International Symposium on Scheduling 2011
July 2-4, 2011, Osaka, Japan
2A2

SCHEDULING METHOD IN REAL-VIRTUAL FUSION MANUFACTURING SYSTEM WITH SOCIAL CONTRACT BASED APPROACH
-- APPLICATION OF COMBINATORIAL AUCTION AT OPERATIONAL PHASE --

Yi Qian
Graduate School of Engineering
Kobe University
Nada-ku, Kobe, 657-8501, Japan
senki@kaede.cs.kobe-u.ac.jp

Nobutada Fujii
Graduate School of System Informatics
Kobe University
Nada-ku, Kobe, 657-8501, Japan
nfujii@phoenix.kobe-u.ac.jp

Toshiya Kaihara
Graduate School of System Informatics
Kobe University
Nada-ku, Kobe, 657-8501, Japan
kaihara@kobe-u.ac.jp

Susumu Fujii
Graduate School of Science and Technology
Sophia University
Chiyoda-ku, Tokyo, 102-8554, Japan
susumu-f@sophia.ac.jp

Toyohiro Umeda
Production Systems Research Laboratory
Kobe Steel,Ltd
Nishi-ku, Kobe, 657-0845, Japan
umeda.toyohiro@kobelco.com

Abstract

In this study, a new concept named Real-Virtual Fusion Manufacturing System (RVF-MS) is proposed, which aims to adaptively and effectively deal with both external and internal fluctuations by realizing a fusion between real production shop floor (real system) and manufacturing model (virtual system). In order to realize the proposed methodology, a concept based on multi-agent system is used for constructing dynamic model in virtual system. In this paper, production scheduling mechanism at operational phase in RVF-MS is proposed. A social contract based approach named Combinatorial Auction (CA), which is used at planning phase, is also applied. The effectiveness of the proposed method is verified by computational experiments for flexible flow shop.

Keywords: Real-Virtual Fusion, Production Scheduling, Social Contract, Combinatorial Auction, Multi-agent System.

1. INTRODUCTION

Scheduling executed at operational phase is usually called online scheduling, which is used to adapt to unexpected fluctuations happening in the real production floor. There are three represented online scheduling method called real-time scheduling, rolling scheduling, and reactive scheduling shown in Fig. 1. Real-time scheduling allocates jobs based on dispatching rules when idle resources exist, and it is unnecessary to generate initial schedule at planning phase. There are some researches executed on how to effectively choose dispatching rules in different situations (Baykasoglu and Ozbakir, 2010). Although real-time scheduling has quick speed to adapt to the fluctuations, it has low optimality. Rolling scheduling revises the initial schedule at regular intervals, and the suitable timing of rescheduling based on cumulative task delays is given on the research (Suwa, 2007). Rolling scheduling cannot apply to fluctuations promptly because the timing of schedule revision is fixed at regular intervals. Reactive scheduling revises the initial schedule according to Event Driven such as machine failure and order change, and researches on how to decide revision timing are executed based on unscheduled jobs' size (Vieira, *et al.*, 2000) and cumulative delay (Suwa and Sandoh, 2007). However, the researches on the reactive scheduling can not prospect the future progress, because the observation of jobs' states is based on the actual results. For the problem of how to reschedule, effectiveness of Genetic Algorithm (GA) is verified (Sakaguchi, *et al.*, 2003) on the centralized system, and real-time scheduling is usually applied on the decentralized system (Babiceanu, *et al.*, 2005). However, GA costs too much time on execution time of rescheduling though it has good optimality, and real-time scheduling has low optimality though it has quick speed to adapt to the fluctuations. A method that can satisfy both quick response and optimality is needed to be considered in the decentralized system.

