Robotics and Computer-Integrated Manufacturing 26 (2010) 39–45

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

An agent-oriented approach to resolve scheduling optimization in intelligent manufacturing

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ARTICLE INFO

Article history:
Received 11 June 2008
Accepted 23 February 2009

Keywords:
Intelligent manufacturing
Multi-agent
Functional agent
Scheduling optimization
Ontology
Model

ABSTRACT

Agent technology is considered as a promising approach for developing optimizing process plans in intelligent manufacturing. As a bridge between computer aided design (CAD) and computer aided manufacturing (CAM), the computer aided scheduling optimization (CASO) plays an important role in the computer integrated manufacturing (CIM) environment. In order to develop a multi-agent-based scheduling system for intelligent manufacturing, it is necessary to build various functional agents for all the resources and an agent manager to improve the scheduling agility. Identifying the shortcomings of traditional scheduling algorithm in intelligent manufacturing, the architecture of intelligent manufacturing system based on multi-agent is put forward, among which agent represents the basic processing entity. Multi-agent-based scheduling is a new intelligent scheduling method based on the theories of multi-agent system (MAS) and distributed artificial intelligence (DAI). It views intelligent manufacturing as composed of a set of intelligent agents, who are responsible for one or more activities and interacting with other related agents in planning and executing their responsibilities. In this paper, the proposed architecture consists of various autonomous agents that are capable of communicating with each other and making decisions based on their knowledge. The architecture of intelligent manufacturing, the scheduling optimization algorithm, the negotiation processes and protocols among the agents are described in detail. A prototype system is built and validated in an illustrative example, which demonstrates the feasibility of the proposed approach. The experiments prove that the implementation of multi-agent technology in intelligent manufacturing system makes the operations much more flexible, economical and energy efficient.

1. Introduction

Globalization of international markets have created a high level of competition that requires high agility, rapid changes in the production styles and fast configuration of manufacturing systems. The manufacturing system shall adapt to the market change fast in the situation of possessing certain cost benefit, construct manufacturing process quickly and economically based on different products demands and carry out self adaptive, self organizing, self studying, liberalization and self maintenance for the whole manufacturing process dynamically. As a bridge between computer aided design (CAD) and computer aided manufacturing (CAM), the computer aided scheduling optimization (CASO) plays an important role in the computer integrated manufacturing (CIM) environment. The research results of distributed artificial intelligence domain indicate that the intelligent manufacturing system built with agent technology is the most potential development direction.

Manufacturing scheduling is the process of assigning manufacturing resources and arranging time to the set of manufacturing processes in the process plan. The scheduling problem is typically NP-hard. It is impossible to find an optimal solution without the use of an essentially enumerative algorithm and the computation time increases exponentially with the problem size. The problem become more complex when unforeseen dynamic situations are considered, when both process planning and scheduling are to be done at the same time and when other manufacturing resources are also considered. Traditional approaches in solving scheduling problems encountered great difficulties when they are applied in real situations because these scheduling methods use simplified theoretical models and are essentially centralized in the sense that all the computations are carried out in a central computing unit/center [32].

The theory of multi-agent system (MAS) and distributed artificial intelligence (DAI) provide feasible technical support for modeling and realization of intelligent manufacturing system, which becomes one of the research hotspots in manufacturing

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0736-5845/$ - see front matter
doi:10.1016/j.rcim.2009.02.003

domain [29]. Manufacturing process is a typical multi-agent questions solution process, and every department (or segment) in manufacturing system is equal to an agent in the process. Every sub-mission or unit equipment in manufacturing system could be acted upon and realized by a single agent or a well-organized agent group, and complete the manufacturing tasks together through their interaction, mutual coordination and cooperation. Multi-agent-based scheduling is a new intelligent scheduling method based on the theories of multi-agent system and distributed artificial intelligence. Multi-agent-based scheduling can dynamically and flexibly schedule manufacturing processes and rapidly respond to market demands by means of cooperation and coordination among the agents. In the past, researchers had employed multi-agent system in diverse areas of manufacturing. In the study of Sanjay Kumar, a bidding-based multi-agent system was conceptualized for the integration of process planning and scheduling. Kadar et al. [5] constructed a distributed manufacturing framework using a multi-agent system and object-oriented methodology. Kim [20] presented a cooperation mechanism between process planning and production control involving part and machine agents. Lim and Zhang [7,24] developed an agent-based framework that utilizes contract net protocols to enhance the negotiation mechanism of agents, in order to integrate process planning and scheduling. Baker [3] surveyed the dispatching, scheduling, and pull algorithm of factory control, from the viewpoint of their implementation in an MAS. Butler and Ohtsubo [16] and Gu et al. [27] presented an architecture for distributed dynamic manufacturing scheduling (ADDYMS), which have several levels of work cells and sub-work cells and each work cell has a site agent. Sluga et al. [2] and Dornfeld et al. [11] applied an MAS in process planning while Teresedai and Ramesh and Sousa and Ramos [30] applied it in dynamic manufacturing scheduling.

