Worker Cooperation Simulation in Mechanical Manufacturing Cells

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***Abstract* — Worker cooperation has important influence on manufacturing systems. In this paper, worker cooperation plans in mechanical manufacturing cells (MC) are studied using simulation method. First, worker cooperation are classified into three types, including non-cooperation, assigned-cooperation, and autonomous cooperation. Next, a human-integrated simulation model was proposed and used to simulate the working process of the workers in MC, therefore to find out the most reasonable scheme of worker cooperation. The simulation model of a motor-cycle engine manufacturing cell was built as a case study. Simulation results show that the workers in this MC should adopt autonomous cooperation scheme during working, for it can reduce the total changeover time as well as improve the human utilization rate due to human flexibility. This case study shows that the method proposed in this paper provides an effective way for production managers to find out the best worker cooperation plan.**

Keywords - mechanical manufacturing cell, Worker cooperation, Simulation model

I. INTRODUCTION

In order to adapt to the fierce competition, the way of manufacturing industry has changed from mass production to multi-varieties and small batch cellular manufacturing. Compared with the traditional mass manufacturing, manufacturing cell (MC) has been recognized as an effective way to improve the areas utilization, optimize the logistics path [1] and avoid product quality fluctuation in dynamic environment [2]. With multi-varieties and small batch production become main manufacturing style, companies focus on 5 elements which are time, service, quality, cost and environment instead of quality and cost, so when faced with dynamic environment, company's responses ability is to be a key factor of competitiveness [3-4]. For the poor flexibility, slow response and poor ability to deal with abnormal condition, the MC can't adapt to the dynamic environment to improve production efficiency. Because of this situation, a large amount of previous researchers, related to multi skilled workers and human behavior to improve organization flexibility, have tried to solve those problems [5-6]. Brown A et al. found that workers training can improve multi-variety manufacturing cell efficiency [7]. Liu C G et al. believed that multi skilled workers are important in MC, and constructed a mathematic model based on train cost and processing time [8]. Liao Shilong et al. considered the multi skilled workers reassignment and other factors, and constructed MC based on minimum decision cost [9].

The most of the above studies can promote the production efficiency, but they focused on the individual operation, which is time-consuming. So the MC should be researching the worker cooperation which response quickly to dynamic environment. However, a lot of researchers focus human cooperation on enterprise level, similar research like Hausken K et al. [10-12] focused the human cooperation on company organization, and then analyzed the cooperation result, and their results indicated that cooperation can improve the efficiency. Now, only a few researchers are attention to MC worker cooperation. In order to meet the dynamic environment request, Bokhorst J A C et al. [13] studied the influence of cooperation behavior in MC. Qiu J J et al. [14] discussed the maintenance strategy of MC and constructed a simulation model with agent technology, the simulation result showed that collaboration maintenance is better than non- collaboration. Zhang X D et al. studied the human cooperation based on organization learning, and then used this theory in a motor-cycle engine MC. Shi Hongguo et al. constructed an independent cooperation simulation model of MC and used it on real production. In summary, above-mentioned all emphasized the individual ability influence to MC and achieved analysis the influence of human behavior. However, these researches neglected worker's autonomous behavior, environmental adaptability and worker's initiative cooperation, and they didn't in-depth analysis the variety worker cooperation in MC.

MC as a complex manufacture systems, in reality production it has all kinds of workers cooperation to finish the task, like cooperation maintenance and changeover. To improve the organization flexibility based on cooperation, a worker cooperation oriented simulation model was presented. In section 1, three worker cooperation types are studied in MC. In section 2, a human-integrated simulation model which can simulate the working process of the workers in dynamic environment is developed by integrating worker behavior agent model and manufacturing process model, the principle and construction methods is discussed in integrated model. Next the human-machine integrated simulation model is applied in a motor-cycle engine MC, the different worker cooperation plans be simulated, it can provide the scientific view for organization optimization and provides an effective way for production managers to find

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out the best worker cooperation plan. In section 3, the conclusion of this paper is draw.

