# Tactics, Algorithm and Experiences in Schedule Optimization for CNC Resources Grid

Lin Xin, Yuan Huiping, Luo Yabo
School of Mechanical and Electronic Engineering,
Wuhan University of Technology, Wuhan, China
Email: luoyabo1973@163.com

***Abstract*—The burgeoning technology of manufacturing grid provides the impossibility to share manufacturing resource over Web. Taking sharing the cost equipments as the objective, CNC resources grid is a sub category of manufacturing grid, which is facing with the difficulty of scheduling optimization. This research is divided into three parts. First, the elementary model for CNC grid is proposed and some assumptions are given, based which the differences between the CNC grid schedule and traditional schedule are detailed. Second, the selection strategy and algorithm are proposed based on the analysis of the CNC nodes features. Finally, a schedule system for CNC grid is developed and the contrastive experiences are done, which demonstrate the advantages of the novel tactics and algorithm, and the scope of application of the novel methodology.**

***Index Terms*-manufacturing grid, resource sharing, networked manufacturing, constraint satisfaction problem, schedule optimization**

## I. Introduction

The novel technology of networked manufacturing proposes a possible form for dynamic resource sharing and cooperative work in virtual enterprises. Manufacturing grid, as an extension of it in manufacturing field, helps to realize the objectives of resource sharing, collaborative designing and collaborative manufacturing, and attains the expected purpose of reducing the manufacturing cost and improving resource-utilization-rate, so as to offer new ideas and methods for community-based resource sharing, integration and optimal allocation.

Manufacturing grid was earlier researched than the manufacturing grid. Svaolainen [1] and other authors in CAC-research expounded on the application of grid technology in computer integrated manufacturing (CIM) in 1995 and emphasized on the establishment of common framework for grid, which is compatible with different steps, methods and instruments of current CIM system. Tucker's [2] provided a high-efficient model used to analyse or solve the collaborative business process based on the GRAI grid. Altogether, literatures directly introducing manufacturing grid at present are limited, but researches on virtual enterprises, agile manufacturing and networked manufacturing are rather deeper, all of which provide beneficial references and technical supports for the research or development of some key technologies (resource management, task management, etc), as the highly significant report on "US 21$^{th}$ Century Manufacturing Enterprise Strategy" [3] contributed by Lehigh University puts forward FAN (Factory America Net, FAN) aiming at greatly improving the degree of resource sharing and agile manufacturing, linking American manufacturing industries together through high-speed information networks. The importance of network manufacturing concept and servicing mechanism is reflected fully in the report "Next Generation Manufacturing" (NGM) published by massachusetts [4][5]. The Computer Integrated Manufacturing System Lab in University of Maryland intensively makes an intensive study of the key enabling technology supporting networked manufacturing and including manufacture ability analysis, collaborative design and manufacturing based on Web [6], optimization selection oriented to agile manufacturing, and manufacturing system model based on Petri network. In "the fifth framework plan" [7] and "the sixth framework plan" [8] announced by EU (European Union), they all attributed network virtual manufacturing to the same research topic, so as to improve the degree of integration and cooperation in each dispersive entity by using internet technology.

Compared to the research in the pure theory of manufacturing grid, there are more researches in applications of the manufacturing grid over networked manufacturing platform. Yu Tao of Shanghai University, China, proposed the concept of "manufacturing grid" in June 2002, and Academician Wu Cheng of Tsinghua University brought forward "network manufacturing grid" as well, after that other scientific research academies all started the study of "the application of network technology in manufacturing", representative academies among them including: Tsinghua University, Northwestern Polytechnical University, Southeast University, Shanghai University, etc. Documents contirbuted aim at studying on the reality of system architecture, platform construction and resource sharing in manufacturing grid. The main outcomes of the research are as followings: Professor Fan Yushun[9][10] and some other researchers, in the Natinonal Research Center of Computer Integrated Manufacturing System in Tsinghua University, China, has described the concept and soft technology of manufacturing grid, and on the basis of the analysis about the background and requirements of the manufacturing grid, they established the multi-level structural model of manufacturing grid based on the remote design of internet as well as the sharing of