In this paper, the model of intelligent manufacturing system adopts agent as the basic processing entity. The architecture of intelligent manufacturing system based on multi-agent is put forward. The control strategy and scheduling optimization algorithm of intelligent manufacturing is provided. The feasibility is proved by the result of stimulation experiment. Compared with the traditional artificial scheduling, it has distinct advantages. Finally, the model of communication and negotiation between agents in the intelligent manufacturing System is studied.

2. Agent-based manufacturing scheduling

The concept of an agent comes from artificial intelligence (AI). In AI, it grew from the early work on blackboards, contract-nets and actors. The term “agent” is an elusive one to define. An agent can be a person, a machine, a piece of software or a variety of other things. The basic definition of agent in dictionary is one who acts. An agent must be automatic, social, reactive and pro-active. A typical definition of an agent is given by Nwana and Ndumu [17]: “An agent is defined as referring to a component of software and/or hardware which are/is capable of acting exactly in order to accomplish tasks on behalf of its user”. We consider that agent is the object which could finish the given task independently without people’s interference. Now the more common view is that agent should possess three important features, i.e. autonomy, adaptability and coordination. Autonomy means that the agent shall complete the related tasks actively without external interference (human or other software); adaptability refers to that agent who has the abilities of perceiving and adapting to the external environment and self studying. Coordination is an important feature of multi-agent system, in which agents coordinate and complete a task together. Therefore, the capability of multi-agent system is determined not by a single agent but by the intelligence showed by mutual coordination between agents [4,15]. Agent possesses the basic attributes such as object, knowledge, label, etc, which are composed of functional units like communication module, business processing module, inference module, study module, information transmission, etc. [12].

Most agent-based manufacturing process planning and scheduling systems use negotiation protocols for resources and tasks allocation. The CNP or its modified versions are the most common. The disadvantages of CNP are exposed when there are a large number of agents. In addition, it has other disadvantages like not detecting or resolving conflict—the agents in the contract net are considered helpful and no antagonistic (which in real-world scenarios is not realistic) and are rather communication-intensive leading to quite a high cost. Although various methods have been proposed for CNP, how to overcome these disadvantages still remains an issue. More effort needs to be put on improving CNP for manufacturing applications, especially on how to apply it to coordinate and negotiate in a collaborative process planning system needs to be investigated. In our scheduling optimization system, the specific composition structure of agent is as follows: (1) Label: an attribute that one agent differentiates from others in a multi-agent system, including name, address; (2) Object: the specific targets that agent consistently pursues, determines the responsibility and obligation of agent; (3) Knowledge: it includes facts and rules stored in the knowledge base of agent; (4) Communication module: it is responsible for communication, information receiving and sending, could transfer tasks, operate results and realize knowledge sharing; (5) Reasoning module: it infers and makes decision based on the object, knowledge, ability and latest information of agent, acts on information processing and business processing modules. The decisions it makes must be helpful for the realization of the objects; (6) Business processing module: processes business. As the main body of agent realizing objects, it is composed of business processing method; and (7) Learning module: summarizes the experiences from the operating process of agent, adds new knowledge to knowledge base and improves the capability of adapting to the changeable environment.

In an agent-based manufacturing system, the product information exchange among agents, which could be various CAD/CAM/CASO tools, databases and manufacturing execution systems, can be based on STEP, which is an international standard for computer-interpretable presentation and exchange of product data. STEP provides a mechanism capable of describing product data throughout the life cycle of a product [18,26]. The agents share resources through computer network, and compose an organized group to complete a common task. It is generally considered that multi-agent system is especially suitable for applications, which disintegrate and divide based on space, time or function.

