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INTEGRATED SIMULATION MODEL FOR ALUMINUM ROLLING-PROCESSING LINE

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Abstract: In the aluminum rolling-processing factory, at each manufacturing facility, the same type of processing is grouped to one operation lot based on the operating conditions specific to the facility and priority is given to the processing jobs in accordance with particular situations. To support production planning in such processes, we developed an integrated simulator for scheduling, which has a parallel queue model for each lot-making condition. In addition, a high precision model was made by controlling lot scheduling in accordance with work-load. The simulation system constructed has effectively been used as a daily support tool for production planning in aluminum rolling-processing factories.

1. Introduction

Recently, material flows in large-scale production factories have been very complicated because of the extension of multi-product and small-batch production. On the other hand, the reduction of production lead-time and WIP (work in process) are essential requirements, so it is difficult even for skilled planning staff to control the distribution of semi-finished products in the factory. Usually, manufacturing of the aluminum rolling-processing is job shop type and follows a manufacturing route which changes depending on the specification of the job, so the operating condition of the production line is complex. This complexity leads to difficulty in the construction of mathematical models. Even if the models were built, it is not realistic to apply the optimization technique to solve them because of its long computing time. For such reasons, it is usual to develop a simulation based scheduling method and apply it to actual production (Nakano, 1997; Inoue, et al., 1994). That is, the simulation models that accurately describe the targeted processes are constructed, and several case studies are carried out changing operation parameters to find out proper results suitable for a production plan. In the metal processing field considered here, the application studies on the simulator are reported in iron and steel making processes (Ueno, 1991; Omura, et al., 1993). However, its applications are limited to the operation planning in a specific process and to the evaluation of line capacity.

In the following report, the problems of conventional simulation technology for a large-scale material processing process are described. Next, an integrated simulation model to solve these problems is proposed. In this simulation model, attention was paid to the lot-making operation peculiar to metal processing, and also added dispatching rules based on the operation know-how by which the priority of the jobs were dynamically assessed according to the work-load situation. Finally, the effectiveness of the proposed simulation model is reported through applied examples in the aluminum rolling-processing factory.

2. Problems of conventional simulation methods

2.1 Studies on simulation methods

In recent years, several examples for operation support in large-scale production processes have been reported accompanied by a great improvement in computer performance. As for semiconductor factories, the examples are as follows. 1) Fuyuki, et al. defined the three kinds of elements to describe models such as Job, Work-center, and Operation, and constructed a model with high generality (Fuyuki, et al., 1992). This model can express lot-making by specifying the lot size individually in the batch processing equipment. 2) Fukushima, et al. paid attention to the characteristics of the semiconductor manufacturing process where the operating conditions were different according to both production stage and kind, and proposed a model in which lot-making in the simulator was able to be done efficiently (Fukushima, et al., 1997). 3) Fujii, et al. proposed a method of efficiently constructing a simulation model for large-scale production systems by integrating independent simulators for each area through an information network (Fujii, et al., 1997). Separating the model of the product flow and that of the information can easily change the scheduling rules. Moreover, the following research contains examples of directly using the simulation results in production planning. 4) The organization problem of the lot input to the production line is evaluated by using the simulation (Nakano, 1997). 5) The production planning to conform the due date is made by combining the backward and forward simulation (Fuyuki, et al., 1995).

These are summarized as follows; a) Insufficient function of lot formation which leads to slow down in calculation in cases of large-scale simulations, b) Poor scheduling function, which leads to deterioration of calculation accuracy.

2.2 Problems for metal processing

"Lot-making operation" is one of the reasons for difficulty in applying simulators to metal processing line. That is, while the specification of the product is written in detail based on the order from the client, it is necessary to assemble two or more jobs of the same condition together to improve productivity and decrease the setup time loss (Umeda, et al., 1998).

Naturally, the operation know-how exists in the method of lot-making. Since two or more processes exist in the downstream of one process, the method of lot-making in each manufacturing facility must reflect operations in its downstream. That is, priorities set to jobs in the lot have great influence on material flow in the whole process. In the actual production line, skilled staff considering the work-load distribution in the entire line and the specification of each job organizes lots. However, in the situation where a number of jobs and facilities exist, it becomes difficult for human experts to make the appropriate plan.