doi:10.4304/jsw.5.12.1395-1401

manufacturing and resources. Mo Rong [11-14] and her colleagues, in a key lab of ministry of education on the field of modern design and integrated manufacturing of Northwestern Polytechnical University, also studied the concept and the meaning of manufacturing grid, and compared to analyze the similarities and differences between the manufacturing resource grid and other advanced manufacturing models in the aspect of realizing resource sharing, then constructed a task management system faced to the resource sharing and grid service, furthermore, they investigated some essential technologies, such as task model and resource nodes model, the encapsulation and integration of software system, resource management, task management and dispatching method, etc. Gao Yang [15] of Central South University investigated the description and encapsulation of manufacturing resource, along with the resource matching, the preference foundation and methods, then offered the architecture of the resource scheduling terrace, and moreover he designed the terrace-realizing model based on agent technology and globus software package. Liu Lilan [16-18] in the CIMS and the center of robot, showed the theoretical value and realistic meaning of manufacturing grid based on psychology, economics and systematology, then proposed the concept to build its system architecture, at the same time, they also researched the encapsulation and modeling to realize the function of task decomposition and planning or manufacturing resources selection and scheduling.

In summary, study on application of network technology in manufacturing is at the stage of preliminary exploration and puts forward the concept of manufacturing grid and framework model by the help thoughts of computing network, combining with research results of network manufacturing to study primarily key technologies. At present, there is no document taking CNC resources grid as a stand-alone object in China and abroad to analyze and research detailedly, but the aspect of all manufacturing resources sharing is described, whose scope involved is extensive and multiple, leading to taking no account of CNC resources which is the most important equipment in the manufacturing enterprise. There are some difficulties needed to be solved, as how to utilize effectively current CNC machine in order to realize the dynamic alliance profit maximization and cost minimization, optimize the allocation of CNC resources from the perspective of resource providers and users.

## II. Problem Description of CNC Equipments Resources Scheduling In Job-shop Form

Job-shop scheduling problem (JSP) [19] is the most general production scheduling problem and the most complicated one as well. We can describe this problem as follows:

If there are n workpieces and each work-piece is processed by m machines. The course that a work-piece processed by a machine has been called a "process", the "processing time" of which refers to the corresponding processing time, "machining paths" given before hand represent constraints encountered by work-pieces processed technically, that is the processing procedures of work-pieces.

Assumption conditions are as follows:

Assumption 1: each work-piece can only be processed by a machine at the same time.

Assumption 2: to the whole work-piece, parallel moving model should be taken in processing. That is, work-piece will be transported to the next process immediately after the former one finished.

Assumption 3: each machine can only process a work-piece at the same time.

Assumption 4: each process can only be processed by a machine and each machine can only process a process of each work-piece.

Assumption 5: it is allowed work-pieces to wait in the processes and machines to be free when work-pieces don’t reach.

Assumption 6: interruption isn’t permitted when work-piece is being processed. When one process of the work-piece once starts, it isn’t permitted to stop to insert other work-pieces on the half-way until finishing this process.

Assumption 7: technical constraints of work-piece machining should be given in advance, that is the processing sequence of various work-piece processes should have been identified beforehand.

Assumption 8: the number of work-pieces and machines and the processing time of each process has been known, and the processing time of each process including machine setting time, actual processing time, transporting time etc should keep invariant in the whole machining process.

Assumption 9: the number of each work-piece's processes should be equal with the total number of machines, and also each work-piece can only be processed once by each machine, and the different processes of the same work-piece need to be processed by different machines.

Assumption 10: the work-piece preparation time is null, that is, we can obtain all work-pieces at the beginning of processing.

Assumption 11: there is no constraint in time order among the processes of different work-pieces.

Assumption 12: work-piece must be in the state of continuous processing and not permitted to wait in the idle resource node.

Assumption 13: the priority of work-piece machining need not to be considered.

