Development of New Production Scheduling and Manufacturing Logistics System for Takasago Machinery Plant

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For the machinery plant of the make-to-order (MTO) type Machinery Center in the Takasago Works of Kobe Steel, a system for scheduling and logistics management has been developed to improve the product assortment rate, an index for the rate of on-time delivery to the subsequent assembly plant. For scheduling, a method was devised for estimating excessive overloading to support the determination of the amount to be outsourced. For the logistics, a mechanism was established to collect progress data and the locations of parts with RFIDs, the information necessary for preparing schedules. The introduction of this system has improved the assortment rate by approximately 20% compared with the value normalized by the average assortment rate before the introduction of the system.

Introduction

Kobe Steel's Machinery Business manufactures made-to-order machinery such as (reciprocating, turbo, and screw) compressors, resin mixers and rubber mixers at its Takasago Works. Parts machined in-house are manufactured at the processing plant in the Works and assembled together with outsourced items into final products in the assembly plant. To improve the productivity of assembly, it is essential that necessary parts be available in the assembly process on the scheduled start date of assembly. In order to improve the "assortment rate," the index of availability, the machines and workers, which are the resources of the processing plant, must be fully used. In addition, to avoid overload situations, the minimum required amount of work must be outsourced beforehand to adjust the load of the processing plant.

The processing plant, however, is a large-scale, job-shop type plant that processes each item to order, and it has conventionally been impossible to prepare the schedules for the total of 50,000 operations even with multiple planners. There was no way of making instructions for the work site considering the plant as a whole. Thus, at a large-scale plant, the process planning was unavoidably limited to certain types of machines. It has been difficult to accurately estimate the load situation for the next half year or so, an estimation necessary for production management, making it impossible to properly judge the need for outsourcing or to adjust the load by overtime work. Also, no location management of a large number of parts was implemented in the plant, making it difficult to synchronize transportation with the plans, posing a challenge to the improvement of the assortment rate.

There are various studies on the technique for solving scheduling problems in job-shop-type plants, and simulation-based techniques have been proposed for due-date oriented problems.[1] There also have been proposed simulation-based techniques for adjusting overtime work to prevent delayed delivery.[2), 3)] A technique has also been proposed for estimating the amount of overtime using a genetic algorithm so as to strictly adhere to the due date.[4)]

The reported examples,[2)-4)] however, are based on the adjustment of the overtime put in by in-house workers and do not assume the use of outsourcing. Meanwhile, a time-bucket technique that calculates the load per unit period has been proposed as a technique for estimating the required strengthening of in-house machines, rather than outsourcing.[5)] The time-bucket technique, however, cannot determine the clock time of a task by its nature, and its accuracy tends to be rough, making it difficult to properly adjust the load.

In order to solve the problem of estimating the amount of outsourcing necessary in order to strictly meet the due date in job-shop-type factories, Kobe Steel proposed a simulation-based technique allowing high-speed calculation and constructed a scheduling system using it. Also developed was a logistics management system, called Innovative Logistics and Intelligent Scheduling System (hereinafter referred to as "iLiss"), for collecting the progress information necessary for planning and information on the parts locations required for transportation synchronized with the plan. This paper outlines those systems.

1. System configuration

As shown in **Fig. 1**, the newly developed system consists of a scheduling system (hereinafter referred to as "iLiss-S") and a logistics management system (hereinafter referred to as "iLiss-L"). The scheduling

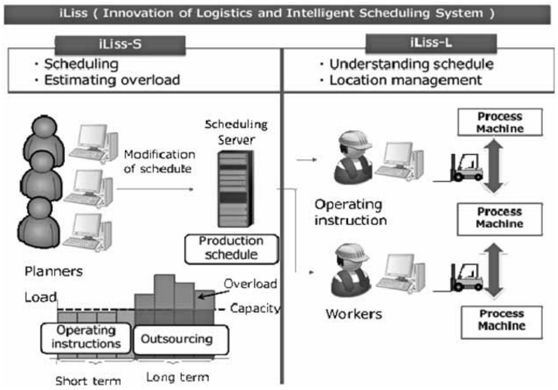

Fig. 1 Outline of newly developed scheduling and logistics systems

system draws up medium-to-long term plans (more than 1 month away) and short term plans (current to 1 month away). These plans are devised and used differently. The short term plan is used to transmit task orders to the field workers, and the medium-to-long term plan is used to determine outsourcing. The logistics management system enables the confirmation of scheduling and progress input by PCs installed on the work site. It also uses radio frequency identifications (RFIDs) to perform the location management of parts necessary to realize transportation synchronized with the plan.