II. WORKER COOPERATION ANALYSIS IN MC

With product demanded, purchase and sale becoming more uncertain, MC is involved in external dynamic environment, the product delivery cycle growing shorter and resource status is difficult to predict. Besides, because the schedule, resource, machine and worker are uncertain, which lead the internal manufacturing environment diversified, the manufacturing system and organization becoming unsteadily. When faced with uncertain environment, traditional individual operation can't quickly organize production, so a quick cooperative operation is crucial for MC, as it can provide the ability to match the product to dynamic environment demand, i.e. cooperative maintenance can improve efficiency and quality when equipment failure in complex conditions. Generally, the production behavior involved machine operators, maintenance, quality control and exception handling in a MC. Although those behaviors are different, the processes of cooperation have in common. In actual production, not all staff is willing to cooperate with others, so non-cooperation is a special case of cooperation. So that this paper classify three cooperation styles, that is non-cooperation, assigned cooperation and autonomy-cooperation.

(1) Non-cooperation. In this style, the worker who don't cooperate with others only do their own work, they refusal all the cooperative requests. The non- cooperation process is as shown as Fig. 1.

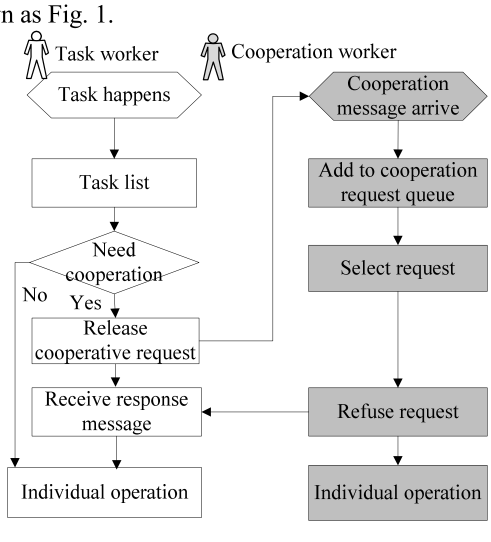

Figure 1. Non- cooperation Process

(2) Assigned cooperation. In this style, each worker has a fixed cooperation partner, when the task coming, the task worker only send the message to fixed cooperation partner for request. If the cooperation partner is busy, task worker should be waiting until the partner is idle. At the same time, all the workers just participate in one task. The assigned cooperation process is as shown as Fig. 2.

(3) Autonomy-cooperation. In this style, each worker don't have a fixed cooperation partner, they can send message to all of the workers. In general, the task worker fined the best cooperation partner based on the task attribute, production condition and operation skill. When cooperation partner is busy, task worker can find another one or wait until the partner is idle, but at the same time, all the workers just participate in one task. Actual cooperative process is task worker send message to cooperation partner. When the partner receives the message, he will decide whether to accept or refuse the task to his current condition. Because the cooperation process is complex, the autonomy- cooperation process is as shown as Fig. 3.