This study proposes a Real-Virtual Fusion Manufacturing System (RVF-MS) by couping real and virtual systems, and considers a new idea of dynamic constructing virtual models according to the current situation of the real system (Qian, *et al.*, 2010a). In order to realize the fusion between the real and virtual systems, a concept based on multi-agent system is used for constructing dynamic model in the virtual system. The RVF-MS detects both external fluctuations and internal uncertain factors in the real shop floor and constructs virtual models dynamically when new decision making is necessary. In the previous works, production scheduling mechanism at planning phase in RVF-MS has been proposed (Qian, *et al.*, 2010b), in which a social contract based approach, named Combinatorial Auction (CA)

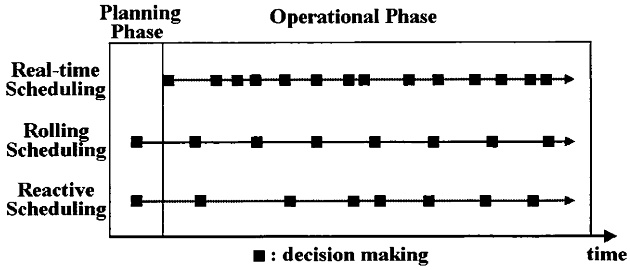


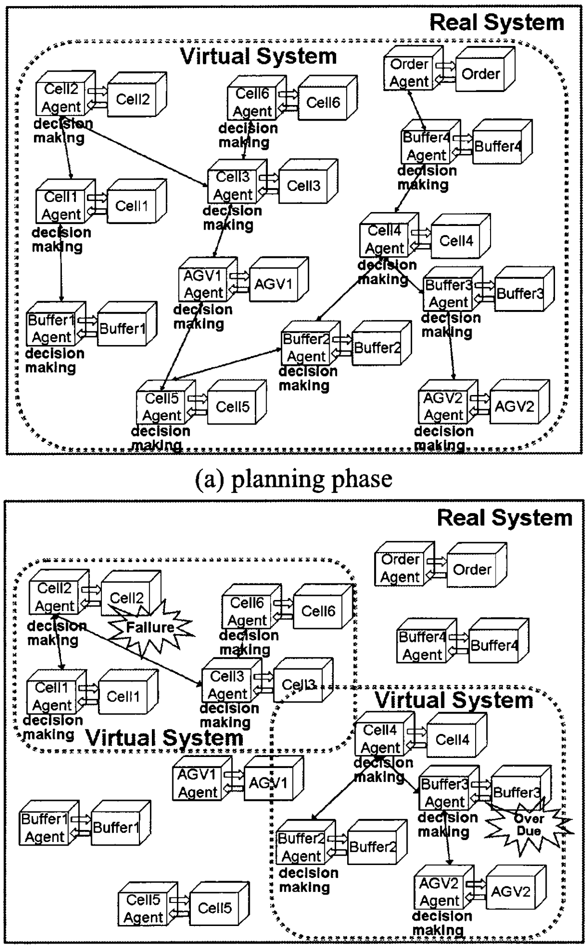
Fig. 1 Decision making timing of online scheduling.

(Kaihara, *et al.*, 2009) is applied. At the operational phase, the parameter modification by each agent is verified by using a physical model plant (Qian, *et al.*, 2009), and the rescheduling timing is determined by Information Propagation method (Qian, *et al.*, 2010a). The Information Propagation method can prospect the influence of process delay, and judge rescheduling is necessary only when tardiness will be caused by the process delay. In this paper, production scheduling mechanism at operational phase in RVF-MS is proposed, and the CA method is also applied. The balance of quick response and rescheduling optimality can be satisfied by appropriately limiting the range of influenced resources and adjusting the parameters of CA. The effectiveness of the proposed method is verified by computational experiments for flexible flow shop problem.

2. REAL-VIRTUAL FUSION MANUFACTURING SYSTEM

In RVF-MS, there are two kinds of agents, order agent which is used for generating jobs, and resource agents such as machine agent, AGV agent, and etc. They are modeled as decentralized autonomous agents which can make decision in the virtual system and instruct production activities in the real system simultaneously. In order to realize the above function, agents have to hold information both in the real system and the virtual system; the agents use the information in the real system for instructing production activities and recording the actual production results fed back from the real shop floor to modify parameters of themselves continuously. On the other hand, the agents use the information in the virtual system for decision making when a new requirement is necessary. The virtual part of the agent does not always exist; it is constructed dynamically only when decision making is necessary by duplicating information from the real system, just like a copy of the agent. The result of the decision making will be noticed from the virtual system to the real system.

