access and guide optimal search space, which adaptively adjust the search direction and do not need to determine the rules. Genetic algorithm has been widely used in the fields of combinatorial optimization [11-13], machine learning [14-16], aided design [17], adaptive control [18,19], partner selection in virtual enterprise [20,21], robotic assembly line balancing [22], electronics component placement design [23], flexible manufacturing [24-26] and resource scheduling problem [27-29]. It is the key technology of modern intelligent calculation. Genetic algorithm usually adopts a natural evolution model, such as selection, crossover and mutation to solve problem. It will demonstrate the exhaustive solution to the problem of production scheduling from coding, fitness function and the genetic operators.

A. Encoding operator

Genetic algorithm is deployed for the research on scheduling optimization problems, the purpose of which is to designs a wide ordering optimization genetic algorithm through coding and genetic operators. Genetic algorithm coding problem is related to the core algorithm. Genetic algorithm coding must consider "chromosome" validity, feasibility, validity and the integrity of the problem solution space representation. In addition, the decoding complexity, the encoding spatial characteristics and storage demand are key considerable factors related to genetic algorithm coding.

As the *n* workpieces of *m* machines scheduling problem, the code length reflects the coding on the storage demand. $n \times m$ is GA chromosome in standard length. Accordingly, coding can be divided into three categories: code length is equal to the standard length; code length is smaller than the standard length; code length is greater than the standard length.

For the 3×3 JSP problem, there has 216 kinds of combinations. Take three workpieces three machines as example. The various expressions are introduced. The procedure processing time and procedure constraints of workpiece are shown in table 1:

Processing time and constraints

	Workminen	Procedure					
	workpiece	1	2	3			
Operation Time	J_1	3	3	2			
	J_2	1	5	3			
	J_3	3	2	3			
	J_1	M_1	M_2	M_3			
Machine sequence	J_2	M_1	M_3	M_2			
	J_3	M_2	M_1	M_3			

1) Operation coding expression

Operation coding expression is that each chromosome consists of $n \times m$ genes expressing operations, which is a combination of all operations, wherein each workpiece has appeared in *m* time. If the hypothesis of chromosome [2 1 1 3 2 1 3 3 2], C_{ijk} workpiece *i* operation *j* is completed at machine m, match the procedure constraint, then the chromosome corresponding to the operation sequence is [$C_{211} C_{111} C_{122} C_{312} C_{233} C_{321} C_{333} C_{232}$]. The corresponding scheduling is shown in Figure 1.



2) The workpiece expression

The workpiece encoding is that each chromosome consists of n genes expressing workpiece, which is a combination of workpiece. This process is that processing all operations of the first workpiece, and consequently, processing all operations of the following workpieces at the allowed earliest processing time. For example, let chromosome be [1 2 3], then processing the workpiece 1 (as shown in Figure 2(a)), then processing the workpiece 3, (as shown in Figure 2(c)).



Figure 2. Workpiece processing Gantt chart

3) The machine processing procedure coding

The machine processing procedure coding consists of m substring (the number of machines), where each has a length of n strings, in order to express the priority list, which each symbol refers to the corresponding machine operation. The corresponding procedure table refers to the first one appearing in the procedure table (waiting queue) will be selected in operation.

4) The completion time coding

The chromosome is expressed as a sequence table of each operation completion time. For example, let C_{ijk} be the completion time of operation *j* of workpiece *i* at the machine *k*, then the chromosomes can be expressed as:

[C111 C312 C211 C321 C223 C122 C123 C333 C232]

B. Fitness function

It is function to measure the individual fitness, also known as the evaluation function. It is a benchmark, which is used to identify individuals from groups, and is the regulation of natural selection. The higher fitness, the greater probability the next generation can inherit; vice verse. The design of function meets the following conditions:

(1) A small amount of calculation, as simple as possible, which reduces the computing time.

(2) Rationality and consistency, which reflects the quality extent of the corresponding solutions.

(3) Single, continuous, nonnegative and maximized.

(4) Generality, averting changing the function parameters frequently by different users.

As a production scheduling problem, the objective function f(x) requires minimizing the problem of maximum completion time. Here, the fitness function is expressed as:

$$fit\{f(x)\} = \frac{1}{1+c+f(x)} (c \ge 0, c+f(x) \ge 0)$$
(13)

where c is the estimated value of the threshold of the objective function.

