Modeling and Simulation on Worker Collaboration in Production Cell under Dynamic Environment

Xu ZHANG[1], Yong-qiang ZHAO[2]

[1]School of Economics and Management, University of Science and Technology Beijing, Beijing, P.R. China

[2]School of Mechanical Engineering, Wuhan University, Wuhan, P.R. China

Abstract: Faced with dynamic environment, it is essential for production cells to improve the organizational flexibility to win the competition. In order to analyze the impact of collaboration behaviors between workers in production cell, an agent model of worker was developed and integrated into the production simulation model. Then, using the method proposed, a simulation on a motorcycle engine box production cell was carried out, and four different collaboration strategies were evaluated in the simulation. The results indicate that collaboration between multi-skill workers can lead to a better performance of the production cell facing unstable manufacturing environment..

Keywords: production cell; worker collaboration; dynamic environment; modeling and simulation

1. Introduction

Production cell (PC) is a typical discrete manufacturing system with high complexity, who is faced with an increasingly dynamic and fluctuant manufacturing environment in recent years. With external product demand becoming more uncertain, diversified, and the product life cycle growing shorter, the PC is forced to improve its flexibility to adapt to the unstable environment. Enhancing organizational flexibility is an effective way for PC to cope with the uncertain environment and turbulent market, which is mainly realized by using flexible organization pattern and high-quality production personnel[1-3].

Because of the important role of the organizational flexibility in improving the PC's performance and benefit potential, the research focus has transferred from manufacturing flexibility to organizational flexibility in recent years. Typical qualitative researches includes Yauch using balance theory studied the impacts of multifunctional team, dynamic configuration, cooperative behaviors on the member load in agile manufacturing context[4]. Cordero analyzed the relationships between organization technology, AMT, competent workers and manufacturing performance & flexibility through questionnaires[5]. Sara discussed the influence factors of flexibility in manufacturing system based on contingency theory, and proposed several flexible strategy about organization structure, task integration and etc.[6]. However, because of lacking quantitative analysis about organizational flexibility elements and their influence mechanism, these researches are unable to provide operationable optimization strategies of organizational flexibility. Fortunately, computer modeling and simulation can support dynamic analysis and scheme evaluation for complex system, which is now wildly applied in manufacturing operation mechnism analysis, evaluation and improvement, and is a most promising method for researching flexibility strategy analysis. Some valuable researches have been carried out in this area, for example, Zuelch used active networks to establish decision-making process model for manufacturing workers and applied it into the simulation of the process of equipment maintenance operations[7]. Robinson established a visual simulation model for a single person's decision-making process, which was used to evaluate and improve decision-making ability of the workers[8]. Zee adopted object-oriented technology and proposed a modeling method for manufacturing simulation model including actions of control[9]. Tan modelled the collaboration between human and robot in cell production system by task analysis approach, an assembly operation simulation was made to verify the impact of human-machine collaboration on the performance of manufacturing system[10].

However, these above-mentioned simulation studies mainly focus on individual behaviors of human workers, its initiative and learning behavior, the organizational collaboration behaviors between workers and their impact on system performance are seldom studied. So, in this paper, firstly the dynamic manufactuing environment and the collaboration behaviors of PC is studied, an agent model of worker is developped based on complex adaptive system (CAS) theory. Then, the agent model is integrated with production model established by discrete system simulation software, to simulate the impact of collaboration strategy on PC. Finally, comparative simulation experiments of different collaborative schemes are designed and conducted based on the background of a motorcycle engine box production cell.