Assumption 1, assumption 2 and assumption 7 show that processing order constraints exist in different processes of the same work-piece, so the processing must be performed by the scheduled machining path. Assumption 3 show that different work-pieces in the same machine also must be performed according to the definite machining sequence, without temporal overlap. Assumption 1, assumption 2 and assumption 7 are commonly called sequence constraints, and assumption 3 called resource constraints. Sequence constraints are for processes and resource constraints for machines. Job-shop scheduling problem can be considered essentially as combinatorial optimization in sequence and resource constraints, namely to solve the problem how to determine the machining sequence of various processes and the initial processing time on each machine in this two constraints, so as to optimize some performance index, such as the minimum manufacturing cycle, the minimum mean flow time and the minimum tardiness, etc.

For the general job-shop scheduling problem, processing description matrix D and processing time matrix T are frequently adopted to describe specific examples. Each row of processing description matrix D indicates the machining of a work-piece, each column indicates the process corresponding to each work-piece of the same number, processing time matrix T indicates work-piece processing time corresponding to processing description matrix D. So if there are three work-pieces and four machines, the job-shop scheduling problem could be expressed as follows:

$$D=\begin{bmatrix} 1,1,1 & 1,2,4 & 1,3,2 & 1,4,3 \\ 2,1,3 & 2,2,2 & 2,3,1 & 2,4,4 \\ 3,1,2 & 3,2,3 & 3,3,4 & 3,4,1 \end{bmatrix} \quad (1)$$

$$T=\begin{bmatrix} 3 & 5 & 7 & 6 \\ 5 & 4 & 5 & 7 \\ 8 & 6 & 4 & 5 \end{bmatrix} \quad (2)$$

The element $d_{ij} = (i, j, k)$ in processing description matrix D indicates the process j of work-piece i is demanded to be processed in machine k, and the element $t_{ij}$ in processing time matrix T describes the processing time of the process corresponding to the element $d_{ij}$ in processing description matrix D. For example, process (2, 3, 1) in matrix D indicates the process 3 of work-piece 2 is demanded to be processed in machine 1, and the processing time is 5 time units.

## III. DIFFERENCES AND DIFFICULTIES BETWEEN CNC GRID SCHEDULING AND GENERAL JOB-SHOP SCHEDULING

Many assumptions have been made in classical job-shop scheduling problem aiming at the machining sequence of work-piece, processing time, numerate of l operation sequence and resource location etc, as all processes of each work-piece are required to be machined by a certain sequence in general job-shop scheduling. And yet it is more common that non-sequential processing exists in various processes of the same work-piece in practical scheduling problems. This paper mainly studies the CNC resources grid scheduling problems, and the research objects of which include the general CNC resources scheduling problems located in different geographical positions. The definition of CNC resources grid scheduling problem widen the definition of the classical job-shop scheduling problem to the following conditions:

(1) It is permitted to have "parallel processes" and "free processes" among processes of the same work-piece except serial sequence constraints in the classical job-shop scheduling problem. Parallel process is the process which could be machined at the same time, and free process is the process which is not bounded in by the operational sequence.

(2) The process number of each work-piece could be different.

(3) Each work-piece could have different starting time, and the finish time need not to be restricted by the process sequence constraints and the time constraints.

(4) One machine could process various processes of the same work-piece.

(5) The seat property of resources node is needed to be considered.

(6) The processing time doesn't include the transport time in processes.

To realize the sharing of CNC resources, we should effectively utilize all idle CNC equipments in different positions, not just to perform schedulings in workshop. Therefore, the CNC resources grid scheduling problem is a resources scheduling problem with a much broader representative meaning, and has more theoretical and practical value as well.

Comparing with the general workshop scheduling problem, the grid scheduling problem mainly has the following difficulties:

(1) The process route is fixed, but the operational sequencing is uncertain and the combination quantity is large.

In the general job-shop scheduling problems, all process routes of the work-piece given are linear types. In other words, they are all serial procedures. Taking the procedure $J_{11} \to J_{12} \to J_{13}$ as an example, the sequence of the process is $J_{11}, J_{12}$, $J_{13}$, which is fixed, definite and unique. Suppose that the process routes of n work- pieces which have m procedures are all the same, there will be approximately $O(n^{n(m-1)} n!)$ kinds of the procedure sequences.

