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A Study on the Planning and Scheduling of Production System Considering Demand Changes

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In this paper, we studied a planning and scheduling of production system considering demand changes. In the proposed system, planning part determines lot-size and amount of jobs in production. On the other hand, scheduling part determines the production sequence of jobs. In order to treat with the demand changes, both planning and scheduling should work well simultaneously. In the proposed system, preset and real time production control system is newly constructed from the view point of adaptive control. In the system, production planning is modified when the difference between production amount and demand becomes large. Moreover, production schedule is regenerated when the determined schedule is deviated from the prospected one. The scheduling system is characterized as the autonomous decentralized optimization system where each job works as agent and agent searches its appropriate starting time of processing. The effectiveness of the proposed system is confirmed by numerical examples.

1 INTRODUCTION

Now, many manufactures are facing with market changes. In a production system manufacturing many kinds of products, demand changes make it difficult to create an accurate production schedule in which all of the customer's requests are satisfied[1][2][3][4].

In any production line, plants can hardly be operated according to predetermined schedule due to the unexpected order of products caused by the weather conditions or the change in costomer's needs.

In such situations, predetermined production schedule should be modified in order to meet with demand changes. For the modification, high speed rescheduling method is necessary to compensate the influences of disturbances in a short time[5][6].

As for the production information system which can cope with demand changes is proposed by K.Tanaka et,al[7] (see Figure 1). However, this system is a preset type system and can not meet with the dynamic change in demands. To solve the problem, adding adaptive control scheme to production control system has been constructed. Our system has a feed back control structure with high speed scheduler as a controller.

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In the following, detailed description of our system and its application to production control is presented together with numerical examples. In chapter two, construction of production control system considering demand changes is explained. In chapter three, as the experimental production line, soft drinks production process is explained. In chapter four, relationship between production planning and scheduling, and the method to decide job numbers and due-dates in production planning are explained. In chapter five, the dynamic scheduler that is a main part of the proposed system is explained in detail. That is, mathematical models for scheduler, simulator and adaptive controller are explained. In chapter six, the effectiveness of the proposed system is checked by numerical experiment. In chapter seven, concluding remarks are stated together with the extension of the proposed method.

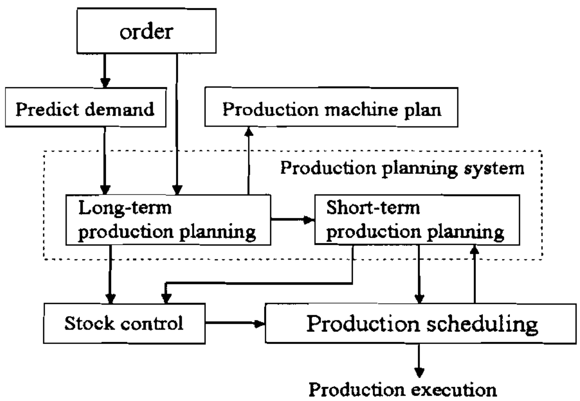


Fig.1 The structure of production control system[7]

2 PLANNING AND SCHEDULING SYSTEM CONSIDERING DEMAND CHANGES

As is well kown by Control Theory, to overcome the problem of deterioration in control performance induced from change in plant characteristics and disturbances, an adaptive control is effective. The structure of control system involving adaptive control is shown in Figure 2[8].

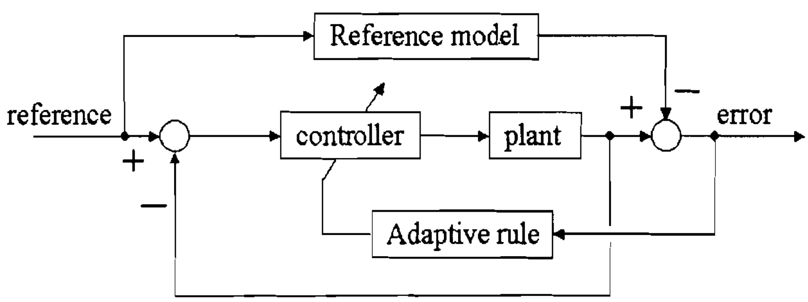


Fig.2 Model Reference Adaptive Control model[8]

Referring to figure 2, we constructed adaptive planning and scheduling system as shown in Figure 3. Proposed production control system mainly consists of two parts, planning part and scheduling part.

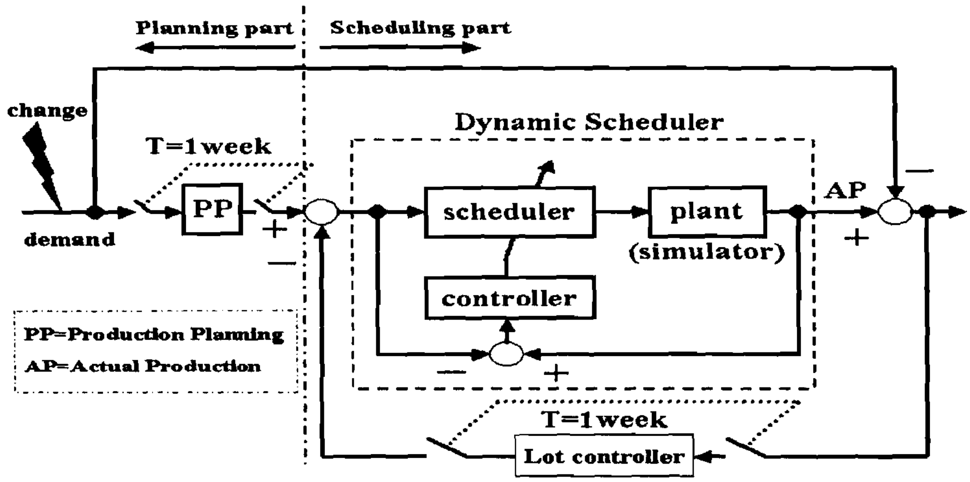


Fig.3 Adaptive planning and scheduling system

In planning part, production planning is made at every sampling time with interval of a week. In scheduling part, starting time of each process is determined at a predetermined sampling time in every day. The scheduling part named dynamic scheduler consists of scheduler, plant and controller. Where plant may be surrogated to plant simulator.

Demand changes are induced from disturbances such as changes in weather conditions and costomer's needs. In order to deal with such demand changes, proposed system have two feed back loops. One, the outer loop, is that to modify production planning. This is feed back loop involving dymnamic scheduler, as a control system. This loop is the coarse control loop which deals with big change in demand. The other, the inner loop, is feed back of the production amount to dynamic scheduler via controller. This loop makes fine adjustment of production schedule and has the function of adaptive control. The control performance, that is the preciseness of proposed system is realized by the loop.

The proposed system has two characteristics, robustness to the disturbance and follow-up ability to the demand changes. It is also the function of our system that real time production control is achieved by feed back loops. Feed back loops are expected to weak the effects of disturbances and the controller may compensate the influence of demand changes. The effectiveness of these two functions will be confirmed by numerical experiments.

In the proposed system, production information is treated as follows.

① Based on demands, production planning is made. Where, number of jobs and due-date of each product are given. These calculated values are necessary demand data for each product schedule.

② The demand data of each product is input to scheduler, and starting time of processing of each product is determined.

③ Starting time of operation for each process is input to plant or simulator, and the amount of production is attained, or calculated.

Actually, demands incessantly change and the amount of production differs from that of the demands. The amount of actual production is feed back to scheduling subsystem to reduce this difference. If there is a certain amount of difference, it is forced to be decreased by the controller. Controller has the function of flexible adaptation to the demand changes.

A production planning is made at every sampling time, and adjustment of processing time is made by the controller in the internal loop of the dynamic scheduler as shown in figure 3.

3 DESCRIPTION OF EXPERIMENTAL PROBLEM

As the experimental production problem to check the effects of the proposed planning method, production line for soft drinks is considered. The line consists of six processes as shown in Figure 4. Each process except 4th process has only one processing facility. In 4th process, there exist three processing facilities. As for the soft drinks production line, 1st process is picking, 2nd process is preparation, 3rd process is separation, 4th process is stock, 5th process is bottling and 6th process is shipping.

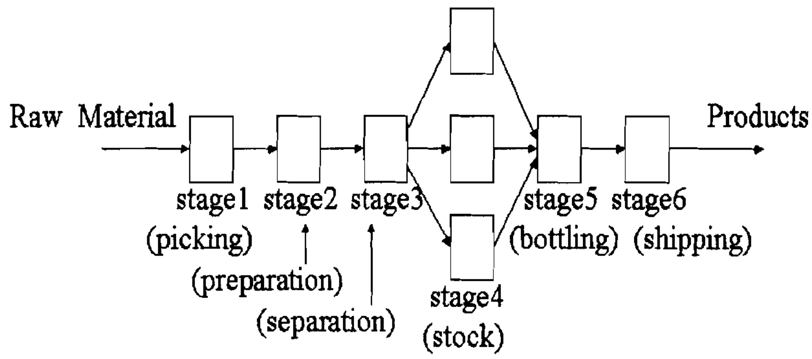


Fig.4 Experimental Production Line

Demand of each product is predetermined for all seasons. The processing time in each process depends on lotsizes which are S(small), M(middle) and L(large). The processing time for each process are listed in Table 1. As the exception, the processing time in process 4 is variable from 8 hours to 20 hours. This means that production order is changeable only in process 4. On the contrary, in processes except process 4, production orders can not be changed. Once the production has began for one product, lotsize of the product can not be changed for the product. Here, the machine trouble and process stop for maintenance are not considered.