Fig. 2 illustrates the concept of RVF-MS. Fig. 2(a) indicates the virtual system is constructed and decision making is executed at planning phase. Decision making is planned by the communication of all the agents to achieve global production optimization. Fig. 2(b) indicates virtual systems are generated when machine failure occurs or job's due time cannot be satisfied at operational phase, and new decision making is executed only by the communication of partial agents by using the present states. It represents that, to give



(a) planning phase

(b) operational phase

Fig. 2 The concept of RVF-MS.

quick response for dynamic fluctuations at operational phase, considering global optimization for the whole manufacturing system is not always necessary, and decision making can be executed only by the agents influenced by the fluctuations; decision making using partial components can be executed faster than using whole components. Although it is a common method to construct a virtual model in advance and modify its parameters for adapting to changes of the real system in application, RVF-MS gives a new idea that the virtual system, which follows the changes of the real system, is not always necessary. The virtual system can be dynamically constructed only when decision making is required, and destructed when decision making is finished. In other words, the virtual system appears from the real system and disappears in the real system when its mission is finished.

3. SCHEDULING MECHANISM IN RVF-MS AT OPERATIONAL PHASE

Scheduling mechanism in RVF-MS at planning phase generates initial schedule per day for ordered productions. Rescheduling at operational phase proposed in this section is used for revising the initial schedule online based on reactive scheduling when tardiness is forecasted in future. As shown in Fig. 2(b), to give quick response for dynamic fluctuations at operational phase, considering global optimization for the whole manufacturing system is not always necessary, and decision making is executed only by the agents influenced by fluctuations. Fig. 3 illustrates a result of the Information Propagation method (Qian, *et al.*, 2010a), and it is used as an example of explanations. In this situation, delay happens in M1's process, so M1 promotes Information Propagation to the downstream processes. It is forecasted that tardiness in M3 will happen, so that the promoter of Information Propagation (M1) judges rescheduling is necessary. The virtual system is constructed only by the influenced resources M1, M3 and M4. The promoter M1 becomes the auctioneer for executing rescheduling, and necessary information of object jobs for rescheduling is gathered by M1. The set of all object jobs for rescheduling (SJ_r) can be determined as

$$SJ_r = \{J_{i,k} \mid st_{i,k} \geq T_s \quad (\forall i, \forall k \quad for \quad m \in F_{ID})\} \tag{1}$$

where $st_{i,k}$ is the start time of job i in process k; $ft_{i,k}$ is the finish time of job i in process k; T_s is the start period of rescheduling; and F_{ID} is the set of influenced resources by Information Propagation. The jobs marked on black triangle in Fig. 3 illustrate the object jobs for rescheduling. All of the jobs' information in SJ_r is collected by the auctioneer. The T_s can be determined as parameters based on the scale of problems, but

$$T_s \geq T_{now} + TS_r \tag{2}$$

is needed to be satisfied, where T_{now} is the finish time of the Information Propagation and TS_r is the expected execution time of rescheduling. The constraining condition at operational phase is stricter than the constraint at the planning phase, because the object jobs for rescheduling is only a part of jobs. Rescheduling can be executed after gathered the necessary information, and the algorithm of decision making applied CA is detailedly explained in section 4.

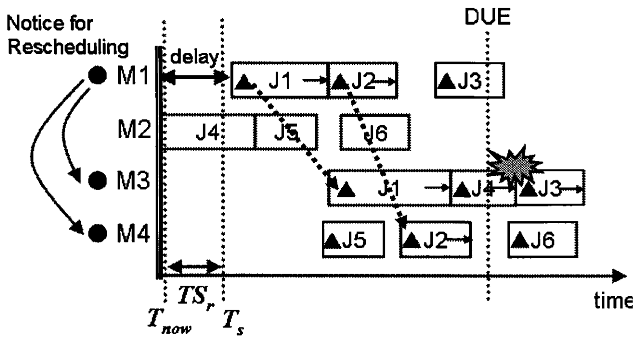


Fig. 3 An example of the object jobs for rescheduling at operational phase.

4. DECISION MAKING METHOD APPLIED COMBINATORIAL AUCTION AT OPERATIONAL PHASE

The social contract based approach CA, used at planning phase for global optimization (Qian, *et al.*, 2010b), is also applied for decision making at operational phase. Although the CA method costs much time for optimality, the balance of quick response and rescheduling optimality can also be achieved by appropriately limiting the range of influenced resources and adjusting the parameters of CA. As mentioned in the previous work, there are two problems in CA called Bid Determination Problem (BDP) and Winner Determination Problem (WDP). BDP determines the efficient placement of bids, which is submitted to the auctioneer. WDP determines the efficient allocation of items for bidders, to maximize the auctioneer's utility. These problems are difficult in large scale, so that using utility restriction in BDP to give an efficient and feasible solution space is effectiveness to solve the problem.