As to the question of the CNC equipments grid scheduling studied in this paper, the existence of some parallel processes and free processes increased the difficulty in scheduling the procedure sequence. Even though the process route of each work-piece is fixed, the processing sequence is uncertain and various. Figure.1 shows a specific process route.

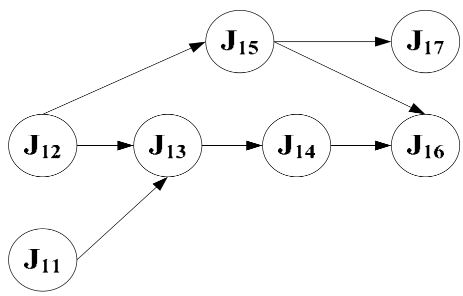


Figure 1. Process route map

There are a variety of possibilities for the processing sequence, such as:

$$J_{11} \to J_{12} \to J_{13} \to J_{14} \to J_{15} \to J_{16} \to J_{17}$$

$$J_{12} \to J_{11} \to J_{13} \to J_{15} \to J_{14} \to J_{16} \to J_{17}$$

$$J_{12} \to J_{15} \to J_{11} \to J_{13} \to J_{14} \to J_{16} \to J_{17}$$

And so on. It is not unique. So if there were n work-pieces having m parallel processes, and each work-piece has pi sorts of processing sequences, the quantity of the possible sequence is approximately $O\left(\prod_{i=1}^{n} p_i n^{n(m-1)} n!\right)$. Obviously, the number of the possible procedure sequences in the problem of CNC equipment grid scheduling will increase exponentially, which will contribute to the increasing of difficulties during procedure sequencing both in the amount of calculation and in the storage mode.

(2) The Allopatry of CNC resources node

For the general job-shop scheduling problem, what we need to consider is the time of equipment processing rather than the transport time caused by the different locations of the equipments. So the essence of the scheduling problem is to optimize the configuration of the equipments, that is to say, only by solving a single design variable $X_{ijk}$ -- the job processing equipments, the starting time of the procedure will be naturally obtained in accordance with the processing equipments and sequences. Even though some articles consider the question about equipment position, they just roughly count the transport time and the processing time, then set a fixed time premium. Actually, this approach just takes transport time into account formally, but comes into no practical effect. The real consideration about the constraints of the equipment location will bring a lot of uncertainty to the scheduling and add the difficulties of implementation.

The transport time -- $M_{ijkl}$ between the procedures is uncertain. It is uncertain ranging from procedure $J_{ij}$ to procedure $J_{ik}$ because of the allopatry of CNC resources node, the multiplicity of procedure sequencing and the diversity of resource node which each procedure has the right to choose. Assuming pi symbols the sequence quantity of work-piece i, $q_{ij}$ and $q_{ik}$ symbol separately the quantity of the resources nodes can be selected by process $J_{ij}$ and $J_{ik}$, the possibility of the $M_{ijkl}$ value comes to:

$$\sum_{i=1}^{n} \sum_{a=1}^{p_i} \sum_{j=1}^{O_i-1} \sum_{[J_{ij}, J_{ik}] \in G_i, or, [J_{ij}, J_{ik}] \in Q_i} q_{ij} \times q_{ik} \quad (3)$$

This number is really large.

The starting time universe ($e_{sij}$, $l_{sij}$) of procedure is unable to be restrained accurately. As a result of the uncertainty of transport time $M_{ijkl}$, the domain of starting time, namely the earliest starting time and the latest starting time, can not be as accurately calculated via the release period and the delivery period of work-piece as it can in a general job-shop scheduling problem, leading to its domain can not be accurately calculated.

It is unable to obtain the procedure starting time of the scheduling problem directly according to the processing resources node and sequence, as the starting time of the procedure needs to consider the relations between the unoccupied time of optional resources node and the transport time when the previous procedure has been completed, so it has to add a design variable -- procedure starting time $s_{tij}$ comparing to the general job-shop scheduling problem.