Table 1 Processing time for each process of each lotsize

	Processing time [hour]		
Process	S	M	L
1	0.3	0.3	0.3
2	4.0	7.0	10.0
3	4.0	7.0	10.0
4	8.0～20.0	8.0～20.0	8.0～20.0
5	0.3	0.3	0.3
6	0.2	0.2	0.2

For above mentioned problem, the object of production contol is to derive lotsize of each product, the amount of production and the production schedule in which the deviations of due-dates are minimized.

In the following, two component parts Production Planning(PP) and Dynamic Scheduler will be explained respectively with related to the experimental problem.

4 PRODUCTION PLANNING

In this chapter, production planning method is presented. That is, the method of determining number of jobs, assignments of each job to lotsizes and due-dates will be described.

4.1 HOW TO DETERMINE DEMAND

A production planning is made to cope with a prospective production, but demands occationally change. Accompanied with the change, demands (the number of jobs) and accordingly due-dates change. In reflecting the change in demands to the production planning, we consider the following assumptions.

- The interval of a production planning is set to one month.
- The amount of demands for every products can be considered as a probabilistic variables characterizing normal distribution with a certain mean values and standard deviations.

The timing for the production planning and scheduling are shown in Figure 5. Where, I, II and III is a production planning term and it is one month. Also, the interval of each term is one week.

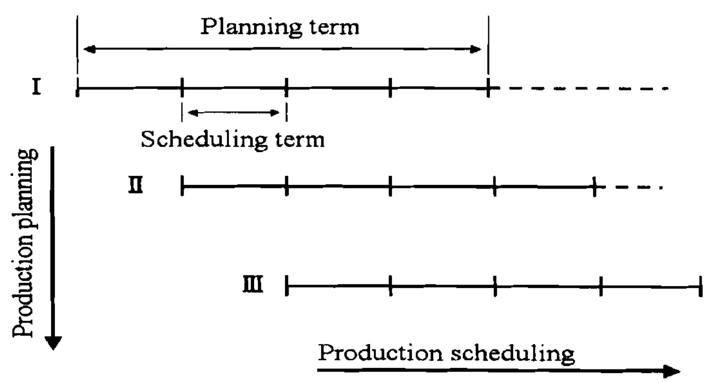


Fig.5 Timing of the production planning and scheduling

4.2 METHOD TO DETERMINE THE NUMBER OF JOBS

Demand D is assigned to one lotsize of S, M and L. In the actual production planning, at the stage of the production planning, we must decide lotsize or to decide the number of jobs for scheduling. The number of jobs is determined as follows.

4.2.1 DETERMINATION OF JOB NUMBERS FOR VARYING LOTSIZE

The number of jobs is decided by the next two evaluation indices.

$$J = S + M + L \tag{1}$$

$$Stock = \sum_{m=1}^{M} (Pr_m - D_m) \tag{2}$$

Where, S, M, L are the number of jobs of each lotsize (see Appendix A-1), J is total number of jobs (see Appendix A-2). Pr_m is the produced amount of product m, D_m is the amount of demands for product m. Stock is sum of the difference between Pr_m and D_m. Equation(1) means the total of jobs and equation(2) means the amount of stock respectively. The above two evaluation indices are used to determine the number of jobs as follows.

$$I_{job} = J + f_p \longrightarrow \min \tag{3}$$

Here, f_p is penalty for excessive stock and given by the function of stock as follows.

$$f_p = e^{(-Stock+5)} \tag{4}$$

The job numbers S, M and L for each lotsize are determined by using the above objective function. Also, the following relations should hold between the demand D and weighted sum of these lotsizes which equals to production Pr.

$$D \leq 3S + 5M + 10L = Pr \tag{5}$$

In equation (5), weights 3, 5 and 10 are the capacity corresponding to these three lotsizes.

4.2.2 NUMERICAL EXPERIMENT

To check the validity of the method stated above, numerical experiment is carried out. Here, simulation result of the lotsize assignment is shown.

Originally, demand D may occationally change according to demand changes. Initially, the value of D is fixed as shown it in Table 2. The calculated number of jobs S, M and L are found and given in Table 3.

Table2 Demands

Product	Demand [kl]
1	100
2	50
3	30
Total	180

Table3 Simulated results

Product	Job [S,M,L]	Production [kl]	Stock [kl]	Cost
1	15 [3,4,8]	109	9	24
2	7 [1,2,4]	53	3	10
3	4 [1,0,3]	33	3	7
Total	26	195	15	41

As is valid from the simulated results, production satisfies its demand.

4.3 THE METHOD TO DECIDE DUE-DATE

Here, the method to decide the due-date is presented. As an example, we consider the demands shown in Table 2. Figure 6 shows demand change in the production planning period. Where the time interval T in the figure is set one month.

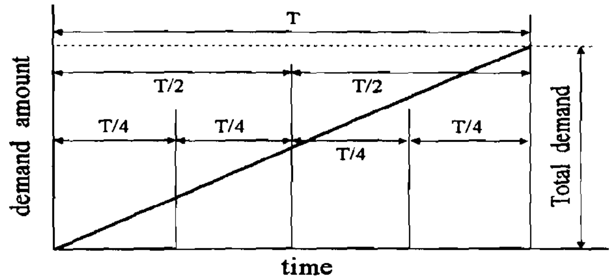


Fig.6 The transition of demand in the production planning period

4.3.1 ASSIGNMENT OF LOTSIZE

Production planning can be made only for the demand within one month of forthcoming. Because a scheduling period is set to one week, the amount of total demand is divided into four, and production amount Pr^w for one week is determined as follows.

$$Pr^w = \frac{1}{4}\sum_{m=1}^{M} D_m \tag{6}$$

Next, Pr^w is assigned to each product. If production in one month must be done uniformly, the production Pr^w_m of each product for one week can be calculated by the following equation.

$$Pr^w_m = \left(\frac{D_m}{\sum_{m=1}^{M} D_m}\right) \times Pr^w \tag{7}$$

This is the desired amount of production in a week. The job needed in the previous subinterval is assigned to each lotsize so that the desired amount of production is attained. The same amount of production is thought to be assigned for each week[9].

Each job is assigned to one of three lotsizes such as mentioned above. The number of jobs of each lotsize may be a real number. However, these numbers must be interpreted to integer number. The flow to decide due-date is shown in Figure 7.

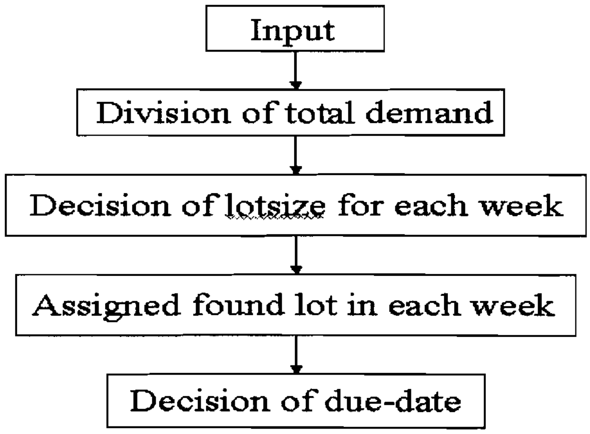


Fig.7 Flow to decide of due-date

In the figure, input is the amount of total demand and the number of jobs in each lotsize for every product. Equation(6) is used for division of the amount of total demand and equation(7) is used for the decision of the aimed amount of production. The number of jobs, that is the assignment of lot, is calculated from equations (A.5) to (A.7) (see Appendix A-3). And, the production proceeds to the next process.

(a) Calculation of number of Jobs

The number of jobs is decided by the following equation.

$$J_m^w = [S_m^w] + r_{\mathrm{S}} + [M_m^w] + r_{\mathrm{M}} + [L_m^w] + r_{\mathrm{L}} \tag{8}$$

Where, S_m^w, M_m^w and L_m^w are the number of jobs of each lotsize of product m for week w (see Appendix A-3), and r_{S}, r_{M} and r_{L} are 0-1 integers.

(b) Calculation of the residual number of jobs

The number of jobs is calculated from the number of jobs for each given lotsize as stated in step(a) and the residual number of jobs is calculated.

(c) Calculation of the cost

The difference in the aimed amount of production and the amount of actual one is used to calculate the estimation cost as follows.

$$I_{\mathrm{lot}} = |Pr_{\mathrm{r}m}^w - Pr_m^w| \tag{9}$$

Where, $Pr_{\mathrm{r}m}^w$ is the amount of actual production given by the following relation.

$$Pr_{\mathrm{r}m}^w = 3S_m^w + 5M_m^w + 10L_m^w \tag{10}$$

(d) Check of the last week

For the second and the three week, steps (a), (b) and (c) are repeated in the same manner as in the first week. The number of jobs of the fourth week is the rest of production amount which is calculated at the end of the third week.

4.3.2 SIMULATION RESULT

Using the steps (a) to (d), numerical experiment is made. The calculated job numbers for each week are shown in Table 4 and in Figure 8.