One of the main characteristics of agents is their capability to use and share knowledge rather than only utilize data. In our paper, we use ontology to express the general knowledge of agents. As “the set of conceptions and relations among conceptions in specific domain”, ontology could express the general knowledge in specific domain efficiently, which is adaptable to be the common semantic model of agents. In many applications of agent integration, which use enquiry-driven integration mode facing to information sources of multiple domains, the agent’ enquiries usually cover many information sources. Therefore, agents usually expect to share knowledge via a kind of ontology, without caring for which information sources the knowledge comes from or what kind of processing it is through. To meet this demand, a general ontology should be constructed among local domain ontologies, which is called pervasive agent ontology (PAO) in our paper [8]. Pervasive agent ontology and local ontologies should collaborate mutually by shared lexical collection, and should be of mapping relations. Pervasive agent ontology is constructed according to the local ontologies, so its construction process is that of ontology integration in essence. Using the multi-view theory in requirement engineering as reference, and based on some limits and hypotheses we put forward the method of pervasive agent ontology upon multi-view. Regarding the local ontology as one viewpoint of pervasive agent ontology, construct pervasive agent ontology by means of heuristic rule and other methods to infer the relations of concepts in different local ontologies, through checking and processing the inconsistency among local ontologies. Although the relations of concepts between ontology viewpoints could be fixed by correlation assertion, it is possible that some potential relations have not been explored. In that case, we consider using heuristic rule to seek the possible relations of concepts between different ontology viewpoints. We concentrate the research of heuristic rule on four semantic relations: Attribute-Of, Part-Of, Kind-Of and Instance-Of. When using heuristic rule to infer, we need to concern the possible situation of semantic implication. If component set Px of concept X is the true subset of component set Py of concept Y, we consider concept X as a component part of concept Y, and their relation is Part-Of. The component part of concepts may consists of smaller parts, so implication relations exist in the component set of concepts.

3. Improved multi-agent model in intelligent manufacturing

The internal architecture of an agent is the description of its modules and how they work together. It specifies how the selected modules are organized in relation to each other. Therefore, it is necessary to define the internal architecture of an agent, to allow the designer of an agent-based system to integrate the agent into an application. Owing to the disadvantages of using deliberative and reactive agents for developing intelligent manufacturing systems, considerable efforts are placed in developing so-called generic agent architectures. However, it is often difficult to apply these generic agent architectures directly to intelligent manufacturing system. Therefore, there is a need to evaluate and develop an improved multi-agent architecture for intelligent manufacturing system. Manufacturing industry has gone through many changes, i.e. manual operation, mechanization, automatization, informatization, integration and intelligence. Industrialization realizes the liberation of human manual labor, informatization further realizes the liberation of human mental work, and intelligent manufacturing has been developed during the recent years. Intelligent manufacturing, (IM), is a man–machine integrated intelligent system composed by intelligent machine and human experts, which can carry out intelligent activities such as analysis, inference, judgment, conception and decision-making during the process of manufacturing. The cooperation between human and intelligent machine will expand, extend and partially replace the mental work of human experts during the process of manufacturing [21]. At the same time, it will collect, store, perfect, share, inherit and develop the manufacturing intelligence of human experts [13].

Selecting suitable system architecture for agent organization is a key issue to realize the potential advantages of an agent-based approach in manufacturing systems. The main types of intelligent manufacturing system are: intelligent manufacturing system that takes improving manufacturing system intelligence as the object and takes intelligent robot and agent as the tool; intelligent manufacturing system that integrates the modeling, processing, measuring and operating of corporations through Internet and biological intelligent manufacturing system that adopts solution procedure for biological problems [6,10]. At present, the distributed network IMS model based on agent is mainly adopted [25]. On the one hand, each manufacturing unit is endowed autonomy by agent to become the entity with perfect functions and autonomy independence; on the other hand, the system is endowed with self-organization capacity through the coordination and cooperation between agents.