2. Agent Model for Worker of PC

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2.1 Dynamic Environment Parameters of PC

The PC dynamic environment parameters can be divided into internal environment parameters and external environment parameters, the internal environment parameters is with respect to the changes of production lot size, product combination, process equipment, etc. While the external environment parameters is regarding to the changes about production pattern, which includes patterns such as individual customization, multi-varieties and small-batch production, etc. Based on this, the dynamic environment parameters of PC is represented by a septuple:

$$VE=\{E_O, E_R, E_T, E_M, E_P, E_D, E_H\} \quad (1)$$

1) E_O is order parameter, used to represent the change of production pattern, which can be furtherly expressed by a quadruple $E_O=\{O_A, O_T, O_S, O_E\}$. Among them, O_A is order amount, O_T is order type, O_S is order status including cancellation status and normal status, O_E is order emergency degree which is divided into 5 levels in this paper.

2) E_R is resource paremeter, used to represent the change of resource. The short supply, delayed supply, and quality defect can influent the production execution. E_R is furtherly expressed by $E_R=\{R_R,R_A,R_S,R_E\}$, where R_R is status of raw material including normal supply status and short supply status, R_A is status of purchased parts containing arrived status and delayed status, R_S is status of auxiliary resource including short supply status and normal supply status , R_E is the quality defection identifier which is set as a probability in the models.

3) E_T is process parameter, used to represent change of process. Usually, process change includes new process introduction, process function structure change, and product function change. The E_T in this paper is just set at two status, process didn't changed and process changed.

4) E_M is equipment parameter, used to represent change of equipment. The change of machines, especially when failure occurs, will seriously affects the production. E_M is expressed as $E_M=\{M_L, M_N\}$, where M_L is the equipment layout including two status, didn't changed and changed. While M_N is the status of equipment which contains normal status and abnormal status, and the abnormal degree is divided into different levels according to its severity.

5) E_P is product parameter, used to represent the change of product. During the prduction process, defective goods will appear with the fluctuation of manufacturing system, the introduction of new product and demand changes can also cause a different environment. E_P is expressed by $E_P=\{P_S, P_C, P_N\}$, where P_S stands for product stability, a proability is set to decide the defective rate, and whether a defective product can be fixed is also determined by another proability in models of this paper. P_C is the complexity of product, P_N is the flag to identify whether the product is newly introduced or not.

6) E_D is due date parameter, including advanced due date, delayed due date, normal due date in the models of this paper.

7) E_H is worker parameter, used to represent the change of worker which will change the organization stability, and the collaboraion efficiency in production process. E_H is expressed as $E_H=\{H_E, H_S, H_P\}$, where H_E stands for misoperation rate which will cause quality fluctuation and equipment failure. H_S is the skill level of a woker, higher skill means shorter operation time and higher quality. H_P is collaboration preference of worker, different worker may have different preference rule which will influent partner selection and collaboration efficiency.

2.2 Agent Model

In a PC, workers not only have simple operation/reaction behaviors, but also should have decision/thinking behaviors and collaboration behaviors. So, based on stimulate-response model[11], a three-layer structure agent model of PC worker is proposed, as shown in Fig.1.

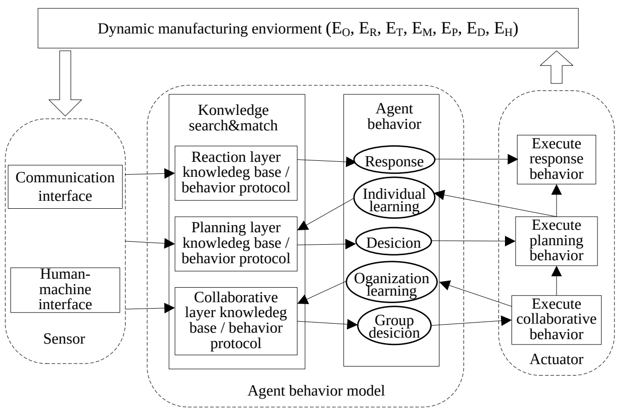

Figure 1. Agent model of worker

Firstly, the agent sensor perceives the production environment information, the information is processed by knowledge searching and behavior matching, and then behaviors are output to act on external environment by actuator. If the information from sensor matches the rules or conditions of the reaction layer, the agent needs no reasoning and reacts according to reaction rules directly. For example, if a defective product is generated, the worker automatically places it in the defective area. If local decision-making is needed according to the environment information, knowledge searching and behavior matching of planning layer will be in operation. For example, when production tasks changes caused by fluctuations of orders, the production manager has to find a suitable scheduling strategy. In some cases, if the information fused by sensors involves multi-agents or exceeds local processing capability, the agent will act according to the knowledge of collaborative layer. For example, a maintenance worker in face of maintenance failure will ask a senior maintenance worker for help; while the senior maintenance worker responds to the request, then the two complete the maintenance tasks together.

