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Development of a Batch Manager for Dynamic Scheduling and Process Management in Multiproduct Batch Processes

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Abstract−A batch manager is developed for the dynamic scheduling and on-line management of process operations. The developed system consists of a process monitoring module and a dynamic scheduling module. When a deviation from the initial schedule is detected in a process monitoring module, dynamic scheduling is performed in the dynamic scheduling module and the initial schedule is adjusted to the proper schedule by using rescheduling algorithms presented in this paper. The adjusted schedule is shown in the process monitoring module. The dynamic scheduler in the batch manager copes with several unexpected process events of batch process operations by adjusting the EST (Earliest Start Time) of equipment, redetermining the batch path and reassigning tasks to equipment. This study focuses on the implementation of a batch manager with on-line dynamic scheduling for batch process management. Examples of fodder production batch processes illustrate the efficiency of the algorithms.

Key words: Dynamic Scheduling, Process Monitoring, Batch Variation, Multiproduct Batch Process

INTRODUCTION

CIM (Computer Integrated Manufacturing) is becoming important in chemical processing systems for improving the efficiency of process operation as well as scheduling of processes. In view of CIM, the operation of a batch plant consists of production planning at the highest level, scheduling at high level and process control at low level. Conventional batch processes involve several difficulties such as complex operations, process time variations and equipment maintenance. In addition, there have been inconsistencies in the high scheduling and the low process control levels. To manage the process effectively and overcome these batch variations, on-line dynamic scheduling of a batch manager is essential. Several researches have been published. Macchietto [1989] suggested POMA (Projected Operation Modification Algorithm), which resets the operation time of equipment whenever batch variation occurs. Djavdan [1993] illustrated a designed on-line scheduling strategy which uses a dynamic simulation model for designing the sequence control and the scheduling of complex plants, checking the production capacity and determining the minimum necessary volume of the buffer vessels. Huercio [1994] handles incorporation of on-line scheduling strategies in integrated batch production control. Kanakamedala [1994] devised reactive schedule modification algorithms based on the search tree analysis, which alternatively reassigns tasks to equipment. Sanmarti [1995] applied a flexible scheduling algorithm considering failure uncertainty of equipment. Ishii and Muraki [1995] proposed a process-variability-based on-line scheduling system (PVSS) which modifies a schedule based on the current process state and possible future processing time variations at short intervals and at the completion of each task. Kim [1997] suggested a rule-based reactive rescheduling system to cope with several unexpected process events for multi-purpose batch process operations. Ko [1997] developed dynamic scheduling algorithms for multi-product processes specially in using in-phase or out-of-phase operations in case of process time variation and unit failures, and [1999] explained the application of rescheduling algorithms to pipeless plants by updating these algorithms. The difference of these algorithms from previous studies is to adopt the in-phase or out-of-phase operation method in order to solve the operation time delay. In summary, this paper focuses on the development of algorithms and the implementation of a batch management system which performs on-line dynamic scheduling of multi-product batch processes to supervise and overcome the frequent batch variations such as process time deviations from the original schedule and unexpected unit failure.

OVERVIEW OF ON-LINE DYNAMIC SCHEDULING

Strategic steps of the CIM master planning hierarchy are shown in Fig. 1. This hierarchy consists of the high level operation for planning and scheduling and the low-level operation for process control. The batch manager includes the on-line dynamic scheduling. Conventional on-line scheduling accepts information on both the customer's order and operating situations. Fig. 2 shows their relationship. The suggested scheme of on-line dynamic scheduling in this research is shown in Fig. 3. For a given campaign information, each batch has production recipe information. By the initial scheduler, the near optimal feasible initial schedule is found for a given production campaign. The initial schedule gives the following information :

– assignment of tasks to valid equipment to produce the batches specified by the given campaign

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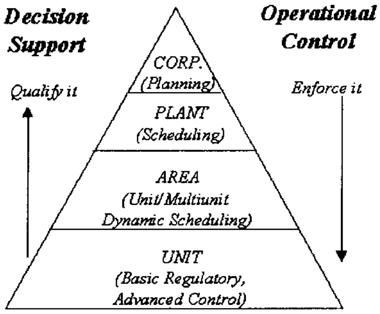

Fig. 1. Strategic steps of CIM master planning hierarchy [Song, 1997].