Table4 Simulation result

	product1			product2			product3				
week	S	M	L	S	M	L	S	M	L	Job	Production [kl]
1	2	2	1	1	0	1	0	0	1	8	49
2	0	1	2	0	0	1	0	0	1	5	45
3	0	1	2	0	0	1	0	0	1	5	45
4	1	0	3	0	2	1	1	0	0	8	56
Total	3	4	8	1	2	4	1	0	3	26	195

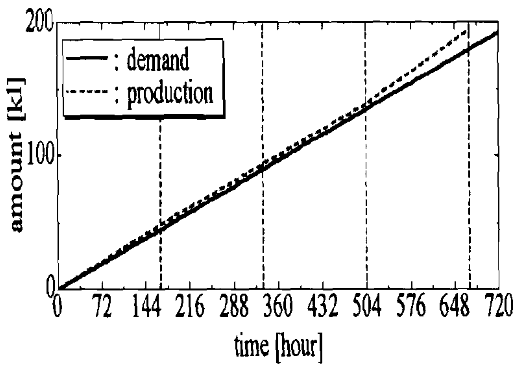


Fig.8 Transition of production

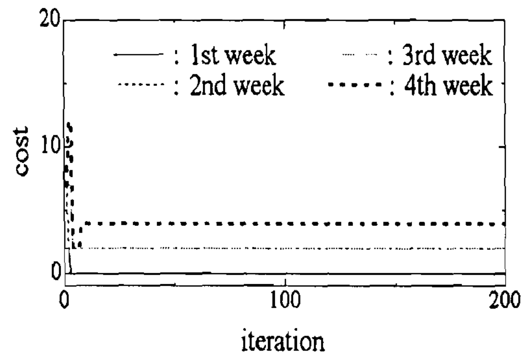


Fig.9 Transition of cost

From the results, it can be said that production was done uniformly during the month. Figure 9 shows the transition of cost during simulation period.

4.3.3 THE DECISION OF DUE-DATE

The method to decide due-date and its results will be presented in the following.

When we determine due-date randomly, machine interference occurs because due-dates of plural order approaches and/or overlaps. The results were same though determination of due-dates are repeated several times (see Appendix A-4). Therefore, as for the decision of due-date, method by random generation can not be adopted.

Here, due-date is decided in consideration of the makespan for each lotsize. The makespans for each lotsize are shown in Table 5.

Table5 The makespan in each lotsize

Lotsize	S	M	L
Makespan [hour]	19	25	31

Due-date is set up in order starting from the job of the L size to smaller sizes, and due-date interval was made half of the makespan of each lotsize. As for the calculation of due-date, we used the following equations.

$$DT_{\mathrm{L}m}^{\ k} = \begin{cases} 35 & ((m,\ k) = (1,\ 1)) \\ 35 + 15 \sum_{m=1}^{M} \sum_{k=1}^{K(m)} L_m^k & (\ otherwise\ ) \end{cases} \tag{11}$$

$$DT_{\mathrm{M}m}^{\ k} = \sum_{m=1}^{M} \sum_{k=1}^{K(m)} DT_{\mathrm{L}m}^{\ k} + 12 \sum_{m=1}^{M} \sum_{k=1}^{K(m)} M_m^k \tag{12}$$

$$DT_{\mathrm{S}m}^{\ k} = \sum_{m=1}^{M} \sum_{k=1}^{K(m)} DT_{\mathrm{M}m}^{\ k} + 9 \sum_{m=1}^{M} \sum_{k=1}^{K(m)} S_m^k \tag{13}$$

Where, $DT_{\mathrm{L}m}^{\ k}$, $DT_{\mathrm{M}m}^{\ k}$ and $DT_{\mathrm{S}m}^{\ k}$ are due-dates of product m and order k for each lotsize respectively and L_m^k, M_m^k and S_m^k are the number of jobs for each lotsize.

Calculated due-dates are shown in Table 6. And, using the due-dates, scheduling is carried out. Scheduled results are shown in Figures 10 to 13.

Table6 Due-Date of each job [hour] [lotsize]

m	k	1st week	2nd week	3rd week	4th week
1	1	35.0 [L]	35.0 [L]	35.0 [L]	35.0 [L]
1	2	77.0 [M]	50.0 [L]	50.0 [L]	50.0 [L]
1	3	89.0 [M]	92.0 [M]	92.0 [M]	65.0 [L]
1	4	98.0 [S]	—	—	113.0 [S]
1	5	107.0 [S]	—	—	—
2	1	50.0 [L]	65.0 [L]	65.0 [L]	80.0 [L]
2	2	116.0 [S]	—	—	92.0 [M]
2	3	—	—	—	104.0 [M]
3	1	65.0 [L]	80.0 [L]	80.0 [L]	122.0 [S]

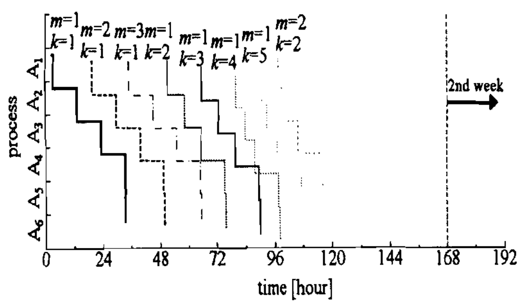


Fig.10 Scheduling resurt (1st week)

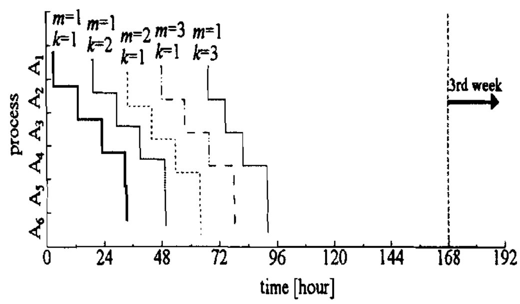


Fig.11 Scheduling resurt (2nd week)

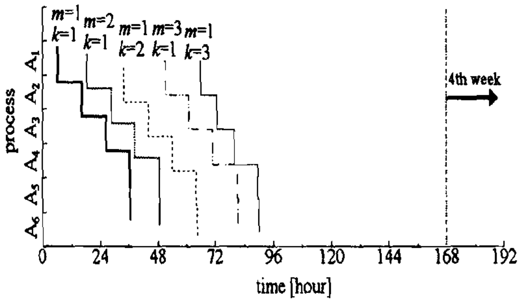


Fig.12 Scheduling resurt (3rd week)

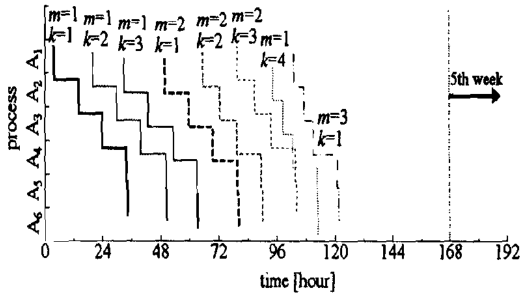


Fig.13 Scheduling resurt (4th week)

From the above results, it can be said that production according to demand is made without machine interference when due-dates are set up in consideration of the makespan.

Another numerical experiment with changing demand of each product is shown in Appendix A-5.

5 DYNAMIC SCHEDULER

In this chapter, explanation of components in dynamic scheduler is given. Figure 14 shows the construction of dynamic scheduler. That is, functions of scheduler, simulator and controller are explained.

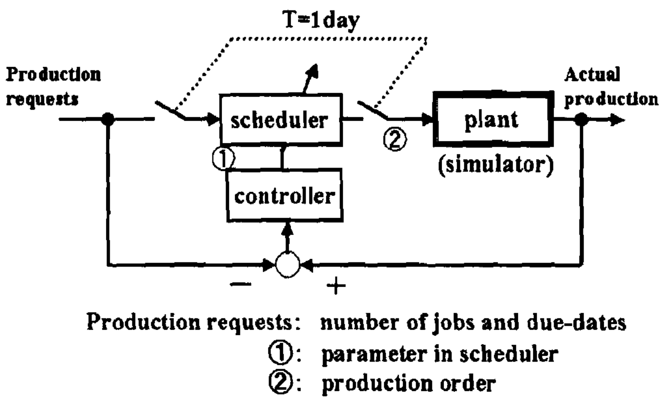


Fig.14 Construction of dynamic scheduler

5.1 SCHEDULER

Here, the scheduler that is a part of the dynamic scheduler is explained. That is, the function of scheduler and scheduling method based on pheromone information is presented. Then, the effectiveness of the scheduling method is verified.

5.1.1 FUNCTION OF THE SCHEDULER

In the scheduler, using due-date of each job, starting time of processing in each process is determined such that the production is in time to due-date. Evaluation of the scheduling is done by the following equation.

$$I = \sum_{m=1}^{M} \sum_{k=1}^{K(m)} \left\{ DT_m^k - (t_{6m}^k + T_{6m}^k) \right\}^2 \longrightarrow \min \tag{14}$$

Where, m is product number, k is order number, DT_m^k is due-date of each job, t_{6m}^k is starting time of processing in process 6 for each job, T_{6m}^k is processing time of each job in process 6. Because problem consist of six processes, production schedule in which penalties for the earliness and tardiness in whole processes are minimized. In the minimization, the following constraints are taken into consideration.

$$t_{(l+1)m}^k \geq t_{lm}^k + T_{lm}^k \qquad (\ l = 1, 2, 3, 4, 5, 6\ ) \tag{15}$$

$$T_4^{min} \leq T_{4m}^k \leq T_4^{max} \tag{16}$$

Where, l is process number, t_{lm}^k is starting time of process l for each job, T_4^{min} is the minimum processing time in process 4, T_4^{max} is the maximum processing time in process 4.