2.3 Collaborative Behavior between Workers

To improved the performance of manufacturing team and the flexibility of PC, effective collaborative behaviors should be adopt to complete tasks. Usually, in production organization there are two types of collaboration, appointed collaboration and spontaneous collaboration. Appointed collaboration means the collaboration relationship is designated beforehand. While under spontaneous collaboration pattern, task agent can send collaboration requirment to all worker agents who are capable of finishing the task, and can select the best parterner to cooperate according to the status and skill list of candidates. Fig.2 depicts the agent searching process of a spontaneous collaboration, two different colors in the figure represents two different worker agents.

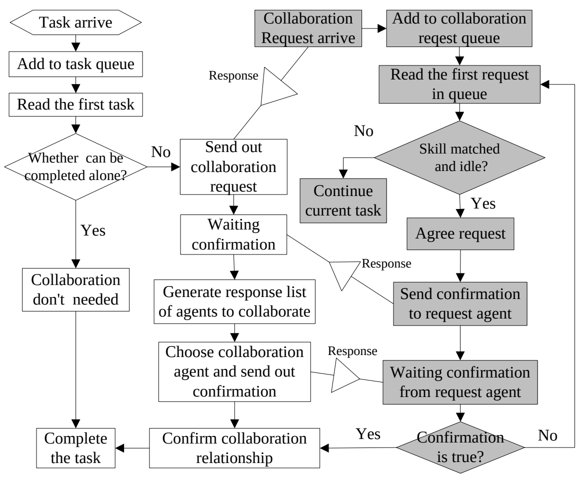

Figure 2. Collaboration process between worker agents

The collaboration seeking process can be divided into four stages:

1) Collaboration task generation. For the nomarl complex task or abnormal task in production cell, if the task can't be completed by the worker, then the task will be considered as collaboration task which needs to cooperate with other workers.

2) Collaboration structure determination. Genarally, in production cell, different worker agents have different skill type, skill level and role, and an idle worker agent has responsibility to collaborate with another worker agent who needs cooperation. Under the same skill type, the higer the skill level is, the shorter task completion time is, and the collaboration effect will be better.

3) Worker agent seeks partner to collaborate and determines how to collaborate. Firstly, the collaboration request agent sends request which contains important collaboration task information to all the worker agents in the production cell. Then, the idle worker agents who are able to complete the task will response to the request agent. After the collaboration request agent received enough response, certain rules will be called to choose collaboration partner from all response agents, and then confirmation will be sent out.

4) Two worker agents established collaboration relationship then complete the collaboration task.

3. Collaboration Simulation Realization

The worker collaboration simulation of PC is realized through integrating worker agent model with production model established by discrete system simulation software, its principle is shown as Fig. 3.

1) The basic information of the PC production process is collected from perspectives of organization structure, logistics layout, workers collaboration relationships etc. Then basic production process model is established using production system simulation software.

2) By analyzing behaviors such as operation, quality control, planning & scheduling, equipment maintenance, the basic behaviors of PC workers can be identified, then these behaviors will be classified into response layer behaviors, planning layer behaviors, and collaborative behaviors. Worker behaviors can be expressed by second developing tools of simulation software or intelligent calculation of data processing software, the reasoning process is encapsulated into reasoning function, and the function will be called by agent class created to stand for a worker. Finally, using dynamic link library (DLL), a whole agent class is packaged as a DLL, the DLL will be used as a platform in which the bottom information is transferred and the logic processing is carried out. The DLLs are connected with the basic production process model, and can be called when simulation runs.