It is difficult for calculation and complicated for the storage structure to take the processing time and the transportation time as the total processing time. The sorts of optional resources node of the pre-and post procedure are numerous, the transport time $M_{ijkl1}$ of each procedure is uncertain, and its total processing time is unable to determine as well; therefore, it is fail to be transformed into a general job-shop scheduling question to get the solution.

## IV. SELECTION STRATEGY AND ALGORITHM

### A. *Operation sequencing*

In the CNC resources grid scheduling problem, even though the process routes of work-pieces including parallel process, free process, disorder process and serial process are certain, the specific pre and post machining sequence of each process is uncertain and non-unique. Therefore it is necessary to sequence the processes. If there are n work-pieces, each of them has m parallel processes and the machining sequences' number of each is pi , so the possible sorts of operation sequencing is about $O\left(\prod_{i=1}^{n} p_i n^{n(m-1)} n!\right)$. Obviously, the possibility of the combination of processing sequences in CNC resources grid scheduling problem will perform an exponential growth, but most arrangement patterns may be incompatible with resource nodes, which will cause the redundancy. In order to reduce invalid search and storage, sequence-operating and value-selecting can't be carried out at the same time in this paper, so we should distribute a resource node and the start time when one process is scheduled, and the ineffective search process should be immediately stopped if they are incompatible with each other.

### B. *Allopatry of the CNC resources nodes*

Geographical position is a factor which should be considered in order to realize the sharing of CNC resources; however, nowadays it is hardly considered scheduling problems, or just as a part of the processing time without considering alone. Actually considerations to CNC resources station constrains will add difficulties of executing and scheduling uncertainties.

Transportation time $M_{ijkl}$ among processes is uncertain due to the allopatry of CNC resources node and the diversity of alternative resources node, leading to the difficulties in calculating the earliest and latest start working time of processes. Therefore, this paper calculates roughly the starting time universe according to the release period and delivery period, and there is less calculation in the prior period , and its universe will be more accurately subtract with the correlating constraint propagation among processes in the course of scheduling. As a result, the calculation is simple, and the universe subtraction in constraint propagation is more accurate.

Because the starting time of a procedure needs to consider the pre-and post time relationship between the leisure time of the selected resources nodes and the time of the former process arriving in resources node after it been completed, it can't be directly obtained by the processing resources node and processing sequence; therefore, it is necessary to add the start time of a process in different resources nodes -- "STARTTIME", which must be obtained by comparing the leisure time of resources nodes and the arrival time of former process been completed in the assignment procedure of processes.

### *C. Conflicts in checking in advance*

The scale of CNC resources grid scheduling problems determines the great combination of its solutions, and it is necessary to inspect solution sets in advance in order to prevent excessive invalid solving processes, accelerate the speed of solving, reduce search range and exclude the possibility of non-solution, avoiding ineffective search caused by non-solution.

Resources node universe of each process could be calculated according to functional constraints of known formulas after each known parameter been determined. Starting time universe will be roughly calculated according to time constraints of process release and delivery period , and it is necessary to proceed pre-checking; if the situation "universe=Φ" exists, then we can reach a direct result : the problem has no solution, and all invalid search processes should be ended. It is necessary to carry out pre-inspections in capacity constraints of resources node sets, if it cannot satisfy, then we could get no solution, exiting the calculation.

### *D. Target constraints*

The constraint satisfaction problem is to solve all feasible solutions meeting constraint conditions. Process optimization objective make it as a special kind of constraint conditions. This restriction does not need to be checked in the general solving process and would be triggered in the condition of obtaining feasible solutions. In order to get the optimal solution, known formula is used to solve the value of goal constraint "Criterion"; if the value of "Criterion" obtained is much less, the original value of "Criterion" will be taken place by a better solution, so as to judge whether the solution is better or not by target constraint.