The following sections describe the respective functions of the scheduling system and the logistics management system.

2. Scheduling system

The scheduling system adapts a planning method of forward scheduling whose details are different from those of short term planning and mediam-to-long term planning.

The medium-to-long term planning aims at grasping the excess load in order to make a decision on outsourcing. Hence, plans are created adhering to the due date restriction, and the machine capacity restriction and worker capacity restriction are relaxed as necessary. The machines and workers that can be allocated in the shortest term, are selected from the available ones in the master data. The dispatching rule applies SLACK,[6)] which is effective in reducing delivery delay. SLACK is a method for performing task allocation in the ascending order of margin time, which is the time remaining after the time for residual tasks is subtracted from the time remaining until the due date. The details will be described in Section 2.1.

The short term plans aim at instructing the work site about tasks; hence a feasible plan that adheres to the machine capacity restriction and worker capacity restriction is drafted. The same machines and workers selected before rescheduling are used, and the dispatching rule is set in the order of the earliness of the start time in the previous plan before rescheduling. **Table 1** shows the scheduling methods of short, medium to long-term plans.

2.1 Planning algorithm for medium-to-long term plan

The planning algorithm for the medium-to-long term plan is as follows.

Step 1: [Selection of task]

The task with the smallest margin time, the time remaining after the time for residual tasks is subtracted from the time remaining until the due date, is selected from among the unallocated tasks whose previous jobs have been allocated. As an example, a case is considered where a certain job is processed through the tasks of the first to third steps. If the allocation up to the first step has been completed, the margin time for the second step is calculated as follows:

$$d - now - \sum_{i=2}^{3} T_i \quad \cdots\cdots (1)$$

wherein d is the due date of the job, now is the end-time of the first step, and T_i is the task time of the i^{th} step.

Step 2: [Preliminary allocation of task]

The selected task is preliminarily allocated within the machine capacity restriction and worker capacity restriction. Here, among the available machines, the one that can be allocated earliest is selected. For the worker, the person who use the smallest number of machines is selected.

Step 3: [Allocation of task]

If the end-time of the preliminarily allocated task does not exceed the latest end-time, the preliminary allocation is regarded as the final allocation, as is. If it exceeds the latest end-time, it is allocated as an overload task immediately after the previous task in

Table 1 Scheduling method for short, and medium-to-long term plans

Term	Purpose	Restriction	Dispatching rule	Machine selection	Worker selection
Short	Operating instructions	Machine and worker capacity	Earliest start-time in prior schedule	Fixed	Fixed
Long	Making decision on outsourcing	Machine and worker capacity (Relaxing restriction if needed) On-time delivery	SLACK	Select machine so that a task can start earliest.	Select worker with smallest number of available machines.

the job of said task. Here the term "latest end-time" refers to the time when any task finished after this time causes a delivery delay, even if the later process is allocated the shortest time. For example, the latest end-time of the first step of the job described in Step 1 is as follows:

$$d-\sum_{i=2}^{3}T_i \quad \cdots\cdots (2)$$

[Repeat]

Steps 1 to 3 are repeated until all the tasks have been allocated.

Fig. 2 shows the image of the algorithm. The medium-to-long term plan is made so as always to keep the due date because the allocation as an overload task is restricted by the due date and the restriction of machine capacity is relaxed as necessary. The planners can focus on overload tasks to make decisions on planning modifications such as the outsourcing of the overload task and workers overtime.

2.2 Planning algorithm for short term plan

The specific planning algorithm for the short term plan is as follows:

Step 1: [Selection of task]

The task with the earliest start time before the rescheduling is selected from among the unallocated tasks whose previous jobs have been allocated.

Step 2: [Allocation of task]

The selected task is allocated within the machine capacity restriction and worker capacity restriction. Here, the machine is to be the same one as before the rescheduling. For the worker, the person who can use the smallest number of machines is selected.

In the task selection of Step 1, changes in the plan before and after rescheduling are suppressed, since the task having the earliest start time before rescheduling is selected. For example, a task planned for the next day is not allowed to suddenly be automatically postponed by one week after the rescheduling. This prevents confusion on the work site.

[Repeat]

Steps 1 and 2 are repeated until all the tasks are allocated.