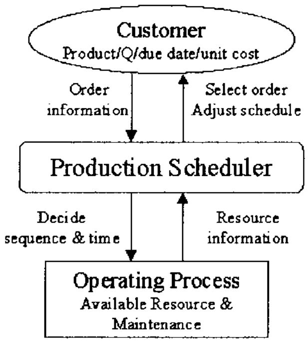

Fig. 2. Conventional on-line scheduling considering order information and operating situations.

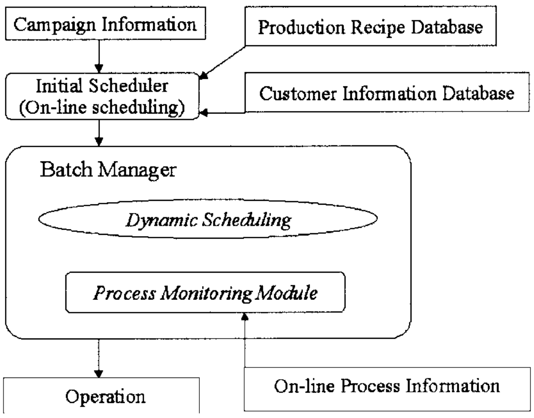

Fig. 3. Suggested scheme of the batch manager.

– production paths for each batch, and
– starting and ending time for each batch in units allocated to process the batch through the path.

Even if the initial schedule for the process is well constructed, the efficiency of the process is reduced due to deviations from the initial schedule. So the dynamic scheduling in the batch manager minimizes the effect of batch variations.

ALGORITHMS OF DYNAMIC SCHEDULING

Our study on dynamic scheduling has the following characteristics. First, the effect of unit failure on the process times, batch sizes and batch paths is considered. Second, an adjusting factor, which is used for modifying original process time, is adopted to make operation similar to schedule and meet the customer's demand. This policy does not always increase the amount of products and shorten makespan (the total elapsed time required to produce all products in the required quantities). These two points of our dynamic scheduling algorithms effectively reduce the process variation. These algorithms consist of DSMM (Dynamic Shift Modification Method), PUOM (Parallel Unit Operation Method) and UVVM (Unit Validity Verification Method). Applications of these algorithms are the following:

(1) NIS (No Intermediate Storage), UIS (Unlimited Intermediate Storage) and FIS (Finite Intermediate Storage) Policy
(2) Network Typed Batch Process

Fig. 4 shows the structure of on-line dynamic scheduler and Fig. 5 shows a structure of the algorithms in this system. In Fig. 5, process data from base level flow into rescheduling module and are compared with original schedule. If there is no deviation between them, the original schedule is sent to the base level. If any deviation is detected, the rescheduling module first checks if unit failure happens. In case of unit failure, the module uses the UVVM (Unit Validity Verification Method) algorithm to modify the devi-

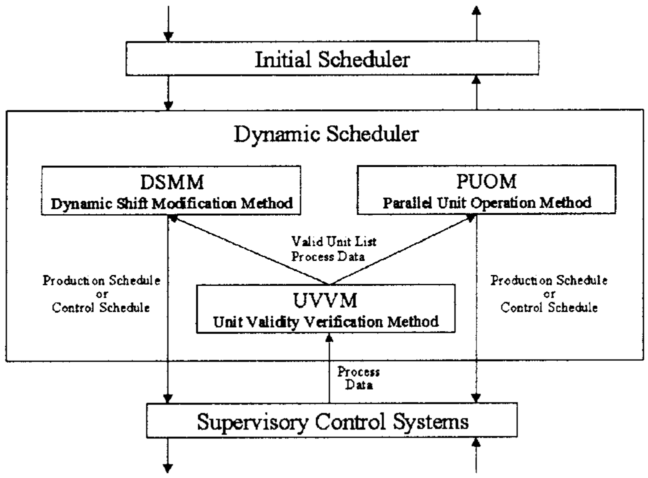

Fig. 4. On-line dynamic scheduler.

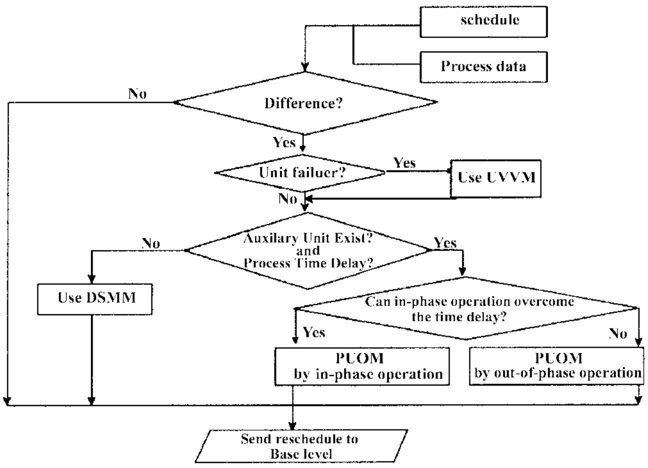

Fig. 5. Dynamic scheduling algorithms.

ation. With UVVM being used, the bad situations can be improved and the failed unit can be used after being repaired. When no unit failure is detected, the module checks if process time delay exists. If not, original schedule is modified through the DSMM (Dynamic Shift Modification Method) algorithm. When process time delay is found, the PUOM (Parallel Unit Operation Method) algorithm is available.