An autonomous agent is usually not controlled or managed by any other software agent or human being, and can communicate and interact directly with other agents in the system and with other external systems, has knowledge about other agents and its environment, has its own goals and an associated set of motivations. The autonomous agent architecture is well-suited for developing intelligent manufacturing system consisting of a small number of agents. Normally, a large number of agents will increase the difficulty of negotiation and conflict resolution, and with the increase of number of agents in such architecture, the communication and coordination is time consuming. In order to improve the overall efficiency, when intelligent manufacturing system integrates the intelligent machine and human on production site, it shall also use all knowledge activities, and flexibly centralizes all activities such as order, design, produce and sales of the company through knowledge base, database, computers and communication network. Viewing the whole manufacturing process, the segments of order, design, produce and sales are functional independent of each other, and their solution procedures are quite different. The functional sub-systems of each segment complete manufacturing sub-tasks independently as well as coordinate with each other. Therefore, inside the manufacturing company, the whole manufacturing process, from design to sale, is a typical solution procedure for multi-agent questions. In order to improve the adaptability of manufacturing system to the state changes, both inside and outside, the general structure design of intelligent manufacturing system shall obey the open principles, which are showed as: (1) openness of the task: the task could be input and processed at any time; (2) openness of the system: the system shall hold the changes from interior system (e.g. Malfunction), and accept the interference from outside (e.g. the configuration that changes physical equipments) and (3) openness of solution procedure: the solution procedure shall accept the changes of information and knowledge.

In order to realize the openness of all three aspects, distributed structure is used in the intelligent manufacturing system, which endows every component entity and sub-system of the system with larger autonomy to form the intelligent autonomous agent. Intelligent autonomous agent is connected with computer communication network by means of intelligent nodes, which are equal in logic (no direction control relations between each other), dispersive in physic and independent in function. The nodes have the loosely coupled relation [23], which contacts each other by transferring messages. Based on the common communication language, they coordinate and cooperate to complete the manufacturing tasks.

4. Collaborative manufacturing and scheduling optimization

When two or more process planners work together to create a process plan, the plan of one individual can affect the job of another. As such, complications may arise. Here, complication is defined as the confused or intricate relationship of conditions or actions. To achieve a harmonious collaborative engineering system, it is important to analyze any factors, elements or conditions that could cause complications. Therefore, it is important to prepare a mediation plan in advance. In this case, mediation is defined as the act of resolving or settling complications by encouraging interested parties to come together in order to reach some form of compromise. This type of mediation is usually handled by an intermediate agent or mechanism.

In order for process planners involved with manufacturing process planning to work collaboratively, a multi-agent system should be applied to the system. A multi-agent system is a workflow management methodology that involves multiple agents and their mediation principle. Applying the multi-agent system, an agent is the object performing its task through mutual cooperation in a distributed environment. In a multi-agent system, a mediator transfers messages and controls each application agent. In this case, all application agents are connected to a mediator. The multi-agent system enables standardized communication between agents and provides flexibility and ease in implementing applications. Communication and cooperation between independent agents also holds an important position in a multi-agent system because this system is focused more on the agents' actions than on the information itself [27].

The self-adaptive modified expert system infers and obtains the modification of some parameters by monitoring the parameters of the control algorithm or identification algorithm, and then resets these parameters to meet the demand of optimized production or safe production. This mode is called self-adaptive modification [36].

The forward inference way "If…then" is usually adopted in expert system, which has low speed and is difficult to deal with fast process [9]. A way of reversal chain "Then→If" is more suitable for control system, because feedback system uses error check to return modified control. The expert system could infer whether "If" condition is qualified or not from the expected "Then" result, thus it could modify control system or select good control mode or control parameter.

Fuzzy set and fuzzy relation shall be used to express the overcomplicated data relation that cannot be described with precise data model. Fuzzy decision-making method has better robustness and possesses brief and bionic features, which is usually used to integrate the significant fuzzy information into the decision selecting organization of the external loop controlled by the closed loop in IMS to select the control action.

In IMS, the control problem could be understood as pattern recognition problem [22]. The neural network could identify the "changeable information" to reflect as the "action" signal of specified system character. The parallelism of neural network to information processing could realize online real-time model reorganization and fast study on the previous experiences, even though the information is fragmented.

The methods of expert system, fuzzy control, self studying control, neural network, etc provide the self studying and self organizing capability for future IMS. From the perspective of total processing procedure, the production feature of intelligent manufacturing system is presented as the divergence of an event. Either processing task or information happens divergently. It is showed as an asynchronous discrete-time interval process, which is different from continuous time process and divergent equal time interval process, and could not be described with the traditional differential and difference equation. Actually, divergent event control system is a mixed dynamic system control method, which contains divergent signal of continuous information and inference signal information of higher class.