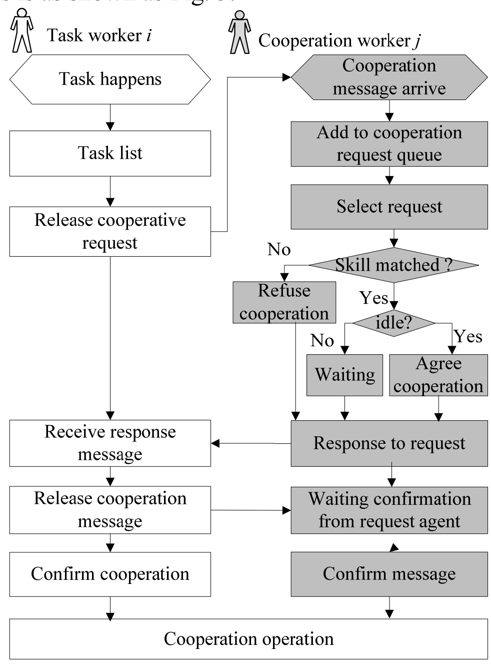

Figure 2.Assigned Cooperation Process

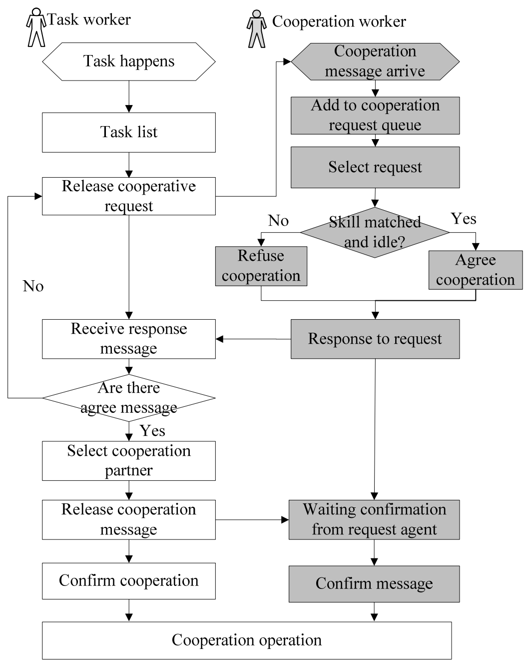

Figure 3. Autonomous Cooperation Process

According to the general process, cooperation behavior is divided into four stages: firstly, task worker adds the task to his task list. If there is more than one task, he will select one with the highest order priority. After task selection, he will send cooperative message to the manufacturing team. Secondly, cooperation workers with required skills will response to his request. If he agree the cooperation then send “yes” to task worker, or send “no”. Thirdly, after finishing receiving the response messages from cooperative worker (workers), when the task worker receive “yes”, the task worker selects a partner to cooperate. If there is more than one workers agree cooperation, the task worker will select one with the highest skill level. But if the task worker receives “no”, he will send cooperative message again. Fourth, after confirmation, the task worker will process operation with the cooperative worker selected.

III. WORKER COOPERATION PLANNING BASED ON SIMULATION

In this part, the human-integrated simulation model structure is given, and then a simulation model of a motor-cycle engine MC was developed used the integrated model theory to study which cooperation style of workers is most reasonable for the production. Based on the simulation result, the best worker cooperation plan can be worked out.

A. *3.1. Simulation modeling*

In order to realize the simulation on worker cooperation of MC, a human-machine integrated model is built, which integrates both manufacturing process model and the worker behavior agent model, the structure framework as shown in Fig. 4.

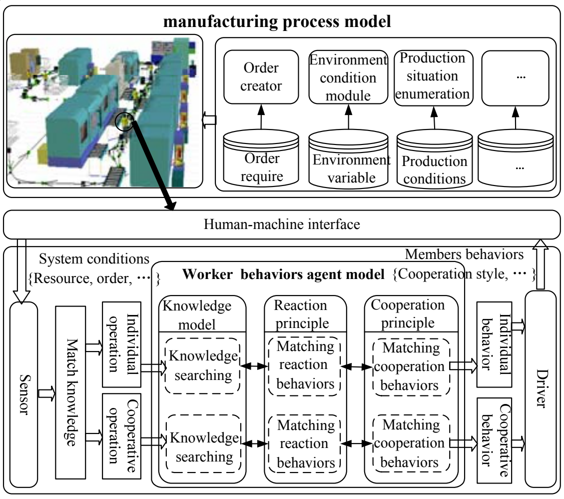

Figure 4. The Human-integrated Simulation Model Structure of MC

The human-machine integrated model includes manufacturing process model, human-machine interface, and worker behavior agent model. The manufacturing process model consists of layout, worker information, production process, production information, logistic route, environment information,and so on. Human-machine interface which is used of transmission data, information and system state connects the manufacturing process model and worker behavior agent model. In real production, workers have different behaviors because of their knowledge and experiences, so the worker behavior agent model which simulates the worker behavior and choice of cooperative partner include cooperation principle, reaction principle and knowledge base. The human- integrated simulation model work theory is when the production task coming into manufacturing process model, the human-machine interface sends the status information to human behavior agent model and start agent program. Then agent began to searching and matching behavior according to knowledge, cooperation principle and reaction principle. At last, the behaviors and worker statues will be return to manufacturing process model.