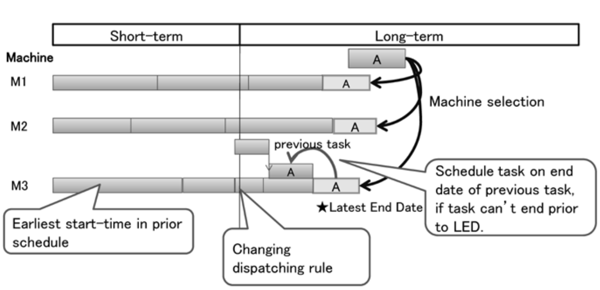

Fig. 2 Scheduling method for overload tasks

2.3 Necessity of plan modification

As mentioned above, allocation in the medium-to-long term plan is performed in the priority order of the margin time based on due date. A task planned for the medium-to-long term will be planned for the short term as time passes. Hence, the short term plan, which prioritizes the start time of the previous plan, is indirectly regarded as an allocation with the priority of margin time. Merely setting such margin time in priority order is inadequate in the following cases, and the plan must be modified according to the judgment of the planner.

- In some cases, tasks can be streamlined by continuing the same type of task. To this end, the planner judges as to whether some tasks are of the same type, and modification occurs to make those tasks continue.
- In the short term plan, a machine change or modification in task order occurs to reduce the non-operating time of the machine caused by the difference between the plan and the progress made. In such cases, if the machine is changed or the task order is modified automatically by the planning logic, there may be confusion on the work site.

On the other hand, the medium-to-long term plan is a plan for at least one month in advance, and an automatic change in the plan after rescheduling will not cause any confusion on the work site. Therefore, if the planning logic is rescheduled in consideration of the margin time in accordance with a progress shift, there will be no need to change machines or task orders with the planner's judgment, and it will only be necessary to decide which processing vendors should be assigned the outsourcing of the overloaded tasks.

2.4 Behavior of rescheduling after modification

Since there are several planners in the plant, a function has been developed to allow more than one planner to modify plans. A modification is focused on the change of task order in each machine and the machine used for each task. For a short-term plan and medium-to-long term plan, the modifiable points differ as follows:

- For short term plans, the task orders and machines are changeable.
- For medium-to-long term plans, machine selection is made within the planning logic, but the machine can be set in advance if the planner

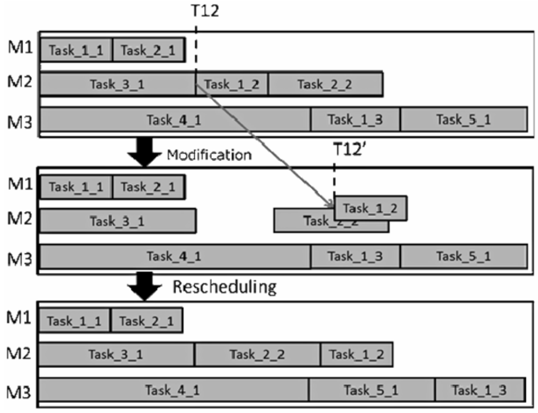

Fig. 3 Rescheduling after modification

wishes. Also, the subcontractors for overload tasks can be selected. Even if the task order in a machine is changed, the planning is performed with the margin time as a priority.

As for the modification of plans by planners, only the tasks that have editing rights in the Gantt chart can be modified. In other words, if the right to edit a task has been given to other planners, that task will not be provided with editing rights. This prevents the same task from being modified by multiple people simultaneously.

The rescheduling behavior after a modification is explained on the basis of the example in **Fig. 3**. The Gantt chart at the top represents the situation before rescheduling; the one in the middle, immediately after the modification; and the one at the bottom, after rescheduling. Here, Task_K_N means the N^{th} step of Job K, and TKN indicates the start time of Task_K_N. Before the rescheduling in the middle, the right to edit Task_1_2 is acquired, and its start time is modified from T12 to T12'. For rescheduling after modification, a short term plan logic is applied for short term plans and a medium-to-long term plan logic is applied for medium-to-long term plans. For modified Task_1_2, T12' is set as the start time of the previous plan.

Immediately after the plan is modified by the planner, the start time, T12', of Task_1_2 falls in the future (later) direction of the start time, T13, of the subsequent task, Task_1_3, causing a contradiction in the anteroposterior relationship of the tasks. It is shown that the contradiction has been resolved after the rescheduling.