The scheduling model of the system is a production workshop, which needs to process multiple components, each of which has many processing methods; a production plan shall be made, which not only decides a processing method for each component but also ensures the shortest production cycle of the whole shop. During the modeling process, in order to meet the scheduling objects, some complements are made on the basis of the standard hypothesis of the previous scheduling:

(1) Processing in advance is not allowed for any components.
(2) All components can be processed at zero time [31].
(3) Every procedure has specified working contents and processing time.
(4) When the processing of a component in one machine tool is finished, it will be sent to the next machine tool in its processing method immediately. The time for delivery shall be omitted.
(5) The auxiliary time of mechanical processing for different procedures is different, which is included in mechanical processing time.
(6) The delay time of workers and robots shall be neglected [14].

In our scheduling optimization algorithm, the notations stand for the following: Z: production cycle; T: finished processing time; i: accessory ID; h: processing line ID; j: process ID; k: machine tool ID; H: large positive number; X: processing line h is selected or not (1 or 0); t: time; L: the installation time of accessory; Y: a worker is selected or not (1 or 0); $[b_k, b_{k+1}]$: the work time of robot r $(k=1,2,\ldots,n)$; $U(k,1)$: the ideal time robot k in the machine started moving parts of machine tools O_{lj}; $U(k,2)$: the ideal time robot k in the machine started moving parts of machine tools O_{lj}; U_{ij}: part i of the first j time demolition procedures; U_{ihjr}: parts i first article h processing in the first line j by robot r processes responsible for processing finished parts from the machine down on handling time (blanking time); r_{ij}: part i of the first j processes become a question of process scheduling time; C_{ij}: the time of ending the processing about processes O_{ij}; r: the number of robot; w: the number of worker; t_{ijk}: process k on the O_{ij} in the machine processing time; S_{ij}: the time of process x having been processed.

Scheduling object:

$$\text{Minimize } Z \tag{1}$$

Constraint condition:

The last procedure in h processing method of component i,

$$T_{ihjk} - H(1 - X_{ih}) \leqslant Z \tag{2}$$

Not the last procedure in h processing method of component i

$$T_{ihjk} - T_{ih(j-1)} + H(1 - X_{ih}) \geqslant t_{ihjk} \quad i,j,k,h,g, \quad j \neq 1 \tag{3}$$

The first procedure in h processing method of component i $(j=1)$,

$$T_{ihjk} + H(1 - X_{ih}) \geqslant t_{ihjk} \quad i,j,k,h \tag{4}$$

There are procedures in h processing method of component i and q processing method of component p processed on the machine tool equipment k

$$T_{ihjk} - T_{pqjk} + HY_{ihjpqsk} + H(1 - X_{ih}) + H(1 - X_{pq}) \geqslant t_{ihjk} \tag{5}$$

$$T_{pqsk} - T_{ihjk} + H(1 - Y_{ihjpqsk}) + H(1 - X_{ih}) + H(1 - X_{pq}) \geqslant t_{pqsk} \tag{6}$$

For all components, only one processing method is chosen,

$$\sum_h x_{ih} = 1 \tag{7}$$

Any processing method of component i and component p need to use machine tool equipment k,

$$-x_{ih} + \sum_q Y_{ihjpqsk} \leqslant 0 \tag{8}$$

$$-x_{pq} + \sum_h Y_{ihjpqsk} \leqslant 0 \tag{9}$$

Any procedure in h processing method of component i,

$$T_{ihjk} \geqslant 0 \quad (10)$$

There are procedures in h processing method of component i and q processing method of component p processed by worker w,

$$T_{ihjk} - T_{pqjk} + HY_{ihjpqsk} + H(1 - X_{ih}) + H(1 - X_{pq}) \geqslant t_{ihjk} \quad (11)$$

$$T_{pqsk} - T_{ihjk} + H(1 - Y_{ihjpqsk}) + H(1 - X_{ih}) + H(1 - X_{pq}) \geqslant t_{pqsk} \quad (12)$$