To overcome the problems described above, it is necessary to develop new types of simulation technology. As for the new simulation method, applicable to production planning in large-scale metal processing process, the following functions are required; 1) Efficiency of the lot-making at each manufacturing facility, 2) Achievement of the scheduling function to make load distribution in the whole line uniform.

In the following, the new simulation technology, the LS (Lot Scheduling) simulator, is described.

3. Concepts of LS simulation technology

The LS simulator has a model structure in which the lot-making can be efficiently done. By this function, construction of the organized lots can be easily compared. That is, to simulate the material flows in the factory with adequate accuracy useable for production planning in large-scale metal processing, it is necessary to satisfy the following points requirements at the same time. 1) Multi-product and small-batch production can be treated, where each job has a different kind of product and operation order. 2) Lot-making operation based on specified operation condition to the facility and contents of the job is necessary. 3) Reproduction of operation know-how to unify the work-load of production facilities and prevent transfer delay of jobs is also necessary. Moreover, it is necessary for the above-mentioned functions to operate at high speed to construct a practicable system.

4. Modeling

A simulation model was made involving priority logic for each job that reflects the above-mentioned conditions in large-scale material processing. The outline of the model is described as follows.

4.1 Queue model for lot-making operation

As already described, in metal processing, lot-making operations are carried out. That is, jobs of the same processing conditions are grouped and processed together. Usually, it is the easiest way of modeling to set one queue at each manufacturing facility, but it is also effective to set the queue to each manufacturing facility according to the operational conditions for effective organization of the lot. We introduced parameters of the lot-making conditions to each facility and constructed a model in which the queue was generated according to the value of this parameter. The outline of the queue model is shown in Fig. 1.

In this queue model as shown in Fig. 1, specified lot-making parameters to each manufacturing facility are set and the queue is composed for the value of each parameter. For instance, if the parameter is "Annealing temperature", the queues are generated according to the annealing temperature. The lower bound and the upper bound of the grouping amount are given to each queue. The numbers of the grouped jobs are summed up in each queue according to the progress of the simulation. This lot enters a state that can be operated when this amount exceeds its lower bound. On the other hand, each facility retrieves the queue linked to it when the following lot becomes ready to be processed, and chooses one from the queues which contains the lot possible to start the operation. At a single processing facility, the jobs included in the chosen lot are stored in the processing reservation queue arranged in front of the equipment after being sorted in order of the processing, and are processed one by one. At the batch processing facility, they are processed collectively without being sorted. Alternatively, there may be jobs processable by two or more facilities. In such a case, the same job was stored in two or more queues and set a link between the jobs. In addition, when the job was processed by a certain queue, the same jobs were deleted from other queues. The jobs connected with the dotted line are showing the same jobs in Fig. 1.