B. *Simulation model inputs*

This MC has 7 workers (which are denoted as H1 to H7), 9 numeral controlled machines (which are denoted as M1 to M9), and 3 part families produced, i.e. XT, GT and K40, the human-machine relationship, human cooperation partnership, and processing sequence of each family are listed in Table 1. Following with the above-mentioned simulation method, the manufacturing process model is built using FLEXSIM software which is discrete event simulation platform, and worker behavior agent model which is developed by C++ programming embedded into the production model by DLL technology. Then the DLL is connected to the manufacturing process model. The 3D model of the integrated model developed is shown as Fig. 5.

As the manufacturing environment complex in motor-cycle engine MC, the human-integrated simulation model should be set a lot of parameters to simulate the uncertain environment. In real production, the motor-cycle engine MC is always involved in worker operation error, material unitability, changeover, orders changes and other dynamic environment. Considering the MC situation, four factors of dynamic environment are designed in simulation model.

(1) Worker operation error. Because of the different of worker skill, labor strength, and environment, the workers will make mistake in the operation. In the model, we set error rate which is 3% to simulation the operation error. When operation error happened, it will take other time to deal with the mistake, which affect production stability and quality.

(2) Materials unitability. The materials unitability is consist of material shortage and quality problem. In production, the MC will reschedule the task if material shortage happened. If the material have quality problem, it will continue production when the problem material be repaired, but the worker has probability to find the problem. In the model, we set material shortage rate is 12%, quality problem rat is 3%, and quality problem found rat is 85%.

(3) Changeover. Because of the multi-varieties and small batch, the machine always should to convert one production to another. In this model, we set production change to simulation the changeover.

TABLE I THE ESSENTIAL INFORMATION OF MC AND COOPERATION PLANS

worker	human-machine relationship	Human cooperation: non-cooperation (Scheme A)	Human cooperation: assigned cooperation (Scheme B)	Human cooperation: autonomy-cooperation (Scheme C)	processing sequence
H1	M1,M2	H1-H7 non-cooperation	H5	H1-H7 autonomy-cooperation	① XT processing sequence is M9→M1→M2→M3→M4→M5. ②K40 processing sequence is M2 or M4 or M7. ③GT processing sequence is M6→M7→M8.
H2	M3,M4		H3		
H3	M5		H2		
H4	M6,M7		H6		
H5	M8		H1		
H6	M9		H4		
H7	M1-M9		H1		

Figure 5. 3D View of the Human Cooperative Simulation Model

(4) Orders changes. In MC, sometimes the order should be cancel or delay because of change of customer demand. In investigation, the model set order change rat is 4%, in which 50% of order is cancellation, 20% of order is ahead of time production, 30% of order is delayed.

Using the four dynamic environments discussed in above, there are three cooperation plans (Scheme A, Scheme B and Scheme C) for changeover in the simulation model are shown as in Table 1.

C. Result analysis

Based on history data, the model simulates 3 moths and run 10 times, selects some indexes to illustrate the cooperation performance, which are show as Fig.6 and Fig.7.