In this paper, the same K-processes Flexible Flow Shop Problem used in the previous work (Qian, *et al.*, 2010b), is considered. The buffers between each process are set to unlimited, and setup time and transportation between processes are ignored. For formulating this problem by CA, jobs are set to items, resource agents are set to bidders, and the promoter (resource) of Information Propagation becomes the auctioneer. That is to say, the promoter of Information Propagation has two roles; the bidder and the auctioneer. The purpose of the problem is minimizing the total tardiness for all rescheduled jobs. Notation used in this section is defined as below.

- Notation

$J_{i,k}$: job i in process k
m_k : resources number in process k
DT_i : due time of job i
$dt_{i,k}$: due time of job i in process k
$N_{k,m}$: upper limit of bid number by resource m in process k
$S^j_{k,m}$: job set of bid No.j by resource m in process k
$B^j_{k,m}$: the value of bid No.j by resource m in process k (total tardiness for handling job set of bid No.j)
$f^j_{k,m}$: the total finish time (makespan) for handling job set of bid No.j by resource m in process k
$U_{k,m}$: the threshold of utility by resource m in process k
ΔU: the relaxation quantity of threshold
LS : repeat number of local search
$st_{i,k}$: start time of job i in process k
$ft_{i,k}$: finish time of job i in process k
$pt_{i,k}$: processing time of job i in process k
$ms^l_{k,m}$: start time of l th process by resource m in process k
$mf^l_{k,m}$: finish time of l th process by resource m in process k
F_{ID}: set of influenced resources by Information Propagation
T_{now} : finish time of Information Propagation
T_s : start period of rescheduling
SJ_r: set of all object jobs for rescheduling (defined by Eq.(1))

Proposed algorithm with CA at operational phase is following, and the flow chart of the proposed algorithm is shown in Fig. 4.

Step 0. Determine SJ_r which means the set of all object jobs for rescheduling.

Step 1. Process Number k=C, where C is the smallest Process Number in jobs set SJ_r.

Step 2. The auctioneer announces jobs in process k to the influenced resources, and executes the combinatorial auction.

Step 3. The influenced resources, which can process the jobs in process k, determine the bids set of jobs (BDP) to satisfy their threshold of utilities ($U_{k,m}$), then submit bids set to the auctioneer.

Step 4. The auctioneer determines winners for jobs in the process k (WDP), and notices these winner resources. If local search in the process k has been repeated to the limited times (LS), go to Step5; else go to Step3 for finding a better solution without changing $U_{k,m}$.

However, at the situation that feasible allocation for all the jobs in process k is not realized after executing local search limited times, the auctioneer will notice the whole resources to relax their thresholds ($U_{k,m}=U_{k,m}+\Delta U$), and go to Step2.

Step 5. if k=K, Finish.

Step 6. k=k+1, $U_{k,m}$ =0, and go to Step2.

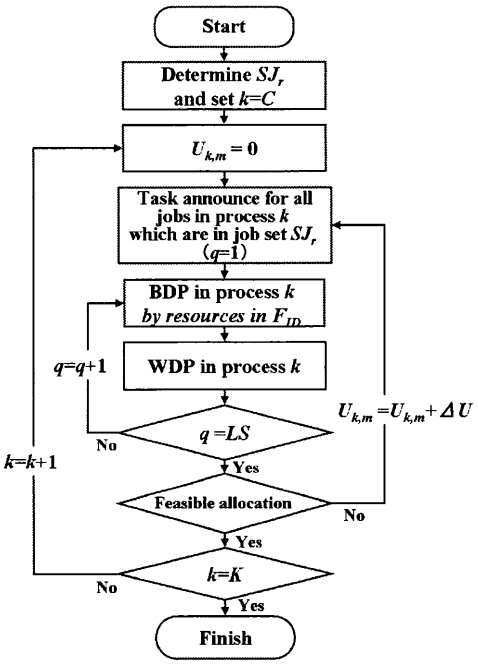


Fig. 4 Proposed algorithm applied CA at operational phase.