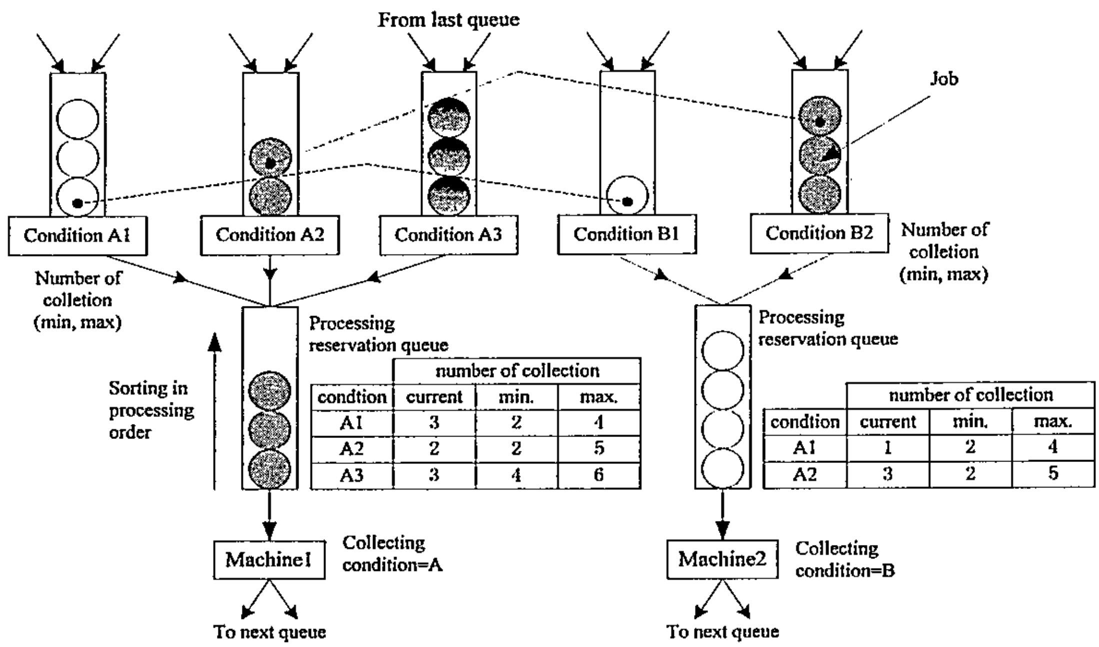


Fig. 1 Hierarchical queue model for lot formation processing

4.2 Expression of know-how by lot scheduling

The model grouping jobs to the lot in a specified condition to each manufacturing facility was completed by the queue model described above. However, when seeing from the viewpoint of operation know-how for material flow control, the following two points remain as the problems to be solved. 1) Priority putting to jobs when they are grouped in the lot. 2) Priority putting of lots being completed grouped when the next processed lot is decided. Then, to reproduce the priority setting of jobs and lots by which the load situation of each stage was considered, we set priority as follows:

1) Priority putting of jobs:

For job i at time t, the amount of WIP in the present stage and in the next stage are defined as $p_i(t)$ and $n_i(t)$ respectively. The proper WIP amount of job i in present stage and that in next stage are assumed P_i and N_i respectively. Moreover,

$$d_i(t) = \left(\frac{p_i(t)}{P_i}\right) \bigg/ \left(\frac{n_i(t)}{N_i}\right) \quad (1)$$

is defined as a load-smoothing index of job i. At this time, the job with larger value of $d_i(t)$ is selected with higher priority. However, when the following conditions are satisfied, the job with a long waiting time after arriving at the queue is processed with higher priority,

$$\frac{1}{a} \le d_i(t) \le a, \qquad (a \ge 1), \tag{2}$$

Here, a is the simulation parameter set beforehand. In other words, priority of the job that has more WIP in the present stage or less WIP in the next stage than usual is raised, and if the value of a is enlarged, the priority of the job with an earlier arrival to queue is raised. When the amount of target production during a day in each stage based on a monthly plan is assumed to be R_j, and the average lead-time from the former stage of stage j to stage j is assumed to be T_j [days], the standard WIP amount $P(j)$ in stage j are

$$P(j) = R_j T_j. \tag{3}$$

2) Priority putting of lots:

When the priority of the lot is decided, the idea for the priority setting of the job is also introduced. That is, when the number of jobs included in the lot is assumed to be M_k for the k-th grouping,

$$D_k(t) = \frac{1}{M_k} \sum_{i=1}^{M_k} d_i(t) \tag{4}$$

it is defined as the load smoothing index of lot k and the lot with larger value of $D_k(t)$ is selected with higher priority. However, when the following conditions are satisfied, the lot whose grouping completion time is earlier is processed with higher priority using the parameter A set before simulating:

$$\frac{1}{A} \le D_k(t) \le A, \qquad (A \ge 1). \tag{5}$$

5. Verification of proposed model

To verify the effect of the simulation model proposed above, numerical experiments were made for the aluminum rolling-processing factory, which is one of the large-scale material processing operations.

5.1 Target process

The outline of the aluminum rolling-processing factory is shown in Fig. 2. Some kinds of products are shipped in this form, but in general, most products are rolled further to the thickness of 1mm or less in the cold-rolling mill after being cooled once. Two or more cold-rolling machines exist in the cold-rolling block, conducting a repetitive process that the same product passes through the rolling several times. Moreover, a part of the product passes through the annealing equipment, dividing and trimming machines. After cold rolling, the products finally go through distortion leveling, washing, various surface processing and annealing are done in the conditioning processes. Then, products are brought to the inspection and packing line. Examples of lot-making operation are shown in Table 1.