The same robot in different working time slice should meet,

$$[b_k,\ b_{k+1}] \cap [b_e,\ b_{e+1}] = \Phi \quad (13)$$

If the h processing method of component i is chosen under the constraint conditions (formula (2) and formula (7)), the objective equation in formula (1) will be used to confine the completion time of the last procedure in the processing method; constraint condition (formula (7)) ensures that only one processing method of each component is selected; constraint conditions (formula (3) and formula (4)) make sure that for one designated component, the procedure $j-1$ processed on machine tool g is prior to the next procedure j processed on machine tool k, meanwhile, it explains the working sequence of robots; constraint conditions (formula (5) and formula (6)) guarantee that two different procedures cannot be processed on the same machine tool at the same time, and any machine tool cannot process more than one procedures at any time; constraint condition (formula (5)) indicates that the s procedure in q processing method of component p is processed prior to the j procedure in h processing method of component i on the machine tool k and constraint condition (formula (6)) shows the opposite processing sequence; in the meantime, when only one processing method of each component is chosen, this precedence is ensured by constraint conditions (formula (8) and formula (9)). Constraint conditions (formula (11) and formula (12)) guarantee that two different procedures cannot be processed by one worker at the same time and any worker cannot process more than one procedure at any time; constraint condition (formula (13)) ensures that the working time of any one robot cannot be intersected [1].

When a task comes to the workshop for processing, the order-handling agent first captures the total conditions. These conditions include the task ID, a list of geometrical features, feature relationships and surface quality requirements. Further, this information is transferred to the component agent, which announces a bid for that task. The content of the announcement includes order-feature sequences and the recommended process for each feature of the task. In addition to this, the announcement also includes a currency, the scheme where virtual currency values are assigned to all features in the task. Process planning and scheduling are integrated at a detailed level at this stage. The leader announces the second feature along with the allocated currency to all machine agents, including the leaders themselves. Machine agents capable of providing the processes for the second feature will come forward to bid for the task [19].

The scheduling algorithm is showed as follow:

Step 1: Calculate the ideal start time of processing for all procedures

Suppose $a_k = 0$, $P_w = 0$, $R_r = (0,0)$, $r_n = 0$

$R_u = L_{i(j-1)}$+$r_{i(j-1)}$ +$t_{i(j-1)k}$ +$U_{i(j-1)}$ (i = 1, 2,…,n and j = 2,…J_i)

Step 2: If there are non-scheduling procedures in procedure set, the one ranked the first shall be taken out from the set, and then turn to step 3

If not, suppose makespan = max (F_i) (i = 1,2,…,n)

Step 3: $L(k,1) = \max\{a_h, P_w, r_{ij}\}$

$L(k,2) = L(k,1)+L_{ij}$

If ($L(k,1)$, $L(k,2)$)$\in R_R$, adjust $L(k,1)$ and $L(k,2)$

$U(k,1) = L(k,2)+ t_{ijk}$

$U(k,2) = U(k,1) +U_{ij}$

If ($U(k,1)$, $U(k,2)$)$\in R_R$, adjust $U(k,1)$ and $U(k,2)$

$f_{ijk} = U(k,2)$

Step 4: Suppose $C_{ij} = \min(f_{ijk})$

If $j = J_i$, $F_i = C_{ij}$

If not, calculate $r_{i(j+h)} = r_{i(j+h)}$+(C_{ij}–$r_{i(j+1)}$), (h = 1,2,…,(J_i-j))

Step 5: Suppose $a_k = E_{ij}$, $P_w = C_{ij}$

Combine ($L(k,1)$, $L(k,2)$) and ($U(k,1)$, $U(k,2)$) into corresponding set R_r

Step 6: Check if there are non-scheduling procedures in set S; if there is, turn to step 2.

If not, makespan = max(F_i)

In each generation, the algorithm distributes machine tools and workers to every procedure, and ensures no interference with the working time of robots.

In a multi-agent system, a distributed autonomous scheduling model replaces the centralised control model; a negotiation process for decision-making is used instead of pre-planned processes. In addition, there is a concurrent execution of tasks instead of the usual sequential processing and different problem solvers in the same environment are used in place of a fixed problem solver. By these means, the multi-agent based modeling method significantly improves the agility and flexibility of scheduling [28].

The resultant process plan, together with part orders, is then given as the input to the scheduling module. This module works on the principle that the first part in the queue is to be scheduled before the next part. A schedule is generated on the basis of the given input (process plan and part orders) and applied heuristic [3]. The outcome of scheduling module is the starting (loading) and end (unloading) time of all the operations of every part in the order. Among many candidates, the scheduling objective considered in this paper is the minimization of the sum of completion times for all features.

5. Experimental results and analysis

We conduct experiment on our scheduling optimization algorithm of intelligent manufacturing. Fig. 1 is the convergence process of scheduling algorithm in multi-resources workshop and Fig. 2 is tasks distribution of workers.