4.1 Bid Determination Problem (in Step3)

$$dt_{i,k}=DT_i\times\frac{\sum_{q=1}^{k}pt_{i,q}}{\sum_{q=1}^{K}pt_{i,q}}\quad(\forall i,\forall k)\tag{3}$$

$$B^j_{k,m}=\sum_{i|J_{i,k}\in S^j_{k,m}} max\left(0,ft_{i,k}-dt_{i,k}\right)\quad(\forall j,\forall m\in F_{ID})\tag{4}$$

$$f^j_{k,m}=\max_{i|J_{i,k}\in S^j_{k,m}}\left(ft_{i,k}\right)\quad(\forall j,\forall m\in F_{ID})\tag{5}$$

$$T_s\le st_{i,k}\quad\left(\forall j,\forall i\,|\,J_{i,k}\in S^j_{k,m}\right)\tag{6}$$

$$ft_{i,k-1}\le st_{i,k}\quad\left(where\ \ ft_{i,0}=0\right)\left(\forall j,\forall i\,|\,J_{i,k}\in S^j_{k,m}\right)\tag{7}$$

$$mf^{l-1}_{k,m}\le ms^l_{k,m}\quad\left(where\ \ mf^0_{k,m}=0\right)\left(\forall m\in F_{ID}\right)\tag{8}$$

$$B^j_{k,m}\le U_{k,m}\ \left(\forall j,\forall m\in F_{ID}\right)\tag{9}$$

$$ft_{i,k}\le st_{i,k+1}\left(\forall j,\forall i\,|\,J_{i,k}\in S^j_{k,m}\quad and\quad J_{i,k+1}\notin SJ_r\right)\tag{10}$$

Eq. (3) indicates due time $dt_{i,k}$ is determined by proportionally divided DT_i using the processing time of each process. Eq. (4) indicates the total tardiness for handling job set $S^j_{k,m}$, and it is used for the value of bid. Eq. (5) shows the total finish time (makespan) for handling job set $S^j_{k,m}$. Eq. (6) represents the rescheduling period constraint. Eq. (7) and (10) indicate the job's preference relation constraint. Eq. (8) shows the processing capacity constraint of resources. Eq. (9) represents the value of bid must satisfy the threshold $U_{k,m}$ of resources (utility restriction). However, if the $U_{k,m}$ of each resource is too strict, feasible allocation for k-process jobs in WDP is hardly realized. Thus, the $U_{k,m}$ of each resource is need to be adjust adaptively. The resources relax their thresholds by $U_{k,m}=U_{k,m}+\Delta U$ when they are noticed from the auctioneer (represented in Step4).

The algorithm of bid determination executed by influenced resources is following.

Step 3-1. Bid No.j=1.

Step 3-2. If the jobs announced from auctioneer can not be processed, go to Step3-8. Otherwise, randomly select jobs announced from auctioneer, then generate job set $S^j_{k,m}$ by all of the selected jobs.

Step 3-3. For all jobs in job set $S^j_{k,m}$, determine the best jobs' order from EDD, SLACK and CR rules, which makes Eq.(4) smallest subject to Eq.(6)(7)(8).

Step 3-4. According to the determined order, calculate the total tardiness $B^j_{k,m}$ and total finish time $f^j_{k,m}$ for handling job set $S^j_{k,m}$ by Eq. (4) and (5) subject to Eq.(6)(7)(8).

If the results determined above are not satisfied Eq. (9)(10), abandon current job set $S^j_{k,m}$ and go to Step3-2.

Step 3-5. Use the total tardiness $B^j_{k,m}$ as the value of bid No.j, and submit bid set { $B^j_{k,m}$, $S^j_{k,m}$ } to the auctioneer.

Step 3-6. if j= $N_{k,m}$, Finish.

Step 3-7. j=j+1, go to Step3-2.

Step 3-8. Send null set to the auctioneer, Finish.