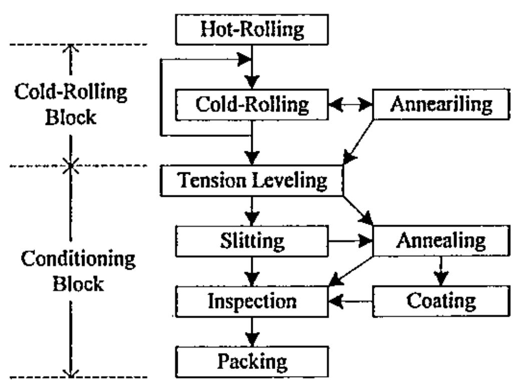


Fig. 2 Outline of aluminum rolling process

Table 1 Examples of lot-making operations in aluminum rolling-processing

Stage	Lot-making condition	Stage	Lot-making condition
Cold Rolling	roll surface form	Surface Processing	king of paint or solution
Annealing	annealing temperature	Slitting	product width

Besides material flow in such processing, there are other factors such as transportation by crane, et al., and also non-processing factors like cooling time after annealing and rolling, and waiting time for inspection. Two or more same kinds of facilities exist excluding hot rolling. The number of equipment in the whole process is about 200 with non-processing factors, and the number of input jobs is 4000-5000 per month.

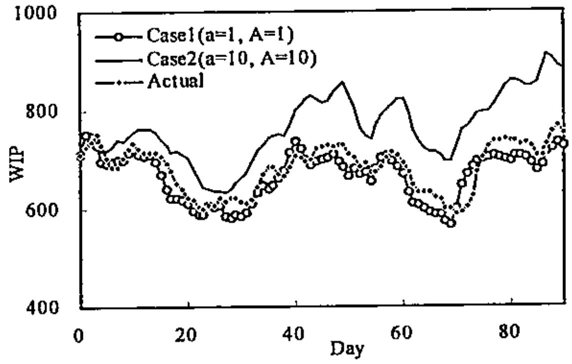
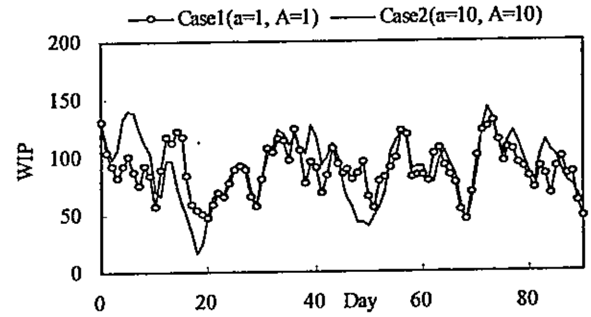
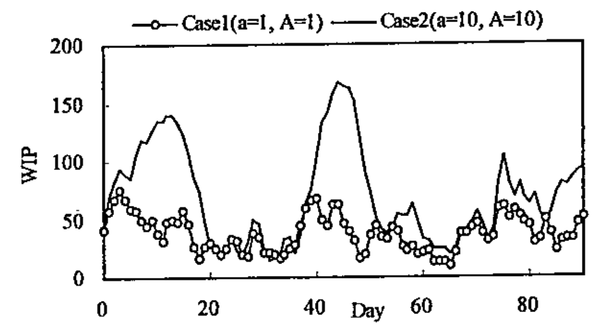


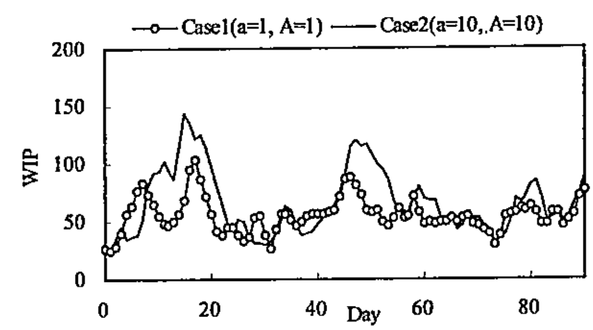
Fig. 3 Total WIP in Cold-Rolling Process