1. DSMM (Dynamic Shift Modification Method)

DSMM (Dynamic Shift Modification Method) can reduce or eliminate the resulting idle time from the process time variation by shifting the EST (Earliest Start Time) of equipment. This study makes the low-level operation similar to the original schedule and also considers stock prices. This does not always minimize total production time to meet the consumer's demands and due dates. Time adjusting factor, F, is also defined to include this idea. F is the weighting factor of the allowance when considering the amount of inventory. The shifting value (SV) is determined by an Eq. (1) using F.

$$SV \equiv F([ECT]_{Schedule} - [ECT]_{operation}), \quad 0 \leq F \leq 1 \tag{1}$$

Here, SV is the shifting value to the left. $[ECT]_{Schedule}$ and $[ECT]_{Operation}$ are Earliest Completion Time of schedule and operation, respectively. For example, in an ice cream production process, F is close to zero, since the maintenance of inventory cost is high. So DSMM almost never modifies the actual schedule. In the case of the shampoo production process, however, F is close to one because of the low inventory cost. Therefore, DSMM makes the EST (Earliest Start Time) of the unit at the next stage of the equipment where idle time occurred shift to the left, almost eliminating idle time. Consequently, the makespan is diminished and the amount of inventory increases. In summary, the algorithm DSMM modifies the given schedule with disturbances when considering not only the productivity but also the inventory cost.

2. PUOM (Parallel Unit Operation Method)

When extra equipment is available, PUOM (Parallel Unit Operation Method) resolves the operation time delay using in-phase or out-of-phase operations. Here, in-phase operation means that more than one unit, which has the identical function, starts the same operation simultaneously. So this module reassigns a task to the equipment in case of unit failures and operation time delay by this operation style. The in-phase operation method cannot always shorten operation time, but in the example of the fodder production process, it is possible to curtail processing time using in-phase operation because most operations of the fodder production process are mixing. If in-phase operation mode is used in this process, the amount of reactants per equipment is reduced and the decreased amount of reactants shortens the operation time, because of physical properties such as heat capacity and viscosity. As a result, the makespan of operations becomes similar to that of the original schedule. However tardiness of processing time in some processes cannot be fixed up only by in-phase operation of PUOM. So PUOM using out-of-phase operation is used. Out-of-phase operation implies that more than one unit capable of doing equal tasks starts the same operation at different times. This is the difference from previous researches which can overcome operating time delay.

3. UVVM (Unit Validity Verification Method)

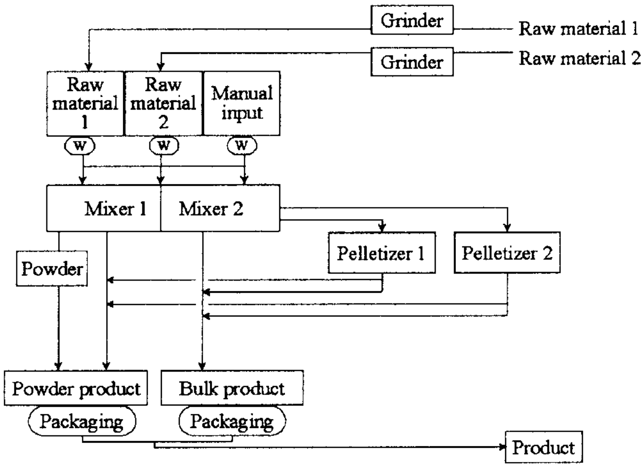

Fig. 6. The network type batch process for fodder production.

If any equipment fails, UVVM (Unit Validity Verification Method) selects valid units and decides optimal batch path depending on that situation. It helps PUOM to use in-phase or out-of-phase operation by assigning tasks to the valid units which batches go through. In other words, it perceives the validity of equipment and informs it to the operation adjustment algorithms such as DSMM and PUOM.