Equation(15) is precedence constraint of operations between process l and process $(l+1)$. Equation(16) denote that T_{4m}^k can be constricted and be expanded between minimum value of T_{4m}^k T_4^{min} and maximum value T_4^{max}.

At the stage of the scheduling, machine interference is not considered and the starting times of each processing are determined in time to due-date. The scheduling method is explained in the following.

5.1.2 SCHEDULING METHOD BASED ON PHEROMONE INFORMATION

Here, scheduling algorithm with pheromone information which is the analogy to Ant System[10] is proposed. In the algorithm, each agent corresponding to each job searches a near optimal solution by using the pheromone information.

Scheduling horizon is devided into several nodes at each process. Figure 15 shows an example of node representation in a gantt-chart. For example, in the plant with four processes, a schedule is determined by the route of nodes for each job. Each job is defined as an agent. Each agent searches its own route using value of the pheromone information. This value is increased when a candidate of a route is adopted as a solution. On the other hand, the value is decreased when a route is not adopted. Using this value, each agent cooperatively searches its own route considering those of the other agents.

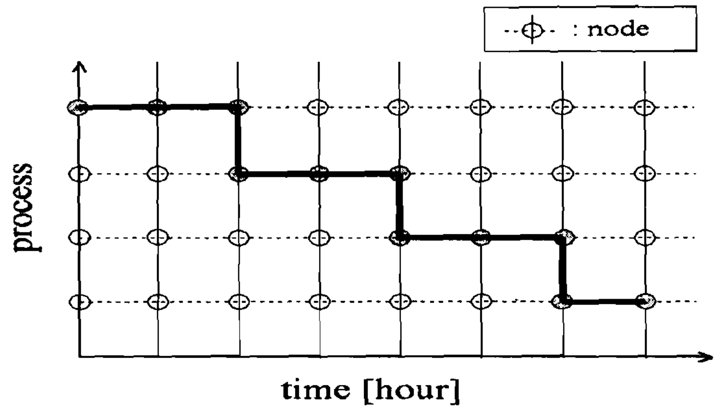


Fig.15 Nodes representation in gantt-chart

5.1.3 SCHEDULING ALGORITHM

In this section, scheduling algorithm by pheromone information is explained. The steps in the algorithm are as follows.

(a) Generation of an initial solution

Starting time t^k_{1m} is given by a randomly generated time from 0 to 200, and the other starting times (t^k_{lm} ($l = 2 \sim 5$)) are determined by the following equation.

$$t^k_{(l+1)m} = t^k_{lm} + T_l \qquad (l = 1,\ 2,\ 3,\ 4,\ 5) \tag{17}$$

From equation(17), a route nodes for each agent is determined. Here, it is possible to change the processing time T^k_{4m} in Process 4. While, the initial value of T^k_{4m} is given by T^0_4. T^0_4 is 10.0.

(b) Improvement of the value of pheromone information

Each agent sets the value of pheromone information at the node(i, j). The values of pheromone information are assignd on the route nodes by equation(18).

$$ph(i, j, iter) \sim ph(i, j + T_l, iter) = W^k_m \tag{18}$$

Where, W^k_m is value of pheromone information. This value is a non-negative integer which is different value for each agent.

(c) Generation of a candidate of solution

A candidate of solution is determined referring to the value of pheromone information which is assignd at the route nodes.

(d) Judgment whether a candidate of solution is adopted or not

In step(d), the judgment whether a candidate of solution is adopted or not is made according to following equation.

$$P_{m,k} = \begin{cases} 1 & (J_{m,k}^{(2)} \leq J_{m,k}^{(1)}) \\ \exp\left\{ -\dfrac{(J_{m,k}^{(2)} - J_{m,k}^{(1)})}{T_p} \right\} & (\mathit{otherwise}) \end{cases} \tag{19}$$

Where, T_p is annealing temperature. This is analogy to a parameter in Simulated Annealing method. The cost $J_{m,k}$ is given by the following.

$$J_{m,k} = \{DT_m^k - (t_{6m}^k + T_6)\}^2 \tag{20}$$

A random number b [0, 1] is generated. If $b < P_{m,k}$, candidate of a solution is adopted, and it becomes new solution, otherwise not adopted.

(e) Update of the value of pheromone information

If the agent searches the same route many times, the value of pheromone information is increased and otherwise, this value is decreased by evaporation as shown in the following equation.

$$ph(i,j,iter+1) = \begin{cases} ph(i,j,iter) \times (1-\rho) + W_m^k & ((i,j,iter)^{(1)} = (i,j,iter)^{(2)}) \\ ph(i,j,iter) \times (1-\rho) & (\mathit{otherwise}) \end{cases} \tag{21}$$

Where, the value ρ is the reduction ratio which means pheromone evaporation factor.

(f) End of iterations

If iteration is terminated, the route nodes for each agent which is the most concentrated pheromone are the final solution. Otherwise return to step(c).

From the above procedure, the flow chart of scheduling method by pheromone information is shown in Figure 16.

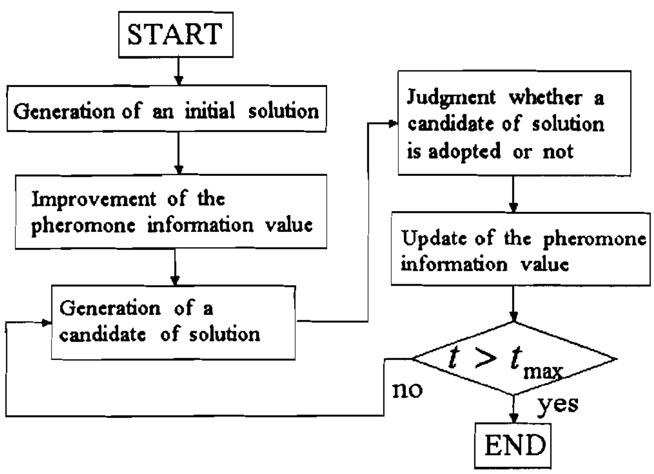
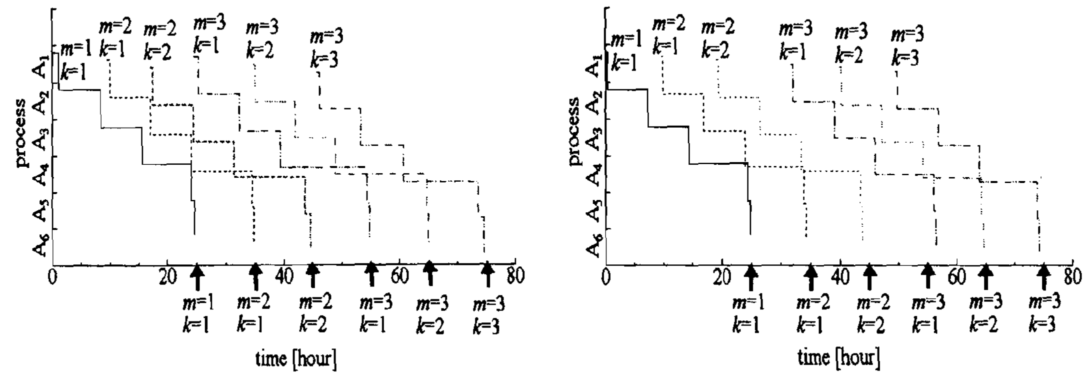


Fig.16 Flow chart of scheduling

5.1.4 EFFECTIVENESS OF PHEROMONE INFORMATION METHOD

A gradient method called flexible polyhedron method(FPM)[11] is used to calculate optimal solution of scheduling. Comparing the results of FPM and pheromone information method, the effectiveness of pheromone information method will be confirmed. The scheduling results of FPM and pheromone information method are shown in Figure 17.



(a) flexible polyhedron method (b) pheromone information method

Fig.17 gantt-chart

As shown in figure 17, both flexible polyhedoron method and pheromone information method obtained almost the same results. Using pheromone information method, the computation times to find these solutions is shown in Figure 18. In the figure, the computer spec is CPU of Pentium Ⅲ 533MHz and Memory of 128Mb. The computation time using FPM is not shown, but the time is several hours. That is, using pheromone information method the computation time to search solution is very short and the optimality is assured. Therefore, the effectiveness of pheromone information method is confirmed.

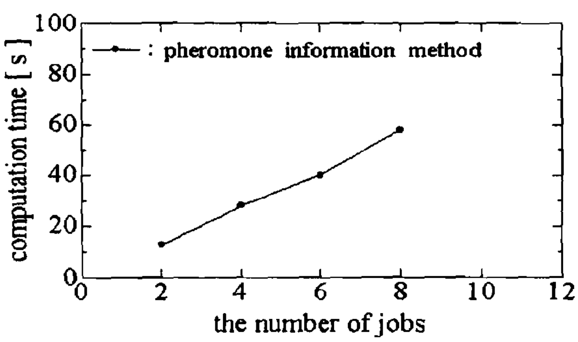


Fig.18 Computation times

5.2 SIMULATOR

The role of the simulator is to find the amount of production. The starting time of each process which is output from the scheduler is input to the simulator, and the amount of production is simulated. Machine interference is checked at this stage, and any jobs inducing machine interference are rejected. As for the assignment to machine, the job with faster starting time is preferred than that with later starting time. The constraints to avoid machine interferences are the following.

$$\sum_{m=1}^{M} \sum_{k=1}^{K(m)} w_{lm}^{k} \leq 1 \qquad (l = 1,2,3,5,6) \tag{22}$$

$$w_{lm}^{k} = \begin{cases} 1 & \text{(During use of a machine)} \\ 0 & \text{(Unused machine)} \end{cases} \tag{23}$$

Equation(22) means that each job assigns only one process at a time. But, relation for process 4 is avoided from the constraint.