4.2 Winner Determination Problem (in Step4)

$$min\quad\sum_{m=1}^{m_k}\sum_{j=1}^{N_{k,m}}B^j_{k,m}x^j_{k,m}\tag{11}$$

$$s.t.\quad\sum_{j=1}^{N_{k,m}}x^j_{k,m}\le 1\quad\left(\forall m\in F_{ID}\right)\tag{12}$$

$$\sum_{m|J_{i,k}\in S^j_{k,m}}^{m_k}\ \sum_{j|J_{i,k}\in S^j_{k,m}}^{N_{k,m}}x^j_{k,m}=1\quad\left(\forall i\,|\,J_{i,k}\in SJ_r\right)\tag{13}$$

$$x^j_{k,m}\in\{0,1\}\quad\left(\forall j,\forall m\in F_{ID}\right)\tag{14}$$

Eq. (11) is the objective function to minimize the whole tardiness for all rescheduled jobs. Eq. (12) indicates there is not more than one successful bid of winner's all bids, and Eq. (13) shows there must have one winner existing for rescheduled job i in process k. $x^{j}_{k,m}$ in Eq. (14) is the coefficient of determination. $x^{j}_{k,m} = 1$ means the bid No.j is the successful bid for resource m in process k.

5. COMPUTATIONAL EXPERIMENTS

5.1 Production conditions of experiments

In order to verify the effectiveness of the proposed method, computational experiments on 3-processes Flexible Flow Shop Problem are executed. The system configuration of RVF-MS is illustrated as Fig. 5. Machine 1 and 2 are used to Process 1, Machine 3, 4 and 5 are used to Process 2, and Machine 6 and 7 are used to Process 3. All of the machines and order agent can communicate with each other by TCP/IP Network, and decision making can be executed by the communication among agents. At planning phase, initial schedule is generated to achieve global production optimization by all of the agents (order and Machine 1 to 7). At operational phase, rescheduling is executed only by partial resources influenced by Information Propagation.

In the experiments, planning period at planning phase is set to one day (10 hours from 8 a.m. to 6 p.m.), and eight jobs A001 to D002 with different due time are processed. The execution time of rescheduling (TS_r) at operational phase is not considered. That is to say, T_s is set to T_{now}. Moreover, All-Bids method is used for determining bids (Step 3) in the experiments. The All-Bids method also belongs to the proposed method, in which all combination of jobs are bided in BDP, without considering the utility restriction (Eq. (9)). Besides, it does not include local search between Step 3 and 4, because it is a kind of strict search methods.

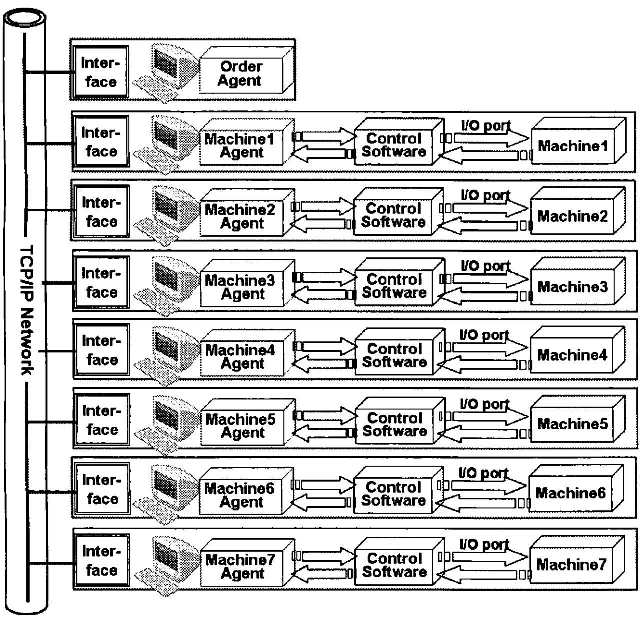
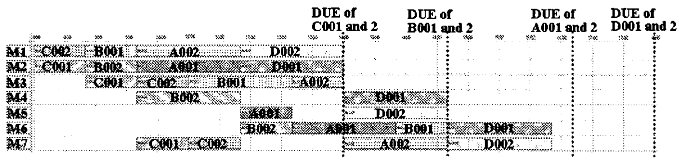


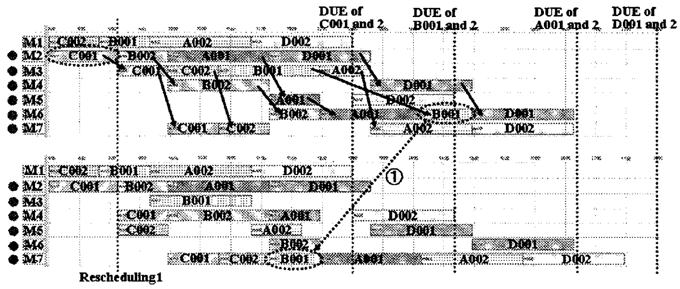
Fig. 5 RVF-MS configuration on 3-processes Flexible Flow Shop Problem.