3) Data interface processes the communication events, generates order demands, simulate environment changes, machine failures, transfers related data to the basic model, and processes the status data of PC as well.

4) During simulation, dynamic data of target vectors can be collected real-timely for further use.

To start the simulation, self-defined simulation control interface should be opened first, and initial parameters need input. When simlation arrive the node where worker agent decision-making is needed, program will wait for a decision which will in turn change the simulation parameters to make simulation continue. When terminal condition is satisfied, simulation stops.

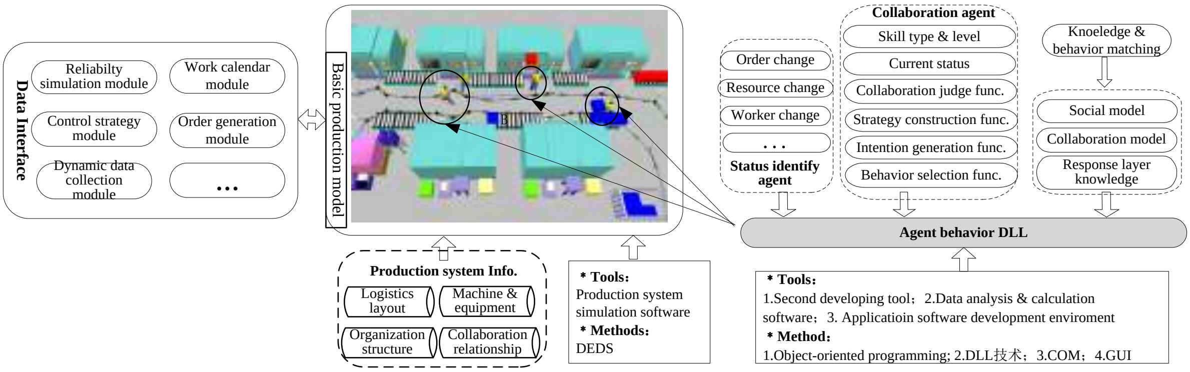

Figure 3. Realization of worker collaboration simulation

4. Case Study

4.1 Basic Information of the PC

A production cell of motorcycle engine box has totally 9 CNC machines, numbered from M1-M9. Three kinds of parts are processed, named by XT, GT, and K40. The production route of XT is M9→M1→M2→M3→M4→M5, GT is M6→M7→M8, and K40 can be processed by M2, M4 or M7 alone. The orders of the PC vary with a high frequency, changeover tasks are frequently needed. The PC has 6 operators(Op1- Op6), and 1 monitor (Op0), each operator is responsible for the processing and changeover tasks of his own machines designated for him. Among them, Op1 is designated with M1 and M2, while Op2 with M3 and M4, Op3 with M5, Op4 with M6 and M7, Op5 with M8, and Op6 with M9. The monitor Op0 undertakes no processing tasks, but is responsible for production planning & management, and supporting operators to chang the production lines. The PC team is a multi-skill and autonomous team, all the operators and the monitor are capable of conducting changeover tasks.

Based on the modeling approach proposed above, a worker collaborative changeover simulation model is established, as shown in Fig. 4.

Figure 4. Worker collaborative changeover model

4.2 Simulation Settings

The purpose of this experiment is to simulate partial dynamic environment parameters including product change (E_P), equipment change (E_M), oder change (E_O), and worker change (E_H), and evaluate the impact of 4 different collaborative changover schemes of the PC.

The 4 schemes are as follows:

1) Scheme 1: autonomous production team without collaboration. Under such scheme, each operator responsible for the processing tasks and changover tasks of his own machines.

2) Scheme 2: autonomous team with appointed collaboration partner. Op1 and Op5, Op2 and Op3, Op4 and Op6 is designated to help each other with changovers respectively, and all the operators is allowed cooperate with the monitor.