As for the output of simulator, the transition of production amount is calculated as shown in Figure 19.

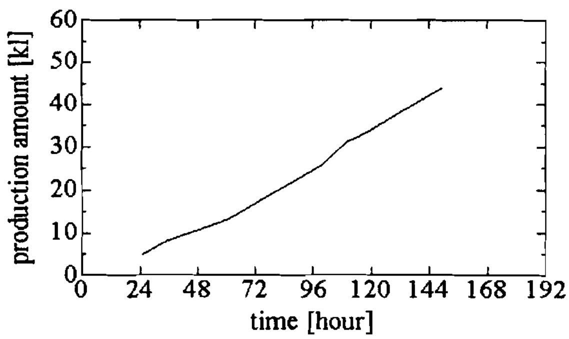


Fig.19 Transition of production amount

Scheduling is made in every week, and a production planning is made in every month.

5.3 CONTOLLER

In figure 14, output result (actual production) is compared with input (production requests), and the difference between them is fed back to the controller. In this study, the difference is controlled to decrease by adjusting processing time T_{4m}^{k} in process 4. The procedure of the control will be described in the following.

(a) Generation of the initial schedule

The initial schedule is generated.

(b) Checking the state for rescheduling

Production demand is given every 24 hours and production schedule is modified every 24 hours as follows.

(1)Check the predetermined schedule under operation.

(2)Check the schedule which is not operated.

(3)Modification of the schedule.

Here, we define two states for rescheduling. In state①, job is under production and variables from t_{4m}^{k} to t_{6m}^{k} can be reset. That is, the starting time after Process 4 where production order are interchangeable may be reset. In state②, the job is not yet produced and variables which may be reset are all the starting time from t_{1m}^{k} to t_{6m}^{k}.

These relations are shown in Tables 7 and 8. Where, DF is the time where production demand is given. In this paper, DF is set to 24.

Table 7 variables for rescheduling

	state	variables
①	$t_{1m}^k \leq DF$	$t_{4m}^k \sim t_{6m}^k$
②	$t_{1m}^k > DF$	$t_{1m}^k \sim t_{6m}^k$

Table 8 Two states for adjustment of T_{4m}^k

	state	adjustment of T_{4m}^k
①	$t_{1m}^k \leq DF$	adjustable
②	$t_{1m}^k > DF$	fixed

(c) Adjustment of T_{4m}^k

T_{4m}^k can be described as follows.

$$T_{4m}^{k\ (2)} = T_{4m}^{k\ (1)} + I_{m,k}^{(1)} - I_{m,k}^{(2)} \tag{24}$$

In Table 8, state ① shows that starting time t_{1m}^k is prior to DF. Therefore, for the job of state ① the schedule can not be modified. Because it is the past event. Process for which modification is possible is the state ② where the starting time is posterior to DF. So, when demand changes in state ①, T_{4m}^k, the processing time of process 4 is adjusted.

Where, indices (1) and (2) added to variable I in equation(24) show the first solution and the second solution respectively. And, variable I means cost given by equation(14). Equation(14) shows the objective function that the earliness and tardiness penalties are to be minimized. That is, equation(24) means that T_{4m}^k is adjusted such that the production is in time to its due-date.

For job of state ②, t_{1m}^k is posterior to DF. For this reason, the job can be canceled or postponed, that is t_{1m}^k can be modified. Therefore, adjustment of T_{4m}^k is not necessary to be considered. So, the production scheduling procedure for job of state② is the same as the initial scheduling.

6 NUMERICAL EXPERIMENT

In this chapter, the effectiveness of dynamic scheduler shown in figure 14 will be presented. Where, lotsizes are three of S, M and L and its capacities are 3, 5 and 10.

6.1 SCHEDULING WITHOUT CONTROLLER

When feed back is cut in figure 14, control block becomes as shown in Figure 20.

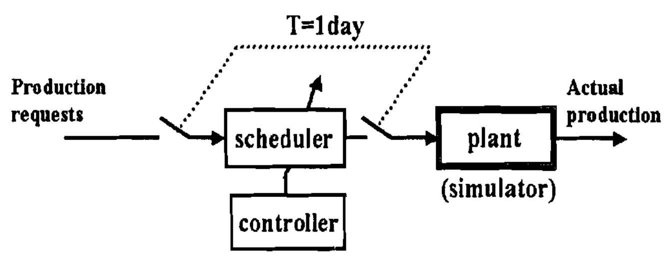


Fig.20 Dynamic scheduler plant without feed back

When feed back controller is not made in scheduling, it can be said that production according to demand can be done so far as machine interference can't occur and a change in demand doesn't occur (see Appendix B-1).

The controller is removed in figure 14. The scheduling results for demand changes in Table 9 are shown in Figures 21 and 22, and the result of production simulation is shown in Figure 23.

In Table 9, we assumed that demand changes in 1st week from (1) to (2) and in 2nd week from (3) to (4).

Table 9 Due-Date of each job [hour] [lotsize]

m	k	1st week (1)	1st week (2)	2nd week (3)	2nd week (4)
1	1	25.0 [M]	25.0 [M]	25.0 [M]	25.0 [M]
1	2	35.0 [S]	40.0 [S]	35.0 [M]	50.0 [M]
1	3	—	125.0 [M]	45.0 [M]	60.0 [M]
1	4	—	130.0 [S]	60.0 [M]	80.0 [M]
1	5	—	—	80.0 [S]	—
2	1	60.0 [M]	60.0 [M]	100.0 [L]	100.0 [L]
2	2	70.0 [S]	70.0 [S]	—	—
3	1	100.0 [L]	90.0 [L]	115.0 [M]	115.0 [M]
3	2	110.0 [S]	—	130.0 [M]	—
3	3	—	—	185.0 [M]	—
4	1	120.0 [S]	110.0 [S]	150.0 [M]	150.0 [M]
4	2	150.0 [L]	150.0 [L]	175.0 [M]	175.0 [M]
5	1	180.0 [L]	180.0 [L]	—	—

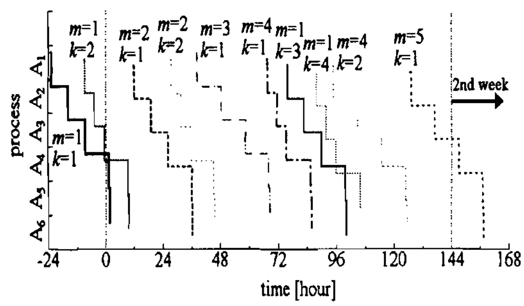


Fig.21 Scheduling result (1st week (2))

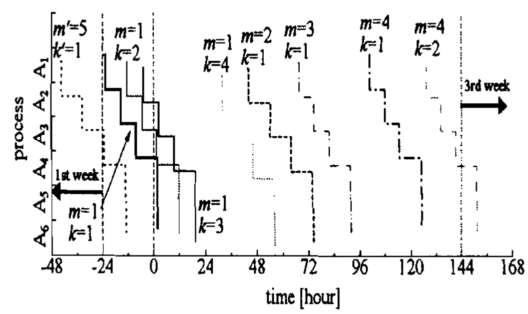


Fig.22 Scheduling result (2nd week (2))

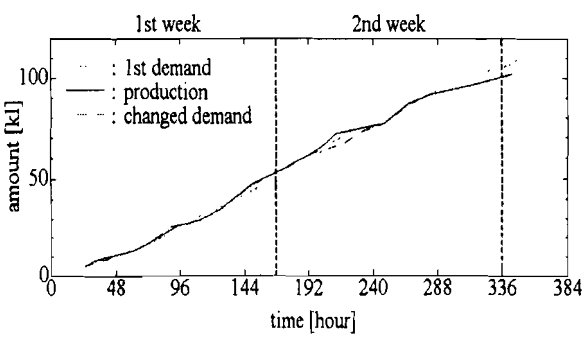


Fig.23 Simulation result

It is shown from these results, when demand changes, regardless of the existence of machine interference, it is difficult to produce demand according to the requirement. Because machine interference doesn't occur in this example, production difference is zero in both the first week and the second week as shown in Table 10.

Table10 Production difference [kl]

	1st week	2nd week
Production error	0.0	0.0
Total error	0.0	0.0

However, figure 23 is understood that a difference induced by change in due-date is big. Especially, as for three jobs (m=1, k=2), (m=1, k=3) and (m=1, k=4) in the second week, due-date is greatly changed, and the job (m=1, k=2) and the job (m=1, k=3) can't follow-up a change in due-date. This is clear from figure 22, as for due-date of two jobs and scheduling result, there is a big difference. For such reason, the amount of production exceeds demand temporarily its limit. This result gives bad influences to stock cost. Reversely, it can be thought that the shortage of production occurs.

6.2 SCHEDULING WITH CONTROLLER

Here, the controller is connected to the scheduler as shown in Figure 24. The experimental results are shown in Figures 25 to 33. Figures 25 and 27 are initial scheduling results, figures 26 and 28 are the rescheduling results corresponding to figures 25 and 27. From Figures 29 to 33 are the simulation results. Experimental considerations for due-dates are the same with those in Table 9.