(a) WIP in Before Cold-Rolling



(b) WIP in the First Half of Cold-Rolling



(c) WIP in the Last Half of Cold-Rolling

Fig. 4 WIP of Each Process in Cold Rolling

5.2 Effects of lot scheduling

We confirmed the effect of the lot-scheduling model proposed here by which the priority was set to the jobs and lots considering machine load. The following two case studies were carried out for the aluminum rolling-processing factory:

Case 1: Lot scheduling was applied. Where parameters were set such that $a = 1$ in equation (2) and $A = 1$ in equation (5).

Case 2: Lot scheduling was not applied. Where parameters were set such that $a = 10$ in equation (2) and $A = 10$ in equation (5).

Here, lots are made, but jobs arriving earlier are selected with higher priority. Data of input for jobs, initial WIP, and stop time of machines are made based on the operation result data. The daily transitions of the number of WIP in the whole cold-rolling block are shown in Fig. 3. In Fig. 3, the WIP transitions in the operation results are shown comparing to these two cases for verification of the simulation's accuracy. Transitions of WIPs in three kinds of processes: before cold rolling; the first half of cold rolling; and the last half of cold rolling as shown in Fig. 4. When the two cases are compared with the operation result in Fig. 3, it is understood that the transitions of WIPs are extremely near that of the result in the case with regard to lot schedule. Although the trends of WIP transitions in two cases are similar, it is also understood that WIP changes with smaller amounts in the case with lot scheduling than without lot scheduling. On the other hand, when we compare WIPs in each process in Fig. 4, it is understood that the difference in these two cases is small in Fig. 4(a) even if there may be a large influence from the hot rolling plan. But, we also find that the WIP peaks are becoming smaller in the case with lot scheduling than without lot scheduling in Fig. 4(b) and (c). It is thought that this has been caused by the supply of jobs being properly adjusted by lot scheduling and stays of jobs in specific facilities are controlled. Moreover, it is thought that the productivity of the whole cold-rolling process has improved by decreasing supply delays of jobs.

6. Application to real system

6.1 Developed system

The developed system received the order information of present WIP and that of the hot-rolling plan. The order of operation and the processing conditions of the processing facilities are assigned to each order based on quality and process design. However, since there is no information on non-processing facilities such as transportation, cooling and processing time, we developed the function to attain such information automatically at the preprocessing stage of the simulation. Simulation results are provided in the form of graphs or text files to forecast the transition of WIP in each production stage, and the processing order in each manufacturing facility.

6.2 Application results

As described before, since aluminum rolling and the processing factory which we treated here is extremely large-scale and operating to almost full capacity, the number of the processing specifications of the job become huge and the material flows in the factory are very complex. Therefore, the forecast of material flows with high accuracy linkable to the production planning was difficult. Various parameters in this simulation system were adjusted, and the transition of WIP amount in each stage comes to be forecasted accurately based on initial WIP and the hot-rolling plan. The calculation time in the workstation (with PowerPC 66MHz) was about one minute for the period of one month, so the need for a speed-up of computation time on a practicable level was achieved. This system has been used for about two years as a daily production-planning support tool. It caused the effects of about 15% WIP compression and that of about 10% improvement of manufacturing lead-times.

7. Conclusion

In this paper, a new type of integrated simulator (LS simulator) for production planning in large-scale aluminum rolling-processing factory where multi-product and small-batch production is done was described. When we constructed the system, we did modeling to which the queue array was set according to the operation conditions in each manufacturing facility to reproduce specific lot-making operations for the equipment effectively. Moreover, we developed the lot scheduling function that decides the priorities for jobs and lots. That is, the ratio of present WIP to the proper amount of that in each process is considered to define priorities to each job and lot. The effectiveness of these technologies was confirmed by case studies reflecting actual problem size. The developed LS simulation system has been linked with the production control system and used as a daily production-planning tool in our aluminum rolling-processing factory since 1997.

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