5.2 Preliminary results of the experiments

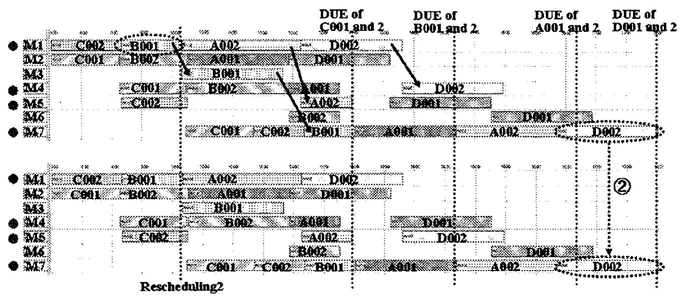
Fig. 6 shows the results of preliminary experiments, in which process delay is determined by random value with the interval of 10 to 20 minutes. Fig. 6(a) is the initial schedule generated at planning phase without tardiness. Fig. 6(b) shows the result of Rescheduling1 when Machine 2 has a delay in its process C001. The upper figure in Fig. 6(b) indicates the result of Information Propagation. Delay is propagated to the downstream processes, and the arrows illustrate the spread of "notice" massage. Rescheduling is adjusted necessary because tardiness of B001 is forecasted in Machine 6. Rescheduling is executed at the time marked Rescheduling1, and the lower figure in Fig. 6(b) indicates the result of rescheduling. The tardiness of B001 is successfully solved by the rescheduling of influenced resources from Machine 2 to 7 (marked with circles). Further, reschedulings are executed twice in Fig. 6(c) and (d). Compared with Rescheduling 2 and 3, tardiness of D002 is not



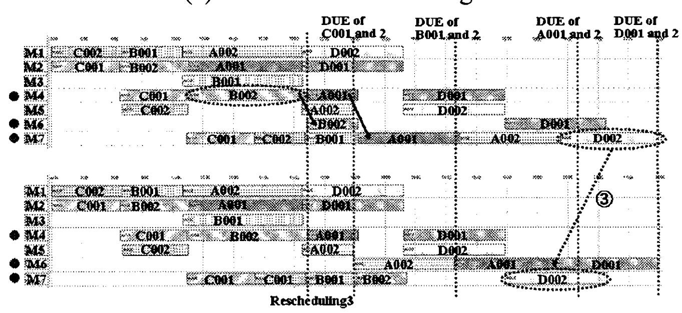
(a) initial schedule



(b) result of Rescheduling1



(c) result of Rescheduling2



(d) result of Rescheduling3

Fig. 6 Preliminary results of the experiments.

solved in Fig. 6(c) but solved in Fig. 6(d). Both reschedulings are executed by partial resources (marked with circles), but they consist of different machines in the final process (Machine 6 and 7). Although EDD, SLACK and CR rules are used in BDP to determining the best order of job set (Step3-3), only Machine 7 in Rescheduling2 is difficult to solve the tardiness by itself. Branch and Bound method seems to be expected to solve the tardiness more effectively by a single resource, but obviously it costs too much time at operational phase. Thus, introducing substitutable machines in the final process for rescheduling might be considered in the next step. Certainly, it is not guaranteed that tardiness can be solved by the rescheduling of partial resources at any situation. This problem is needed to be clear in the future work.