Scheduling strategy has been widely applied in practice for its easier realization and lower computational complexity in the general job-shop scheduling problem. Because scheduling strategy has the global sensitivity and can generate various scheduling schemes by using different rules, which have different effects on different occasions, so the selection of scheduling optimization strategy should be made by the system optimization target. There are some more practical and common optimization strategies in scheduling system: the earliest starting time priority strategy should be chosen generally in the system taking the shortest total logistics time or the minimum longest finishing time as target value; the shortest distance priority strategy should be chosen in the system taking the minimum logistics volume as target value; and the greatest difficulty in machine utilizing priority strategy in the system taking machine utilization as target value…there are other complicated strategies as well.

Scheduling strategy is based on optimization goal oriented, two optimization goals in this paper are: just-in-time and the lowest logistics costs. Just-in-time, that is the less time work-piece being completed in advance spends the better, and the phenomenon of tardiness finishing is not allowed as well. The logistics cost should be lowest, and it can't be too short in transportation time and too near in resources nodes distance. Obviously, there is no inevitable consistency or contradiction between these two objects, and the functions of the three kinds of selection strategies used commonly to optimize objectives are as table 1.

TABLE I.
COMPARISONS OF THE SELETION STRATEGIES' FUNCTIONS

| Selection Strategies | Just-in-time | Logistics Costs |
|---|---|---|
| The Earliest Starting Time Priority | ↓ | ↑ |
| Minimum Distance Priority (nearby principle) | ↓ | ↑ |
| The Greatest Difficulty in Machine Utilizing Priority | ↑ | ↑ |
| Random Selection | ↓ | ↑ |

The mean of the mark of up arrow is to increase the advanced completion time and cost. The mean of the mark of the mark of down arrow is to decrease advanced completion time and cost. So the common selection strategies are unable to play a guiding role. Therefore, this paper uses the optimization strategy based on random selection, and its advantages is that the scheduling solution would not generate partiality, and furthermore, it can search globally and jump out of the local minimum value.

## V. DEVELOPMENT ENVIRONMENT OF SOFTWARE SYSTEM AND EXPERIMENTAL RESULTS

### *A. Main interface of software design*

The main function of scheduling software is composed of three major components, the first part is the input of data in the grid scheduling problem; the second one is how to scheduling algorithm; the third one is the visualization of scheduling results.

The menu bar of main interface mainly includes four parts: system, initialization, simulation and visualization. System module mainly introduces the grid scheduling software; initialization module realizes one of the three functions on scheduling software, the input of scheduling problem data; simulation module mainly realizes the running function of scheduling algorithm; visualization module is used to more directly and vividly show scheduling results.

*B. Scheduling algorithm simulation*

CNC resources grid scheduling algorithm based on constraint satisfaction above-mentioned in this article will be achieved in simulation module, besides traditional first in first out(FIFO) method will be used to schedule the same problem, then the scheduling results will be compared.

(1) Interface design of grid scheduling algorithm

Grid scheduling algorithm based on constraint satisfaction is used to solve the problem above-mentioned according to task, job information and resources node information collected in initialization module or related information in other target constraint, and output scheduling results. Click on scheduling button above the interface of grid scheduling algorithm, then the progress bar will show the progress of scheduling. After the completion of the operation, the left form will show target values of all scheduling schemes, and the right form will show relevant feasible solutions corresponding to the movements of the mouse in the left form.

(2) Interface design of FIFO algorithm

First in first out(FIFO) algorithm perform processing based on the sequence of tasks, and the task assignment is a continuous process, namely starting to schedule the next manufacturing task when all operations of a task have been finished. This traditional scheduling method is often used in practice.

First in first out(FIFO) algorithm is used to solve the problem above-mentioned according to task, job information and resource node information collected in initialization module or related information in other target constraint, which is similar to grid scheduling algorithm, and output scheduling results. The scheduling button decides to schedule or not, and the progress bar shows the progress of the scheduling. The left form will show target values of all scheduling schemes, and the right form will show relevant feasible solutions with the corresponding movement of the mouse in the left form.