CASE STUDIES

Till now the algorithms we developed were generally outlined. The rest of this paper will discuss the application of these algorithms to network type batch process for the production of fodder as shown by Fig. 6. Let us assume that stage 1 includes main mixer 1 and 2, stage 2 has two pelletizers with functions such as pelletizing the mixing raw materials, and stage 3 has two packaging machines. This process is a multi-product batch process producing several kinds of fodder. Here, we do not distinguish the kinds of products, because these algorithms can be applied to SPC (Single Product Campaign) or MPC (Multi Product Campaign).

To manage the batch process, the initial scheduler perceives information such as the amount of product, due date, unit cost and customer's demand, which are varying as shown in Fig. 1.

The following three scenarios were tested by our dynamic scheduling.

[Scenario 1] In times of worsening economic conditions, the production does not have to exceed the demand. Therefore, the scheduler decides to operate only one production line as in Fig. 7 so that there exists an extra production line. If the real operation is the same as the operation in Fig. 8, the dynamic scheduler shifts the EST (Earliest Start Time) of stages 2 and 3 in some degree considering F.

In this case, idle time is eliminated by DSMM because F is assumed to be one, as explained before. Therefore, the makespan is shortened, and the idle time is eliminated; thus DSMM is able to prepare for the unexpected operation time delay, and the supply can be plentiful compared to the demand. Fig. 9 shows the dynamic schedule in this case.

Fig. 10 is the running screen of the first scenario. Original sche-

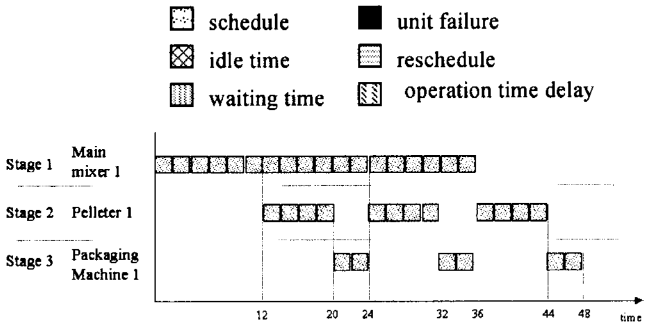

Fig. 7. The schedule for fodder production process of scenario 1.

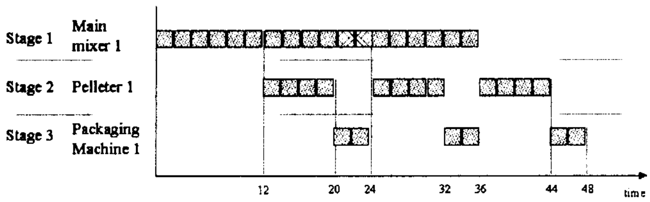

Fig. 8. The real operation without dynamic scheduling of scenario 1.

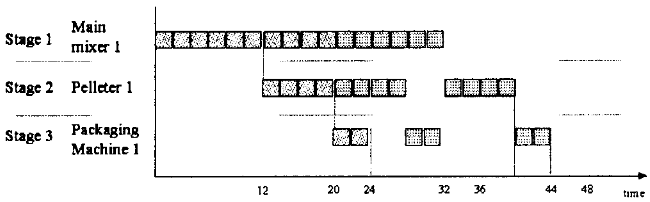

Fig. 9. The dynamic schedule of scenario 1 using DSMM (F=1).

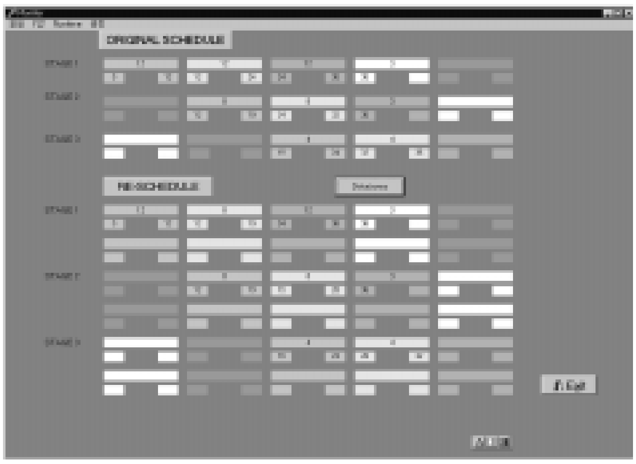

Fig. 10. The running screen of Fig. 7, 8, 9 (F=1).

dules and monitoring session, which shows the operation state resulting from dynamic schedule, are shown together to compare both of them and to show the difference of each makespan. However, if the F is assumed to be 0.5, the resulting dynamic schedule is explained by Fig. 11 and the executing screen of this is Fig. 12. In the case of F=0.0, the dynamic schedule is displayed by Fig. 13, and Fig. 14 shows the running screen.