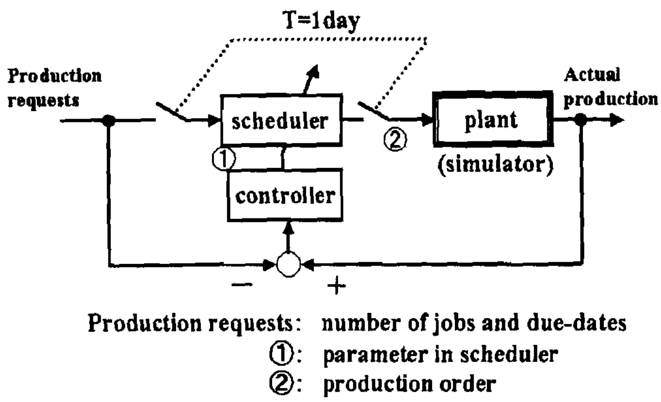


Fig.24 Dynamic scheduler

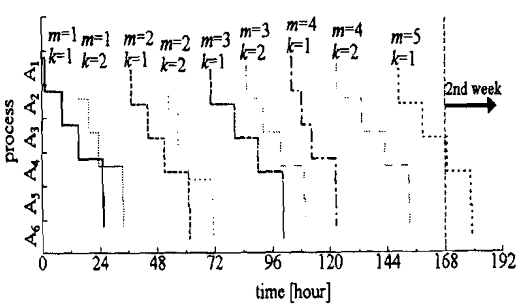


Fig.25 Scheduling result (1st week(1))

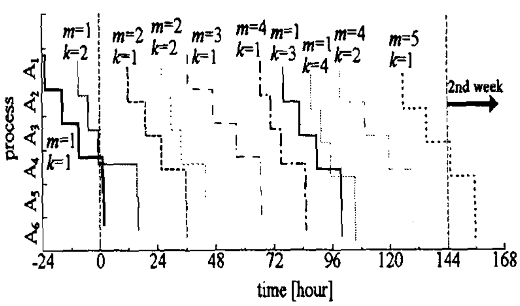


Fig.26 Scheduling result (1st week(2))

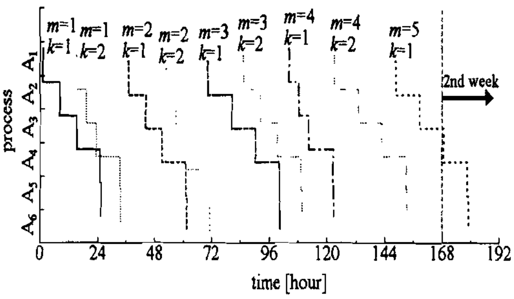


Fig.B.1 Schedule(1st week)

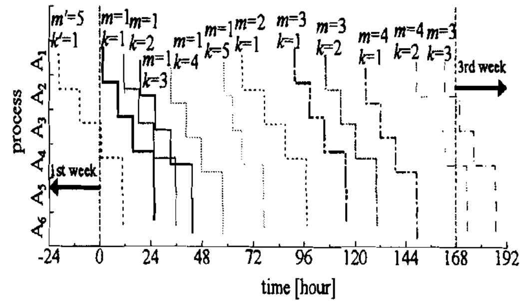


Fig.B.2 Schedule(2nd week)

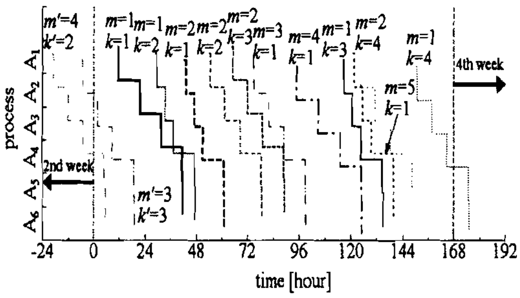


Fig.B.3 Schedule(3rd week)

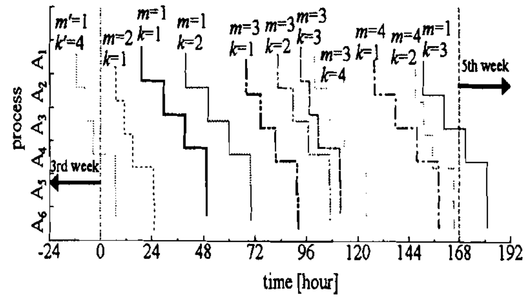


Fig.B.4 Schedule(4th week)

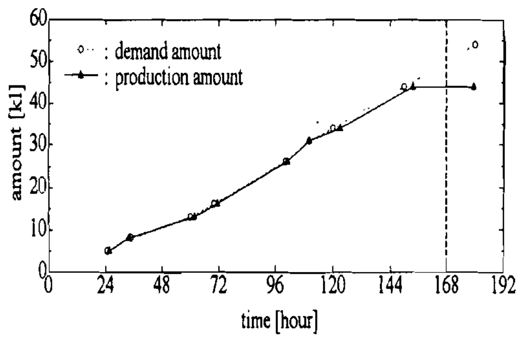


Fig.B.5 Simulation result(1st week)

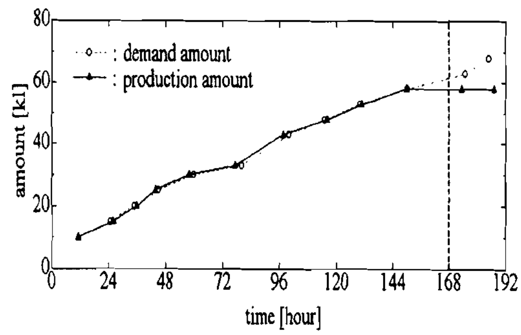


Fig.B.6 Simulation result(2nd week)

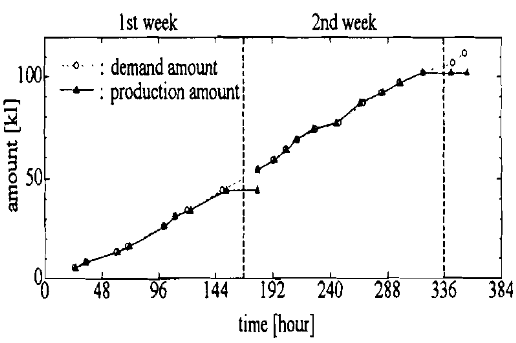


Fig.B.7 Simulation result(1st and 2nd week)

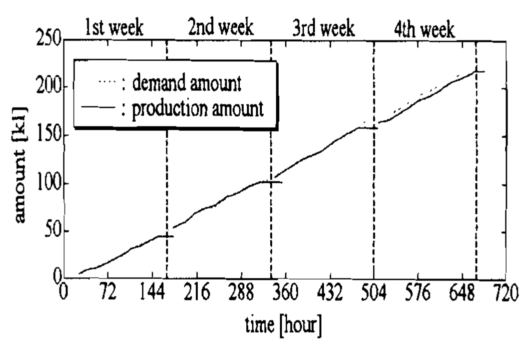


Fig.B.8 Simulation result

Figure B.5 is the result of simulation based on the scheduling result of figure B.1. In case of figure B.1 machine interference does not occur. For such reason, all jobs can produce, as shown in figure B.5, production according to requirement can be done. In figure B.5, there are some errors in the demand quantity and the production quantity and these errors are due to the deviation

From figures 31 and 32, it is understood that production difference (stock cost) is decreased during scheduling by introduction of the controller. Where, production differences are calculated by the amount of demand and production. It is the second week (figures 30 and 32) that the effect of the controller becomes remarkable, and it is understood that accumulated difference decreases by connecting the controller. As for the first week, also the production difference is decreased.

The difference in the second week isn't dissolved completely because controller output becomes upper limit value of adjustable processing time in Process 4. For this reason, as for the jobs (m =1, k=2) and the job (m=1, k=3), a certain amount of differences are left between required due-date and that of scheduled result. As for the job (m=1, k=2) and the job (m=1, k=3), due-date differences between the results with controller and without controller are compared in Table 11.

Table11 Due-date differences [hour]

(a) When controller isn't connected

	(m=1, k=2)	(m=1, k=3)
Requirement	50.0	60.0
no-control	36.1	43.8
error	13.9	16.2

(b) When controller is connected

	(m=1, k=2)	(m=1, k=3)
Requirement	50.0	60.0
control	46.1	53.8
error	3.9	6.2

From the above results, when demands change occurs, it could confirm that production difference could be reduced by connecting the controller forming a feed back loop as shown in figure 14.

7 COCLUSION

Production control system for planning and scheduling has been proposed. The effect of the proposed system was confirmed by numerical experiments assuming soft drinks production line. Proposed system has two functions of planning and scheduling. Studies are carried out for these functions. First, in the part of planning, smoothing procedure of production plan is presented. These are, (1)generation of number of jobs to be treated, (2)assignment of every product orders to one of three lotsizes, S, M and L, and (3)calculation of due-dates. Second, for scheduling part, the performances of dynamic scheduler consisting of scheduler, simulator and controller are investigated by numerical experiments.

In this paper, main study is focused on the design of dynamic scheduler. The feed back of the substitution of target value from attained value in the amount of production to the scheduler is introduced which enabled follow-up ability of production system to such disturbances as weather conditions, rush order products and unexpected orders. In the feed back loop, adaptation of parameters in scheduler is equiped and its effectiveness is tested.

As the result, in the planning, smoothness of production amount in planning term is attained. Also, by dynamic scheduling, it becomes possible to follow-up flexibly to the change in demands.