Advantages and disadvantages analysis about optimization algorithm of solving problem mainly show in two respects:

(1) Theoretical analysis

This paper theoretically analyses grid scheduling algorithm which solves scheduling problem from the perspective of "constraint satisfaction problem", fuses consistency technique based on tree-searching and finds rebound algorithm for fundamental collision variables. This kind of technology not only describes scheduling problem and its complicated constraints but also dynamically eliminates unreasonable solutions, trims the search space, decreases the combination explosion and reduces the time or space complexities in calculation from the range of variables by using constraint relations among variables, providing theoretical basis for the design of algorithm.

(2) Application analysis

Theoretical analysis is undoubtedly necessary, but it isn’t an effective method by testing questions to inspect algorithms from the applied angle. Despite it reduces the complexity in theory, some algorithms having higher complexity are widely applied because of their intuition, simplicity or easiness to code in practical application, for the simplex method is not a polynomial algorithm in linear programming problems, it is so intuitive and simple that could be more widely applied than polynomial algorithm[20][21]. So people analysis complexity in the time of developing new algorithms, and test the efficiency of algorithm by testing example as well, especially for computational intelligence algorithm whose theoretical basis generally is weak; therefore, people examine whether a algorithm is effective or not by testing example in more conditions, as comparing the running time for algorithm, the scale for solving problem and running iterations, etc.

It is the comparison of two kinds of algorithms in iterations and computation time in a certain rang of target value. The FIFO algorithm in solving efficiency is far away from the grid scheduling algorithm; system time need to be spent is 344 when grid scheduling algorithm iterates once, its target value up to 1654.80, but FIFO algorithm need to iterate 552 times and spend 22734 to achieve the similar target value, getting final result of this scheduling scheme 1640.00. The optimal target value of FIFO algorithm only can reach 1631.00 when it spends $\infty$, but grid scheduling algorithm could readily obtain the scheduling scheme whose target value is 1476.80, meanwhile its optimal target value could reach 901.60, much less than the one of FIFO algorithm. Obviously, the efficiency of grid scheduling algorithm in iterations and solving time is higher than ones of FIFO algorithm.

Of course, the grid scheduling algorithm is also far more advanced than FIFO algorithm in the scale, and it can satisfy scheduling requirements including small-scale scheduling problems having several assignments, medium-scale scheduling problems having dozens of scheduling operations, or large-scale problems having hundreds of assignments. At the same time, the grid scheduling algorithm can still find corresponding scheduling scheme when the due date of task, the processing time of operation, the quantity of resource nodes or other known conditions more harsh than before, but FIFO algorithm can’t make it.

It is certain that some problems also exist in grid scheduling algorithm, and comparative graphics show that algorithm using random selection strategy improves global search but causes poor stability in solving, big fluctuation of solution and weak convergence of algorithm.

## VI. SUMMARIES

The grid scheduling algorithm has the following advantages:

(1) The ability to find solutions is strong, so it is easy to find lots of different feasible solutions. The quality of its solution and target value is high.

(2) The efficiency to find solutions is high, and it is superior to FIFO algorithm in aspect of iterations and computation time on the process of obtaining feasible solutions in the same range of target value.

(3) The scale of solvable problems is wide, and it is feasible to solve scheduling problems including a few or even hundreds of work-pieces.

(4) The algorithm has a great capability to jump out the local optimal solution and to perform a global search , there is not any guiding information to make algorithm jump out the local optimal solution because of adopting random strategy.

(5) Based on "constraint satisfaction problem", algorithm is more simple, more intuitive and closer to real world's expression way.

Limitations of grid scheduling algorithm are as follows:

(1) The stability of algorithm solving is inferior.

(2) Process of solving is independent each time, leading to the slow convergence process of algorithm.