3. Logistics management system

Approximately 190 PC terminals were installed beside the processing machines in order to instruct the work site concerning the plan prepared by the scheduling system and to collect the latest progress information necessary at the time of rescheduling.

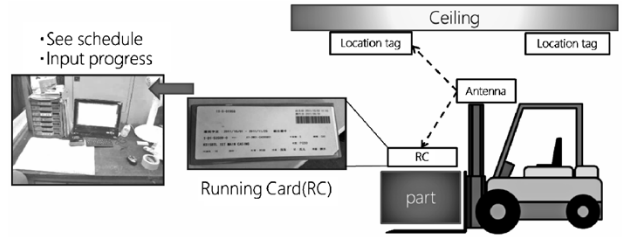

Fig. 4 Logistics management system

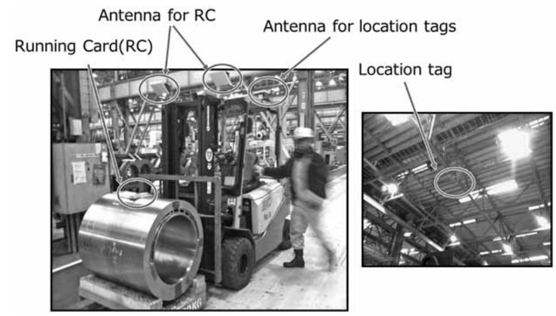

Fig. 5 Location management functions in logistics management system

In addition, RFIDs were introduced to carry out the location management of the parts necessary for realizing transport synchronized with the plan. **Fig. 4** shows the configuration of the logistics management system.

3.1 Achievement collection function

Progress information, such as which tasks are completed, and how long they are in progress and how long they are likely to take to be completed in the case of long tasks that take several days is important for highly accurate scheduling. Hence, an achievement collection function has been developed to allow PC terminals to read the task instruction cards with an RFID placed on each part and allow management to input progress information.

3.2 Location management function

A function has been developed to detect which items have been transported to which locations by installing approximately 300 long-distance detection type RFID tags on the above task instruction cards, ceilings, pillars, etc., while detecting them using an antenna installed on each forklift. Another function has also been developed so that a worker can wirelessly transmit a request to a forklift terminal to transfer processed parts to the next process. These two functions have enabled the synchronization of processing and logistics within the plant, synchronization being difficult to achieve by scheduling alone. **Fig. 5** shows the operational status of location management.

4. Operational status

The developed scheduling/logistics management systems were put in operation in the processing plant in February 2012. The time required to schedule the preparation of 50,000 tasks up to six months in advance is about 20 minutes; this includes the acquisition of order data and actual data from the upper production management system. **Table 2** shows the specifications used by the scheduling server in preparing the schedules.

The transition of the assortment rate since the start of operations was normalized by the average assortment rate in 2011 and is shown in **Fig. 6**. The improvement in the assortment rate has been confirmed after the introduction of this system.

Table 2 Specifications of scheduling server

OS	Windows Server 2008
CPU	Intel Xeon 2.30 GHz
MEMORY	12 GB

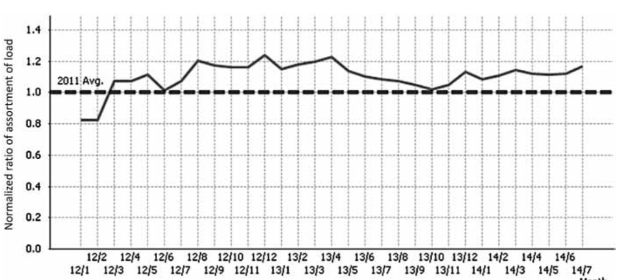

Fig. 6 Normalized assortment rate

Conclusions

A scheduling system has been constructed for a plant machining parts for machinery to prepare medium-to-long term plans that support the judgment on outsourcing necessary to meet the due date of processing, and short term plans to be used for task instruction. This system comprises two plan newly developed logics; namely, a medium-to-long term plan logic, which takes the due date as a restriction for outsourcing decision while relaxing as necessary the restriction on machine capacity, and a short-term plan logic to prepare a short-term plan seamlessly connected with each medium-to-long term plan. In addition, a logistics management system utilizing RFIDs has been developed to collect progress information and other data necessary for preparing the plans.

The direct effect of this system has been confirmed by the improvement of assortment rate after operation. The future technical challenge lies in the method of extracting a task that makes a large contribution to the improvement of the assortment rate upon outsourcing, in order to further improve the efficiency of the outsourcing study.

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