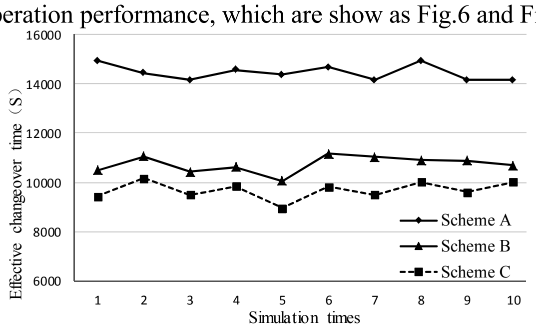

Figure 6. Effective Changeover Time

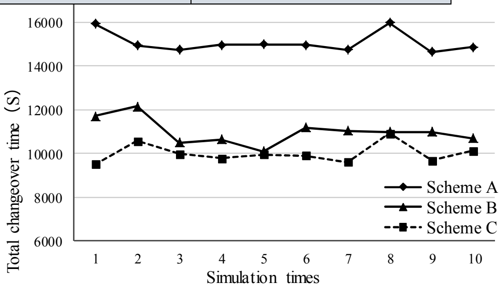

Figure 7. Total Changeover Time

Fig. 6 and Fig.7 is the comparison of changeover time in different cooperation plans when the workers have the same operation skill. It shows that the total time of scheme C is shorter than scheme A and B, but the waiting time of scheme B is longer than scheme A and C. In scheme A (non-cooperation), because the machine operator changeover himself, so the operator don’t have waiting time. Similarly, for scheme B, because of assigned cooperation, when the cooperation partner is busy the task worker should be waiting until he is idle, so the waiting time is longer than others. From the Fig. 6 and Fig. 7 show that the autonomy-cooperation efficiency is best than others, and assigned cooperation efficiency is better than non-cooperation although it don’t have waiting time.

The average worker utilization ratio, the average machine utilization ratio and the output is another important concern in MC, the different cooperation plans have much effect on those index, which are show as Fig.8, Fig.9 and Fig.10.

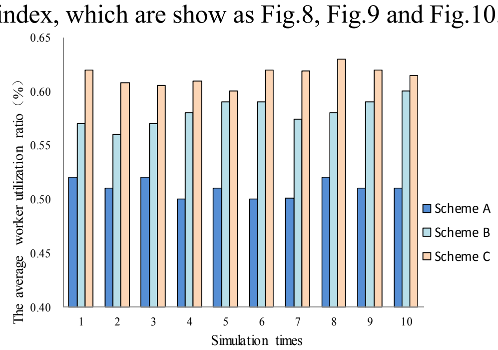

Figure 8. The Average Worker Utilization Ratio

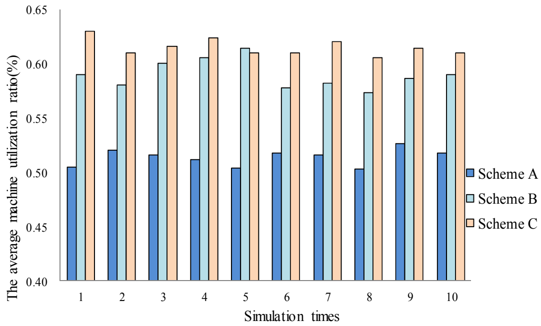

Figure 9. The Average Machine Utilization Ratio

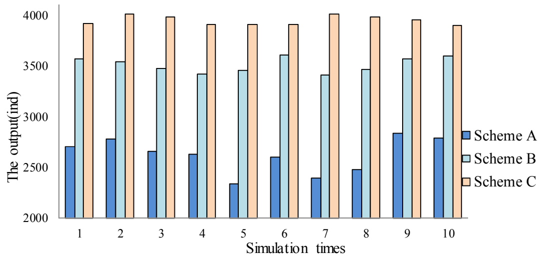

Figure 10. The Output

As Fig.8, Fig.9 and Fig. 10 shown, the autonomy-cooperation is best than non-cooperation and assigned cooperation, because indexes of scheme A and B changed significantly than scheme C. In order to test the effect of different cooperative plans performance, a one-way analysis of variance (ANOVA) is conducted, as shown in Table 2. The effect is statistically significant as the P-value is less than 0.05, which indicates that autonomy-cooperation behavior have significant impact on the performance of production.

TABLE II ANOVA RESULT FOR DIFFERENT COOPERATION BEHAVIOR SCHEMES

Index	Ineffective assumption H0	Scheme	Average value	Variance	Simulation times	F test	Test results	Conclusion
Effective changeover time	Equality	A	14451.78	97199.07	10	549.89 （df=29)	Refusal	Inequality
		B	10735.18	114890.20				
		C	9680.86	130580.80				
total changeover time	Equality	A	15080.78	228212.10	10	281.31 (df=29)	Refusal	Inequality
		B	10997.78	350455.40				
		C	9996.86	194833.60				
Average machine utilization	Equality	A	0.51	0.000058	10	290.9 (df=29)	Refusal	Inequality
		B	0.59	0.000168				
		C	0.61	0.0000592				
Average worker utilization	Equality	A	0.51	0.0000645	10	291.96 (df=29)	Refusal	Inequality
		B	0.58	0.0001482				
		C	0.61	0.000079				
Output	Equality	A	2617.40	28935.60	10	2.03 (df=29)	Refusal	Inequality
		B	3507.80	5580.84				
		C	3945.20	2146.84				

Table 2 shows that the schemes A, B and C have significant difference impact on the performance of worker cooperation, the autonomy-cooperation is best than others.