Further, the amount of stock is decreased by parameter tuning of scheduler. Thus, proposed production control system is appeared fairly compensatable for the change in demands.

As for the problem to be solved in the future, another feed back loop to production planning is to be added for the improvement of the accuracy of production control effect. In that stage, the appropriate term for planning of each parts and sampling intervals will be pursued.

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APPENDICES

A Production Planning

A.1 An initial solution of Each Lotsize

An initial solution is generated by using the following equations.

$$S = \frac{D[kl] \times (0,\ 1)}{3[kl]} \tag{A.1}$$

$$M = \frac{(D - 3S)[kl] \times (0,\ 1)}{5[kl]} \tag{A.2}$$

$$L = \frac{(D - 3S - 5M)[kl]}{10[kl]} \tag{A.3}$$

A.2 Job Numbers for Fixed Lotsize

The job number J can be decided as follows using demand D and fixed lotsize L_S.

$$J = \left\lceil \frac{D}{L_S} \right\rceil + 1 \tag{A.4}$$

A.3 Smoothing of Each Lotsize

The number of jobs of each product for one week is decided by using the following equation.

$$S_m^w = \frac{S_m/3}{J_m} \times Pr_m^w \tag{A.5}$$

$$M_m^w = \frac{M_m/5}{J_m} \times Pr_m^w \tag{A.6}$$

$$L_m^w = \frac{L_m/10}{J_m} \times Pr_m^w \tag{A.7}$$

Constants 3, 5 and 10 used in these the equations are the capacity of lotsize S, M and L.

A.4 The Decision of Due-date by Using Random Number

Here due-date is determined randomly by using random number and shown in Table A.1. Using these due-date, production scheduling is carried out. Its results are shown in Figures A.1 to A.4.

TableA.1 Due-Date of each job [hour] [lotsize]

m	k	1st week	2nd week	3rd week	4th week
1	1	20.0 [S]	64.0 [L]	25.0 [M]	96.0 [L]
1	2	28.0 [S]	114.0 [L]	46.0 [L]	117.0 [L]
1	3	35.0 [L]	144.0 [M]	92.0 [L]	120.0 [L]
1	4	72.0 [M]	—	—	155.0 [S]
1	5	82.0 [M]	—	—	—
2	1	62.0 [L]	144.0 [L]	153.0 [L]	25.0 [M]
2	2	137.0 [S]	—	—	35.0 [L]
2	3	—	—	—	153.0 [M]
3	1	150 [L]	47.0 [L]	35.0 [L]	65.0 [S]

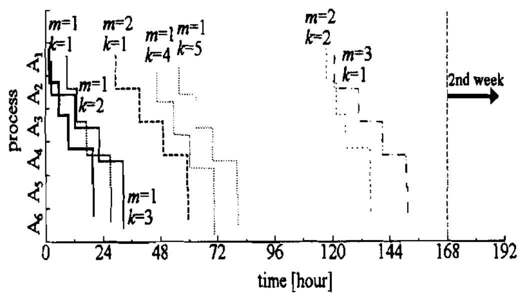

Fig.A.1 Scheduling resurt (1st week)

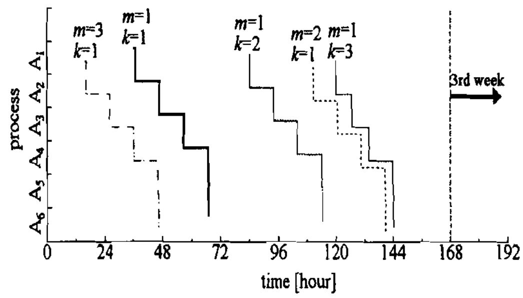

Fig.A.2 Scheduling resurt (2nd week)

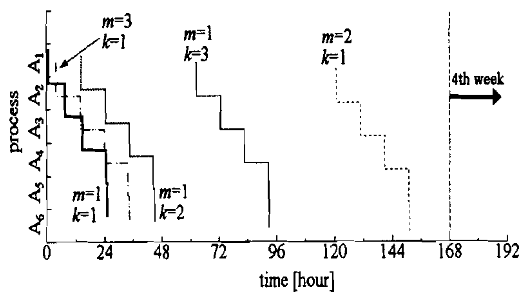

Fig.A.3 Scheduling resurt (3rd week)

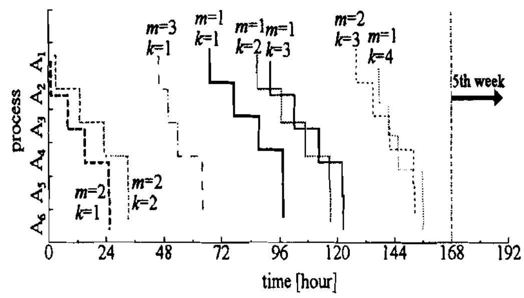

Fig.A.4 Scheduling resurt (4th week)

A.5 Production Planning Changing Demand of Each Product

When we consider example as shown in TableA.2, the results of production planning shows the following.

TableA.2 Demands

product	Demand [kl]
1	30
2	50
3	100
合計	180

TableA.3 Sum of job

product	Job [S,M,L]	Production [kl]	Stock [kl]	Cost
1	8 [4,4,0]	32	2	10
2	12 [6,5,1]	53	3	15
3	14 [0,7,7]	105	5	19
合計	34	190	10	44

TableA.4 The numbers of job in each week

	product1			product2			product3				
week	S	M	L	S	M	L	S	M	L	Job	Production [kl]
1	1	1	0	2	1	0	0	3	1	9	44
2	1	1	0	2	1	0	0	3	1	9	44
3	1	1	0	0	1	1	0	0	2	6	43
4	1	1	0	2	2	0	0	2	3	10	59
合計	4	4	0	6	5	1	0	7	7	34	190

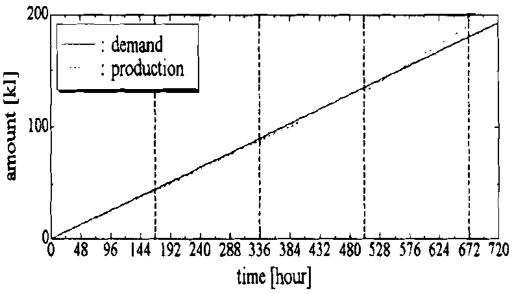

Fig.A.5 Transition of production

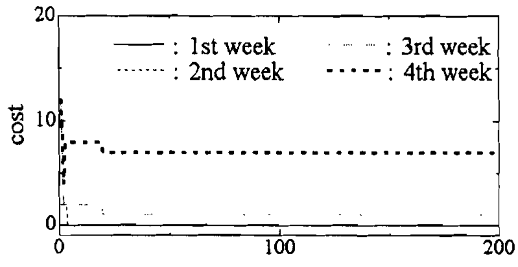

Fig.A.6 Transition of cost

TableA.5 Due-date of each job [hour] [lotsize]

m	k	1st week	2nd week	3rd week	4th week
1	1	47.0 [M]	47.0 [M]	77.0 [M]	77.0 [M]
1	2	104.0 [S]	104.0 [S]	98.0 [S]	122.0 [S]
2	1	59.0 [M]	59.0 [M]	35.0 [L]	89.0 [M]
2	2	113.0 [S]	113.0 [S]	89.0 [M]	101.0 [M]
2	3	122.0 [S]	122.0 [S]	—	131.0 [S]
2	4	—	—	—	140.0 [S]
3	1	35.0 [L]	35.0 [L]	50.0 [L]	35.0 [L]
3	2	71.0 [M]	71.0 [M]	65.0 [L]	50.0 [L]
3	3	83.0 [M]	83.0 [M]	—	65.0 [L]
3	4	95.0 [M]	95.0 [M]	—	113.0 [M]

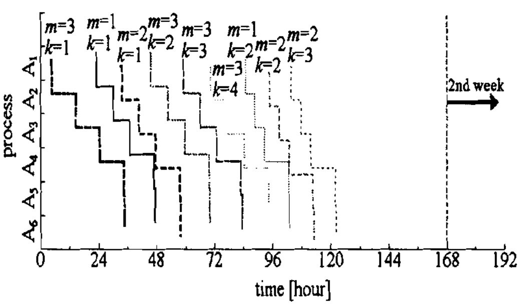

Fig.A.7 Schedule(1st week)

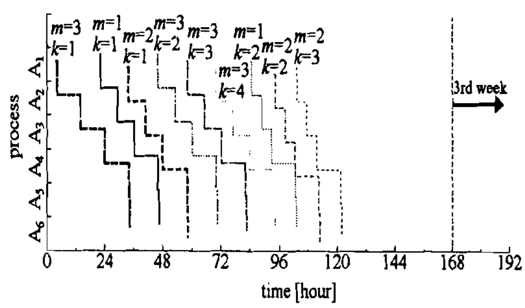

Fig.A.8 Schedule(2nd week)

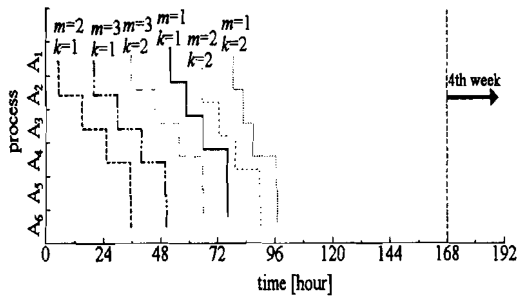

Fig.A.9 Schedule(3rd week)

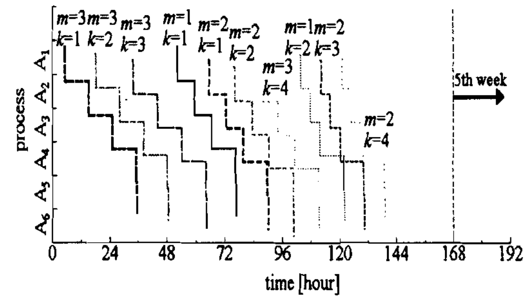

Fig.A.10 Schedule(4th week)

B Scheduling

B.1 Scheduling Without Feed Back Control

When demands don't change, that is, when numbers of job and due-date don't change in figure 20, scheduling results show in Figuers B.1 to B.8. Due-date of each jobs is given in Table B.1. From figures B.1 to B.4 scheduling results for each week are shown. Figures B.5 to B.8 are production simulation results.