Fig. 1 illustrates the convergence process of the algorithm. We can see that, the minimum value of function is decreasing with the evolution of group, and finally, the speed of convergence to extreme value is fast. The average value of objective function in

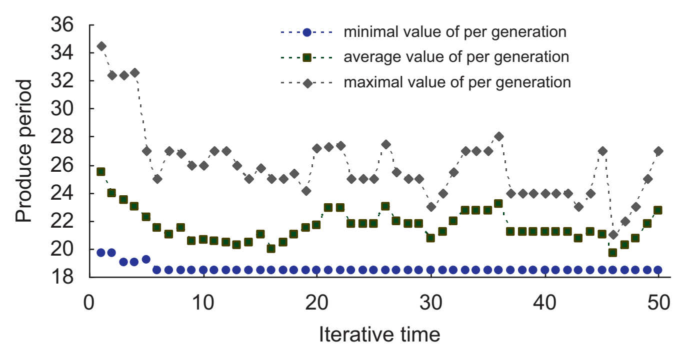

Fig. 1. Convergence process of scheduling algorithm in multi-resources shop.

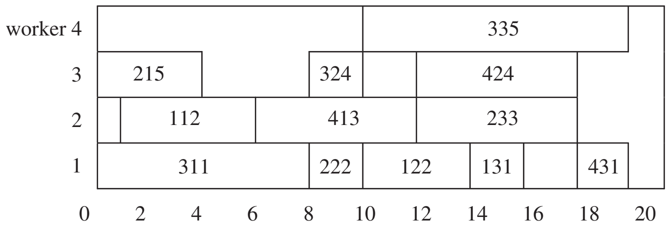

Fig. 2. Tasks distribution of workers.

the group is also decreasing with the evolution of group, and tends to the minimum value of the objective function.

Fig. 2 illustrates the corresponding relation among components, workers and machine tools. The abscissa in the figure shows the time of components processing, while ordinate indicates workers. A square with three characters stands for one procedure: the first character is the number of component, the second is the number of procedure and the third is the number of machine tool. For example, worker 3 with the first work "215" means he processes the first procedure of component 2 on the fifth machine tool, and the man-hour shall be obtained from abscissa. The time from processing start to finish shall be checked from abscissa, in the same way, the final completion time of each component shall be obtained. From this figure, it is easy to count workload of each worker.

6. Conclusions

On the basis of multi-technique scheduling problem, we study the constraint of machine tools, workers and robots in manufacturing scheduling problem for the first time. The paper also studies the production workshop-scheduling problem and gives the algorithm and results of scheduling. The stimulation result proves the algorithm to be feasible. Compared to traditional artificial scheduling, it has distinct advantages. The manufacturing system modeling and processing model based on agent have the following features: compared with general Petri net model, the processing entity agent has the features of autonomy, response capacity and activity. The cooperation is completed through the interaction and negotiation between agents, thus the consistency of functions could be guaranteed. Meanwhile, the distributed feature of processing entity agent can meet the geographic distribution in supply chain of virtual companies.

In this paper, an effective method for intelligent manufacturing in a virtual workshop environment has been formulated based on multi-agent. The architecture of intelligent manufacturing based on multi-agent is proposed to resolve the conflicts and respond to the unforeseen events. This multi-agent-based hybrid hierarchical architecture has been applied to scheduling optimization in an intelligent manufacturing workshop. Using this architecture, the developed scheduling system will be much simpler and its reliability and robustness can be improved greatly.

The future focal point of the research should be on this basis and in accordance with the purpose of the research to reasonably divide the granularity of agent in manufacturing system, establish the deep relation between agents and realize high-precision coordinating work of multi-agent. In the course of research, Internet and Intranet technology shall be fully used, especially the inherent distributed computing environment such as Web, distributed object technology, XML, etc. The combination of agent technology and computer network is the fundamental way to realize network intelligent manufacturing and global manufacturing.

Acknowledgment

The authors would like to thank the anonymous reviewers and the associate editor for their constructive comments and suggestions to our paper. And we also acknowledge the support from the Foundation of Post-Doctor in China (20080430250), the National High Technology Research and Development Program (863 Program in china: 2009AA01Z143, 2009AA01Z136), the National Natural Science Foundation of China (60773162, 60672171), HP Labs China under "On line course organization", Special Fund supported by the Doctoral Program of Higher Education of China for Fast Sharing of Science Paper in Net Era by CSTD.

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