The above performance is considered the indexes of whole MC, as a MC is consist of a group of people and machines, the worker cooperation is also effect the performance of individual worker and machine, which is average 10 times of H1-H7and M1-M9 as shown in Fig.11 and Fig.12.

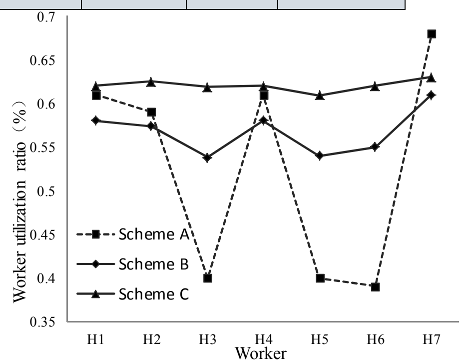

Figure 11. Worker Utilization Ratio Figure

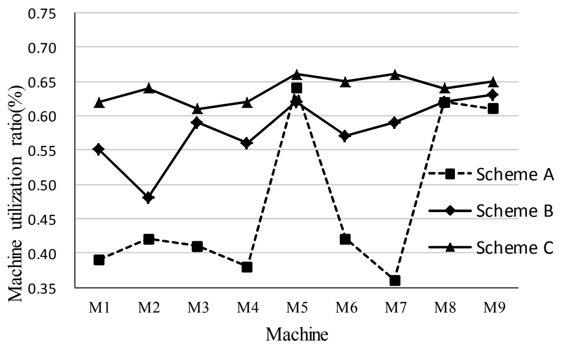

Figure 12. Machine Utilization Ratio

In Fig.11, compared with scheme A, the worker utilization of scheme B and C is stability, especially the performance scheme C better than A and B. Because scheme C is autonomy-cooperation, the waiting time and operation time is shorter than others. At the same time, scheme A has much operation time (when someone is operation changeover, others are waiting) and scheme B has much waiting time (when changeover happens, the task worker wait the assigned cooperation partner until he is idle), that moment the worker have nothing to do. Fig.12 shows that machine utilization of scheme C is stability. The reason of is that, in scheme C, the machines don't take more time to waiting operator in autonomy-cooperation style. In scheme A, as H7 collaboration with others, so H7 utilization is higher than other workers, and because MC is flow line production, when M1, M4, M7 change line the other machine should be stop work, so the H1, H2 and H4 utilization higher than H3, H5 and H6, M1, M4, M7 lower than others. In scheme B, when the assigned cooperation partner is busy, they can't accept the cooperation request until the partner is idle, so the utilization of H1-H7 and M1-M9 is fluctuation.

By simulation, the autonomy-cooperation has the best performance than other cooperation schemes, and it means the workers in this MC should adopt autonomous cooperation style during working.

IV. CONCLUSION

As the MC is a complex system, the worker cooperative is essential to improve the organization flexibility and production efficiency. This paper classified three worker cooperation types of MC, established a human-integrated simulation model which include manufacturing process model and the worker agent model, then using this method to a motor-cycle engine to simulate three cooperation plans. Simulation results showed that worker cooperative has a significant effect on the performance of the MC, and autonomous cooperation with high organization flexibility can effectively respond to the dynamic manufacturing environment.

Besides, the research of simulation method, such as cooperation principle, reaction principle knowledge base can take a new method for simulation, which can provide a scientific view for organization optimization and worker cooperation analysis. Moreover, cooperation principle, reaction principle and knowledge base which are linked to simulation model, can provide the complex worker cooperation process with the research continue enrichment and enlargement.

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