TableB.1 Due-Date of each job [hour] [lotsize]

m	k	1st week	2nd week	3rd week	4th week
1	1	25.0 [M]	25.0 [M]	40.0 [L]	50.0 [L]
1	2	35.0 [S]	35.0 [M]	50.0 [S]	70.0 [L]
1	3	—	45.0 [M]	135.0 [S]	180 [L]
1	4	—	60.0 [M]	175.0 [M]	—
1	5	—	80.0 [S]	—	—
2	1	60.0 [M]	100.0 [L]	60.0 [S]	25.0 [S]
2	2	70.0 [S]	—	80.0 [M]	—
2	3	—	—	90.0 [M]	—
2	4	—	—	150.0 [M]	—
3	1	100.0 [L]	115.0 [M]	100.0 [M]	90.0 [M]
3	2	110.0 [M]	130.0 [M]	—	105.0 [M]
3	3	—	185.0 [M]	—	110.0 [S]
3	4	—	—	—	125.0 [M]
4	1	120.0 [S]	150.0 [M]	125.0 [L]	160.0 [L]
4	2	150.0 [L]	175.0 [M]	—	165.0 [S]
5	1	180 [L]	—	140.0 [S]	—

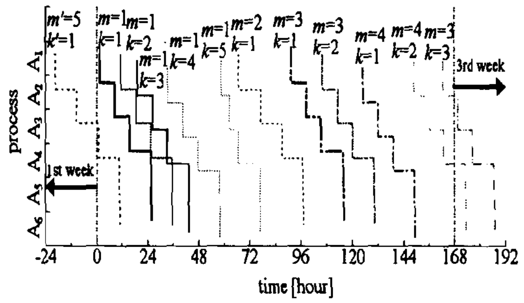

Fig.27 Scheduling result (2nd week(1))

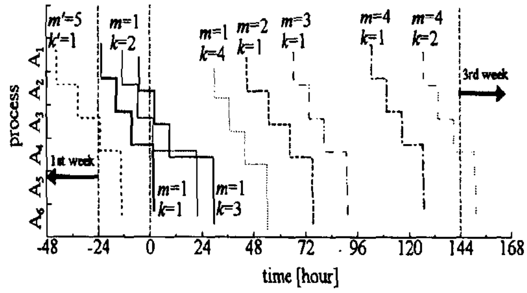

Fig.28 Scheduling result (2nd week(2))

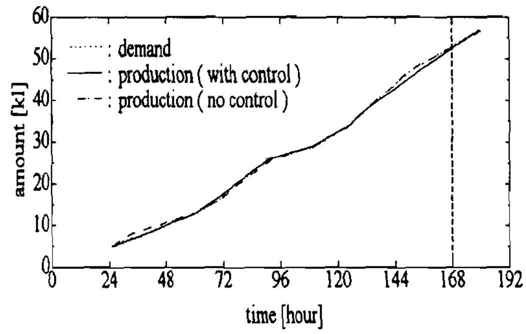

Fig.29 Simulation result (1st week)

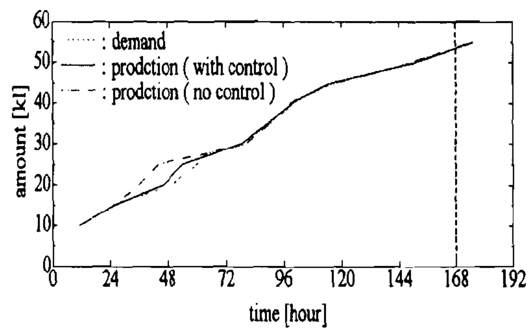

Fig.30 Simulation result (2nd week)

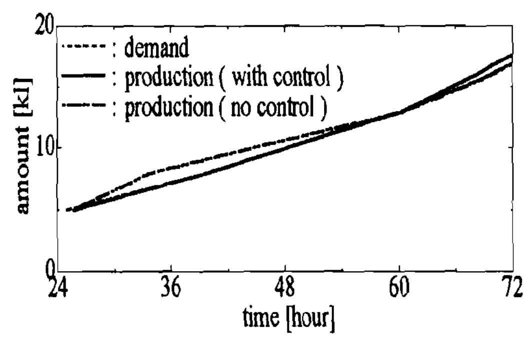

Fig.31 Enlarged of Fig.29

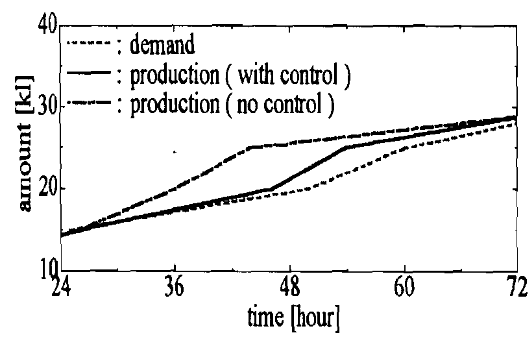

Fig.32 Enlarged of Fig.30

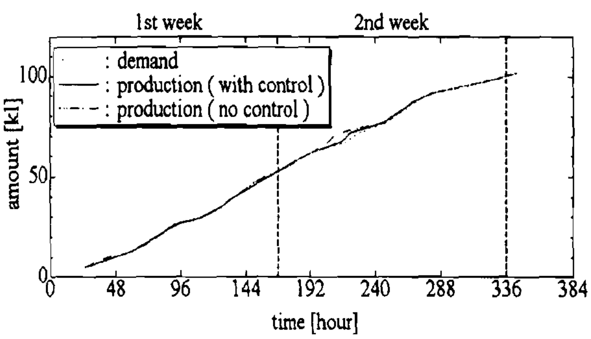

Fig.33 Simulation result

Figure 29 is the result which simulated on the basis of scheduling result of figure 26. Figure 30 is result which simulated on the basis of scheduling result of figure 28. Figures 31 and 32 are enlarged figures of figures 29 and 30. Seeing from these figures, we can understand problems stated above more clearly. Fig.33 is the result connecting figures 29 and 30.

of due-date. That is, the difference from the shipping time of each job and the required due-date appears as an error. But, there is no problem in the error at this case. Because, this error occurs in the middle of the first week, required demand is satisfied in the amount of total for one week. Again, in figure B.5, there is a big error in the amount of demand and the amount of production after 144 hours, and the amount of production becomes a constant from the neighborhood for 144 hours, and doesn't change. This is clear from the figure B.1, It knows this cause when it pays attention to the last job (m=5, k=1) of the first week. The job (m=5, k=1) is being produced at the moment (168 hours) when the 1st week ended, it isn't counted as an amount of production. Because of this, when there is a job over week, it only seems that there is an error in the amount of demand and the amount of production at the week latter half, production error is a zero in case of this problem unless machine interference happens.

Figure B.6 is result which simulated on the basis of scheduling result of figure B.2. The production error is a zero as well as figure B.5. Figure B.7 is the result that figures B.5 and B.6 were unified.

From the above, the result for two weeks becomes a figure B.7, it is understood that a production error is a zero. And, as for the job (m=4, k=2) and the job (m=3, k=3), production is carried in the next week as well as the first week forward no less than the second week.

Figure B.8 is result which simulated on the basis of scheduling result of four weeks (for one month) from figures B.1 to B.4. The amount of total production which the amount of production until the former week was increased to after the second week is shown. The amount of production after the second week shows the amount of total production which the amount of production until the former week was increased. Until the second week, machine interference isn't occurred from figures B.1 and B.2, demands for production are satisfied. The amount of demand exceeds the amount of production when a result of production simulation of the third week is seen. This is clearer than the figure B.3 of scheduling result of the third week, and it is a cause that the job (m=1, k=3) and the job (m=2, k=4) occur machine interference. For such reason, the job (m=2, k=4) that starting time is slow is stopped, and the amount of demand exceeds the amount of production as a result. The error here becomes the capacity 5 [kl] of the lotsize M of the job (m=2, k=4), and becomes shortage of production of 5 [kl]. As for the fourth week, because the job (m=4, k=2) and the job (m=1, k=3) occur machine interference, the production of the job (m=1, k=3) is stopped from Fig.B.4. However, because this job (m=1, k=3) is the job that it is carried forward in the next week, production error is a zero if it is limited to the fourth week. Therefore, it is shortage of production of 5 [kl] in the total for one month. The production error at this time is shown in Table B.2.

TableB.2 Production error [kl]

	1st week	2nd week	3rd week	4th week
Production error	0.0	0.0	–5.0	0.0
Total error	0.0	0.0	–5.0	–5.0