In general, take the objective function as the fitness function. For this problem, take the reciprocal of the objective function of maximum completion time as fitness function. Accordingly, calculate chromosome fitness value, with $f_l(x)$ denoted the maximum completion time of chromosome *l*. Hence, fitness function is:

$$Fit(f_k) = \frac{1}{f_l(x)}$$
(14)

C. Design of genetic operator

(1) Selection operator

The selection operation, as the selection in the biological evolution, is a process of selecting the individual from the progeny generation based on the fitness. Here, let N be population scale, f_i be fitness of individual i, then probability of selecting individual i is:

$$p_i = \frac{f_i}{\sum_{i=1}^N f_i}$$
(15)

(2) Crossover operator

Crossover operation is similar to animal breeding, obtaining new individual. Finally, the genes crossover recombination produces a new excellent individual. When crossover probability Pc is greater, it can enhance the algorithm developing the capacity of searching, which tends to increase the failure progenies probability either. Research indicates that the Pc value ranges from 0.25~1.00. For example, there are two chromosomes (parents), A=[1011001], B=[10010110]. A, B crossover processes is illustrated in Figure 3.

Chromosome A	1	0	1	1	0	0	1 —	Crossov	er point
Chromosome B	1	0	0	1	0	1	0	0100001	n point
New chromosome A'	1	0	1	1	0	1	0		
New chromosome B'	1	0	0	1	0	0	1		
	Figure	e 3. (Cross	sovei	oper	ation			

(3) Mutation operator

Mutation operation simulates the biological gene mutation in nature due to the environment change. The chromosome (binary) encoding is expressed as the $1\rightarrow 0$, $0\leftarrow 1$. The mutation of chromosome (population) produces and maintains diversity, which is an auxiliary searching operation in the genetic algorithm. However, the defence against important gene deletion leads to a lower mutation probability. A high frequency mutation would tend to a completing random search. Let chromosome be [1 5 8 7 3 2 4 5 1 1 2], then Figure 4 demonstrates the mutation operation process.

Chromosome



IV. CASE STUDY

A. case simulation

A workshop is going to process workpieces, while the workpieces are single. There exist 3 batch of $J_{I,}J_{2,}J_{3}$ processed at 3 idle machines respectively by $M_i(i=1,2,3)$. The process procedure has been determined in advance. Additionally, the workpiece can not be simultaneously processed in different machines, while the internal sequence of the workpiece is ordered, which indicates

that when the previous procedure is completed, the sequent procedure could be processed. The sequence is ordered, and is maintained strictly. There is no interruption, and the processing time is independent from the processing sequence. The processing time is fixed. The machine is idle before the arrival of the workpiece. For a better performance of processing the 3 batch of workpieces, there requires a scheduling of the 3 batch of workpieces and 3 machines processing procedure, making the final total completion time minimization and processing procedure optimization. Table 2 is the corresponding processing procedure and the processing time of each operation, where J_i is the workpiece i(i=1,2,3); J is processing procedure matrix; T is processing time matrix; C is the whole task completion time.

Table 1

n .						
Processing	time	and	constraint	ot	each	workpiece

	Warknissa	Procedure					
	workpiece	1	2	3			
Operation Time	J_1	3	2	2			
	J_2	2	5	1			
	J_3	4	1	3			
Machine sequence	J_1	3	2	1			
	J_2	1	3	2			
	J_3	2	3	1			

Table 2 could deduce corresponding processing procedure matrix and processing time matrix below:

	3	2	1
J =	1	3	2
	2	3	1
	3	2	4
T =	2	5	1
	2	1	2

The corresponding workpiece processing time table and machine processing time table could be illustrated in Table 3 and Table 4 below.

Table III

Workpiece processing time							
Workpiece J_i	1	2	3	Sum			
J_i net processing time	7	8	8	23			
J _i processing number	3	3	3	9			

Table IV

Machine processing time							
Machine <i>M_i</i>	1	2	3	Sum			
M_i net processing time	8	7	9	24			
M_i operation number	3	3	3	9			

From the two tables above, it can conclude that the objective function of the case scheduling problem, same as minimum total completion time C value, ranges between 9 and 24. In addition, because of the different

complex extent of processing each workpiece, each machine also has different workflow. Therefore the reasonable scheduling is essential to save time and resources.

In addition, the genetic algorithm parameter settings are as follows: population size M=20, evolutionary iteration number T=800, crossover probability $P_c=0.75$, mutation probability $P_m=0.01$. The objective function is the total processing completion time of all workpieces, i.e. to minimize the maximum completion time of all workpieces. The implementation of simulation and algorithm is running on VC++6.0 environment.