[Scenario 2] When the schedule is the same as scenario 1 and ECT (Earliest Completion Time) of the first stage is delayed as shown in Fig. 15, the dynamic scheduler modifies the original schedule to look like Fig. 16. In Fig. 16, the batch size of the dynamic scheduling, whose batch path is "main mixer 2-pelleter 2-packaging machine," is the same as the original schedule. Fig. 17 represents the implementation of this case.

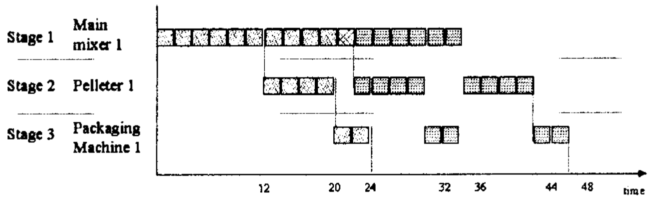

Fig. 11. The dynamic schedule of scenario 1 using DSMM (F=0.5).

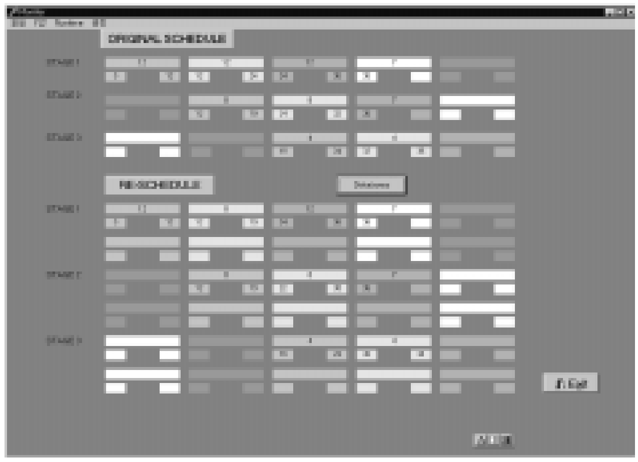

Fig. 12. The running screen of Fig. 7, 8, 11 (F=0.5).

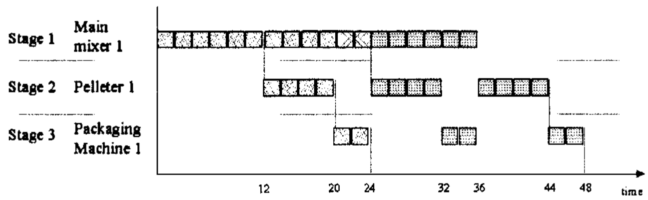

Fig. 13. The dynamic schedule of scenario 1 using DSMM (F=0.0).

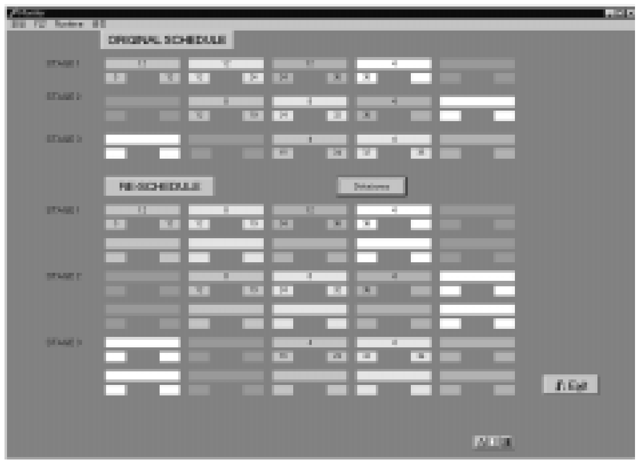

Fig. 14. The running screen of Fig. 7, 8, 13 (F=0.0).

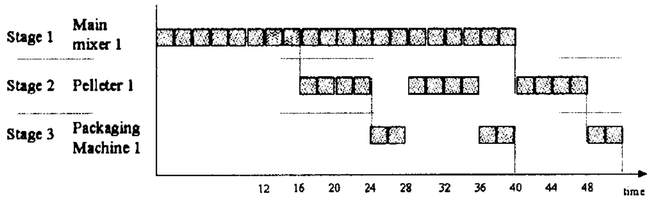

Fig. 15. The operation of scenario 2.