## REFERENCES

[1] T.Savolainen, D.Beeckmann, P.Groumpos, et al, Positioning of modeling approaches, methods and tools [J], Computers in Industry, 1995.3(25):255-262

[2] http://www.u-bordeaux1.fr/

[3] Nagel R.N.21st Century Manufacturing Enterprise Strategy.Bethehem:Iacocco Institute, Lehigh University

[4] J.Jordan, F.Michel.Next generation manufacturing (NGM). CASA/SME Blue Book Series, 1999

[5] N.N.Next-generation manufacturing:a framework for action.Agile Forum and MIT,1997

[6] http://www.isr.umd.edu/labs/CIM

[7] The Fifth Framework Program(FP5): http://www.cordis.lu/fp5/src /over.htm

[8] The Sixth Framework Program(FP6): http://europa.eu.int / comm ./research /fp6/pdf /fp6-in- brief-en.pdf

[9] Yushun FAN, Dazhe ZHAO, Liqin ZHANG, et al. Manufacturing Grid: Needs, Concept, and Architecture. GCC 2003, LNCS 3032, 2004.653-656

[10] Yushun FAN, Liqing ZHANG, Po LIU. Networked Manufacturing and Manufacturing Network. China Mechanical Engineering, 2004,19(15):1733-1738

[11] Shengyou SHI, Rong MO, Haicheng YANG, et al. A Job Management System Design and Implementation in Manufacturing Grid. Proceedings of the 1st International Conference on Semantics, Knowledge and Grid (SKG2005), Beijing, China, Nov27-29, 2005

[12] Shengyou SHI, Rong MO, Haicheng YANG,et al. Resource Allocation Research based on Contract Net in Manufacturing Grid. Proceedings of the International Conference on Advanced Design and Manufacture. (ADM2006), Harbin, China, Jan, 2006

[13] Chuanshun ZHANG, Rong MO, Shengyou SHI, et al. Study on Manufacturing Grid Resource Scheduling Methods Based on Gene Algorithm [J]. China Mechanical Engineering, 2006,17(18):1916-1920

[14] Shengyou SHI, Rong MO, Haicheng YANG, et al. Research on Task Management System Facing Manufacturing Grid [J]. Computer Integrated Manufacturing System, 2006,12(9):1477-1482

[15] Yang GAO, Kun ZHANG. Research on Resource Scheduling Problem in Virtual Enterprise Base on Manufacturing Grid [J]. Computer Utility Research, 2008,25(7):2087-2090

[16] Lilan LIU, Tao YU, Zhanbei SHI, et al. Construction of Rapid Manufacturing Grid and its Service Node. Machine Design and Research, 2003,10(l):57-59

[17] Lilan LIU, Tao YU, Zhanbei SHI, et al. Resource Management and Scheduling in Manufacturing Grid.GCC 2003,LNCS 3033, 2004.137-140

[18] Lilan LIU, Tao YU, Zhanbei SHI. Study on Service Quality Management System in Manufacturing Grid [J]. Computer Integrated Manufacturing System, 2005,11(2):284-288

[19] Lixin TANG, Yaping WU. Branch and Bound Algorithm of Mix Flow Shop Scheduling and Improving Lower Bound [A].,2001.736-740

[20] Juyang ZHANG. Study on the Modern Scheduling System Based on Constraint:[ doctoral dissertation]. Chang Chun: Computer Software and Theory Jilin University,2006

[21] Minge TIAN,Chuangjin LU. Delphi Programming.Bei Jing ：Tsinghua University Publishing House, Beijing Jiaotong University Publishing House,2007.1-15

**Lin Xin** is born in Zhejiang province, China, on 1983. She got her bachelor degree and master's degree of mechanical engineering from Wuhan University of Technology, China, respectively at 2006 and 2009. Currently she is interested in the manufacturing schedule optimization and the supply chain management.

**Yuan Huiping** is born in Shandong province, China. She got her bachelor degree of mechanical engineering from Wuhan University of Technology, China, at 2009. Currently she is a graduate student in the school of mechanical and electronic engineering, Wuhan University of Technology, China. She is interested in the optimization algorithm and its applications in manufacturing system.

**Luo Yabo** is born in Hubei province, China, in 1973. He got his master's degree from Jianghan Petroleum University, China, at 1998, and his PhD of mechanical engineering from Wuhan University of Technology, China, at 2001. He had accomplished a post-doctoral research from 2002 to 2004 in the National CIMS Center in Tsinghua University. Currently he is professor in Wuhan University of Technology. His research interesting is the schedule optimization for complex system.