3) Scheme 3: autonomous team with spontaneous collaboration. When collaborative changeover is needed, the operator sends requests to all potential partners, the candidate with the highest skill in the response list will be chosen to cooperate. The collaboration rule for candidate operator is that if he receives a request and he is idle in that moment, he agrees to collaborate with 100%.

4) Scheme 4: autonomous team with spontaneous collaboration, and with a passing rate of collaboration request. The different between scheme 3 and 4 is that, the collaboration rule for candidate operator under scheme 4 is if he receives a request and he is idle in that moment, he will still have a passing rate *r* for the request. *r* is set to 50% in scheme 4.

4.3 Simulation Analysis

In order to validate the feasibility and practicality of the simulation method proposed, a historical order sequence with 99 orders is input into the model and is generated circularly while simulation runs.

After 10 simulation runs (each run lasts 3 months) product output, effective changeover time, and total changeover time are collected. Product output is the sum of three kinds of parts during simulation, effective changeover time is the actually time cost to change the production line, and total changeover time is the effective changeover time plus the time cost to wait for cooperation. Because during each simulation run, many times of changeover are needed, so the effective changeover time and total changeover time are averaged. Comparasion between 4 shcemes as shown in Fig.5 and Fig. 6.

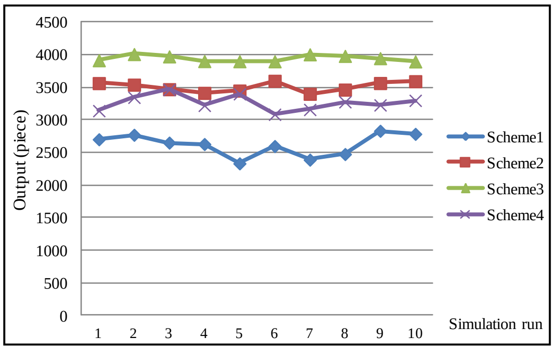

Figure 5. Product output comparasion

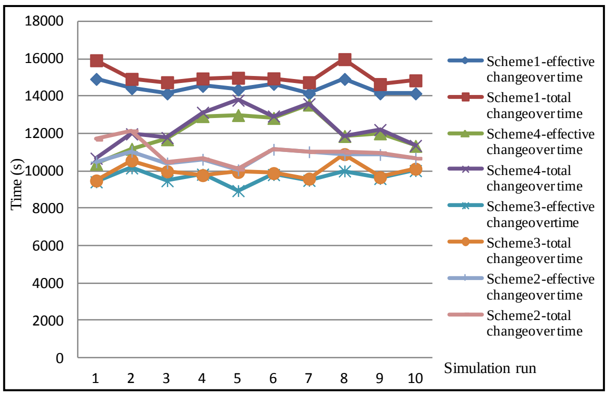

Figure 6. Changeover time comparasion

Results in Fig. 5 and Fig. 6 show that under scheme 3 (autonomous team with spontaneous collaboration), the performance of the PC is best, the product output fluctation is relatively smallest, and because the partner with highest skill can be chose at each collaboration node, the changeover time is relatively shortest. The other 3 schemes display greater fluctation in performance, and the performance of scheme 1(autonomous production team without collaboration) is worst.

Scheme 2 (autonomous team with appointed partner) shows a better performance than Scheme 4 (autonomous team with spontaneous collaboration, and with a passing rate) , this is because under the passing rate 50% much time is cost by waiting for collaboration.

5. Conclusion

This paper analyzed the dynamic manufacturing environment of the PC, established a worker agent model, the simulation realization for worker collaboration behaviors was presented, and the simulation on a PC of motorcycle engine box was carried out to verify the feasibility and practicality of the simulation method proposed. Our further research will focus on improving the behavior protocols of the worker agent model, and researching complex organizational behavior considering hierarchical relationship, different organization structure.

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