The calculation outcome is demonstrated in Figure 5, where the minimum the total processing completion time (i.e., the objective function value) is 12 units of time. The procedure is that workpiece 2,1,3 is processed at machine 1; workpiece 3,1,2 is processed at machine 2; workpiece 1,2,3 is processed at machine 3.



Figure 5. Gantt chart of he final workpiece processing procedure

B. Analysis and discussion

(1) An analysis of the outcome

The scheduling outcome concludes the processing matrix (213; 312; 123), in which the gene 213, 312, 123 are the sequence tables of machine1, 2, 3 respectively. Consequently, we can conclude that during the first procedure of all workpieces in the processing, the workpiece 2, the workpiece 3, the workpiece 1, are processed respectively at the machine 1, machine 2 and machine 3 simultaneously. During the second procedure, due to the constraint, workpiece 2 and workpiece 1 are processed at machine 2 and machine 3, whereas the workpiece 3 could be processed after the completion of workpiece 2 only. During the third procedure, due to the

From the Gantt chart, it can conclude that the machine 3 is always occupied, is never idle. After processing workpiece 2 and workpiece 1, the machine 1 suspends for 4 units time and 1 unit time respectively. After processing workpiece 1, the machine 2 suspends for 2 units time. Meanwhile, from the Gantt chart, it can conclude that the three machines start working simultaneously. Additionally, from the Gantt chart, it can conclude that when the work flow is 1 or less, its utilization rate is not high, especially machine 1. Nonetheless, when the work flow increases, each machine utilization rate can be improved, where there is no idle or excessive machine. And therefore, this solution is feasible.

(2) The influence of population size

In this example, different population sizes have influences on the optimal convergence time, which are shown in Figure 6. With the population expanding, the convergence time in a given interval shows a downward trend. But after a certain threshold value, i.e. the population size expanding at one certain scale, the convergence time begins an upward trend with the population expansion.



Figure 6. Relationship between population size and convergence time

(3) The influence of crossover probability

A large number of studies indicate that the selection of crossover probability has influences on the process of genetic algorithm and its solution. In this case, P_c =0.75, the value is relatively moderate through the assessment. When the P_c value decreases, the search is in a torpid state, i.e. most of the individuals without crossover operation are directly duplicated from one generation to the next generation. As a result, the convergence time is too long, so that the waiting time of final solution is too long or deviates from optimal solution. Similarly when the P_c value increases, the search is in a randomization state. As a result, the convergence accuracy of optimal solution decreases, which finally leads to a more dispersed and dubious outcome.

(4) The influence of mutation probability

For project scheduling problem though genetic algorithm solution, the design and selection of a suitable mutation probability value is very important. In this case, $P_m = 0.01$. Generally speaking, P_m value is relatively little. Little value of P_m helps make the final solution set through genetic algorithm focused in an effective area. Furthermore, the selection of a littler mutation probability would not make it deviated from partial threshold. Instead, the larger P_m value would lead to the search in a randomization state similar as the crossover probability.

V. CONCLUSIONS

In this article, the problem of production scheduling research background is analyzed and discussed. And then, it establishes the mathematic model of the problem to cope with the production scheduling problems with the characteristics of NP-hard via the genetic algorithm. Furthermore, it presents the exhaustive explanation of the parameters and operators in the genetic algorithm. Finally, it verifies the rationality and validity of the model and algorithm through one case in the simulation experiment.

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Professor Tinggui chen is an assistant professor of Information System, College of Computer and Information Engineering at Zhejiang Gongshang university. He was bon in 1979. He got his Ph.D. degree in Industrial engineering from Huazhong University of Science and Technology. His current research interest focuses on management decision theory and decision support systems, swarm intelligence and

complexity science. He has published over 30 publications in academic journals and conference proceedings. His email is ctgsimon@gmail.com.



Dr. Guanglan Zhou is a lecture of Information System, College of Computer and Information Engineering at Zhejiang Gongshang University. He was bon in 1983. He received his Master of Science degree in 2007, conferred by the University of Liverpool, UK. Additionally, he was employed as an Academic secretary, by National Science Foundation of China, NSFC from 2010

to 2011. His research interests include data mining, electronic commerce and supply chain management. He has published over 10 publications in academic journals and conference proceedings. His email is guanglanzhou@mail.zjgsu.edu.cn