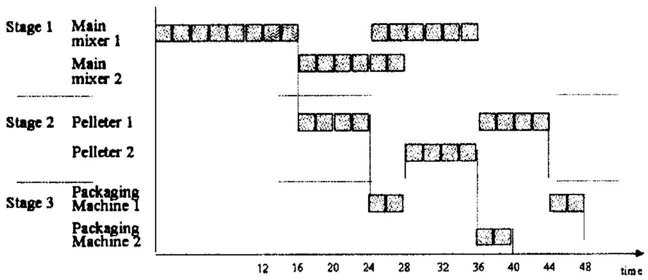

Fig. 16. The dynamic schedule of scenario 2 using PUOM.

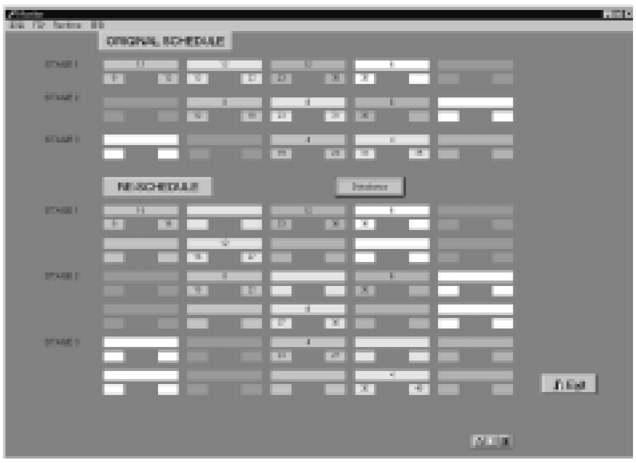

Fig. 17. The running screen of Fig. 7, 15, 16.

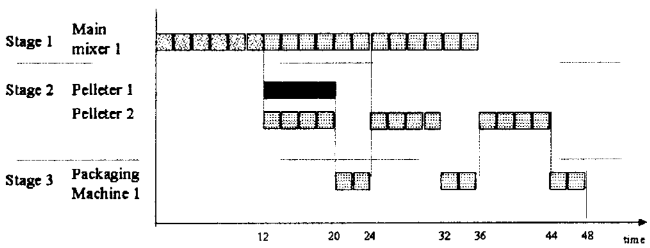

Fig. 18. The dynamic schedule of scenario 3 using UVVM.

[Scenario 3] Let us consider the case of unit failure. When the schedule is as shown in Fig. 7 and the pelleter 1 fails, the dynamic scheduling is to represented by Fig. 18. Fig. 19 is the running screen of this case. In this case, UVVM reassigns the task to pelletizer 2, that is, it redetermines the batch path.

CONCLUSION

In this paper, we construct a batch manager, which performs dynamic scheduling for on-line management of process operation. The proposed system is used to overcome the deviations from original schedules. To minimize the effect of unexpected events during a campaign operation, this system takes three major actions. The first is to readjust the operation time of equipment in case of process time variation using in-phase or out-of-phase operation. The second is to reassign the task to valid equipment in case of unit failure. The last is to redetermine the batch path in case of unit failure and operation time delay. By these actions, the multiproduct batch process can be improved in productivity, operability and safety. This system was implemented and applied to the fodder production process to cope with the operation time variation and unit failure.

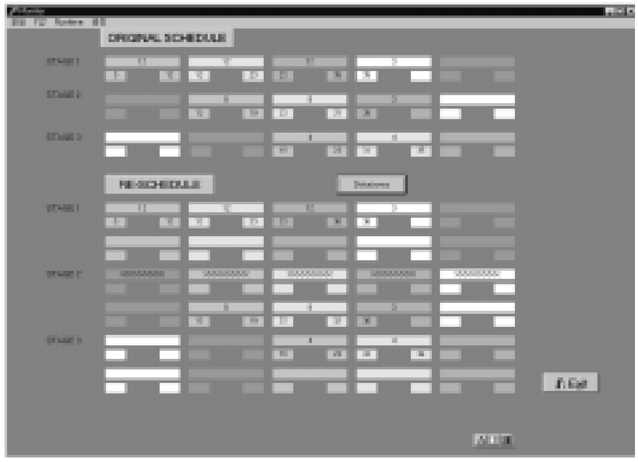

Fig. 19. The running screen of Fig. 7, 18.

NOMENCLATURE

F : adjusting factor
SV : shifting value to the left

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