5.3 Comparison with other methods

The proposed method (P_{part}) is compared with real-time scheduling adopting EDD rule, and the result (20 averages) is given in Table 1. Furthermore, the result of rescheduling always with all resources (P_{all}) is also shown for comparison. ΣT_{Tar} , ΣT_{Res} , ΣT_N , T_{Res} indicate the total tardiness of actual result (min.), total rescheduling time (sec.), total rescheduling times and average rescheduling time for once (sec.), respectively. As shown in Table 1, it is verified that the proposed method P_{part} succeeds in reducing the total tardiness (ΣT_{Tar}) compared to EDD method. Compared with the P_{all} method, although the proposed method P_{part} has larger total tardiness (ΣT_{Tar}), the total rescheduling time (ΣT_{Res}) and average rescheduling time for once (T_{Res}) are succeeded to be reduced. It is verified the advantage of the proposed method by using partial resources, but the P_{all} method seems to be better than the P_{part} method in this experiment because the difference of average rescheduling time for once (T_{Res}) is only about 1 second. The P_{part} method can be expected more effective in large scale problem because the total number of jobs and resources obviously increase along with the scale of problems.

Table 1 Comparison with other methods

Method	ΣT_{Tar} (min.)	ΣT_{Res} (sec.)	ΣT_N	T_{Res} (sec.)
EDD	415.70	2.88	24.00	0.12
P_{part}	87.85	9.36	2.90	3.23
P_{all}	55.15	13.91	3.10	4.50

6. CONCLUSION

In this paper, production scheduling mechanism at operational phase in RVF-MS is proposed, in which the CA method used at planning phase, is also applied. The effectiveness of the proposed method is verified by computational experiments for flexible flow shop problem.

In future, large scale problems are needed to be considered to verify the effectiveness of the proposed method. In these problems, the All-Bids method used in section 5.1 could not be adopted because all combination of jobs increases explosively along with the number of jobs. Therefore, the proposed method with considering utility restriction seems practical approach to solve the large scale problems. Furthermore, the determination of rescheduling period is also considered to reduce the total number of rescheduled jobs, without destroying the initial schedule as far as possible simultaneously. New rescheduling method of combining the P_{part} and P_{all} method is also scheduled for responding to the fluctuations more efficiently in the future work.

References

Babiceanu R. F., Chen F. F., Sturges R. H.. (2005). Real-time holonic scheduling of material handling operations in a dynamic manufacturing environment, *Robotics and Computer-Integrated Manufacturing*, Vol.21, pp.328–337

Baykasoglu A., Ozbakir L.. (2010). Analyzing the effect of dispatching rules on the scheduling performance through grammar based flexible scheduling system, *Int. J. Production Economics*, Vol.124, pp.369–381

Kaihara T., Fujii N., Toide S., Ishibashi H.. (2009). A Study on Optimization Method for Production Scheduling with Batch Process by Combinatorial Auction, *Proceedings of International Symposium on Scheduling 2009*, pp.266-267

Qian Y., Fujii N., Kaihara T.. (2009). A study on Real-Virtual Interaction Method for Production Scheduling, *4th International Conference on. Industrial Applications of Holonic and Multi-Agent Systems (HoloMAS 2009)*, LNAI 5696, pp. 114-123

Qian Y., Fujii N., Kaihara T., Fujii S., Umeda T.. (2010a). Dynamic Construction of Virtual System for Production Planning in Autonomous Distributed Real-Virtual Fusion Manufacturing System, *2010 International Symposium on Flexible Automation (ISFA 2010)*

Qian Y., Fujii N., Kaihara T., Fujii S., Umeda T.. (2010b). Real-Virtual Fusion Manufacturing System with Social Contract Based Algorithm - Application of Combinatorial Auction, *SICE Symposium on Systems and Information (SSI 2010)* [in Japanese]

Sakaguchi T., Tanimizu Y., Sugimura N.. (2003). Reactive Scheduling System for Unscheduled Input of Emergent Jobs, *International Conference on Leading Edge Manufacturing in 21st Century, The Japan Society of Mechanical Engineers*, pp 725-728

Suwa H.. (2007). A new when-to-schedule policy in online scheduling based on cumulative task delays, *Int. J. Production Economics*, Vol.110, pp.175–186

Suwa H., Sandoh H.. (2007). Capability of cumulative delay based reactive scheduling for job shops with machine breakdowns, *Computers & Industrial Engineering*, Vol.53, pp.63–78

Vieira G. E., Herrmann J. W., Lin E.. (2000). Analytical models to predict the performance of a single-machine system under periodic and event-driven rescheduling strategies, *International Journal of Production Research*, Vol. 38, No. 8, pp. 1899-1915