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Optimization Technology for Crane Handling Scheduling in a Steel Manufacturing Process†

KUYAMA Shuji[*1] TOMIYAMA Shinji[*2]

Abstract:

Recently, optimization technologies are commonly applied in logistics scheduling owing to significantly advanced computing technologies. In this paper, a new system applied for scheduling of crane handling in a slab yard was presented. The proposed method consisted of scheduling optimization and logistics simulation. Computational simulation was conducted with operation data in JFE Steel, allowing a comparison to be made between actual and theoretical crane handling operations. The resulting data showed that this paper's proposal can reduce the number of handlings by 30%. The effective transportation of slabs contributes to an increase of the customer satisfaction.

1. Introduction

In recent years, the steel manufacturing process has become more complex as a result of the trends toward higher grades and greater diversity in steel products in response to customers' needs. As there is also a heightened need for shorter delivery dates, logistics scheduling and production planning have also assumed greater importance than in the past. Logistics in a steel works is not simply a matter of transporting finished products and intermediate products from the previous process to the following process in accordance with the delivery schedule; it also has the role of rearranging the order of products in the production schedule in the following process in advance so as to enable smooth transportation to the following process. For this reason, establishing efficient logistics schedules are a challenging task.

On the other hand, accompanying recent increases in computer capacity, optimization technologies have been widely applied to logistics scheduling[1)]. Since quick reformulation of schedules in response to changes in operational conditions and changes in the production schedule is demanded in logistics scheduling, calculation speed is also required in combination with optimality.

This paper presents an example of research and development in which optimization technologies were applied to logistics scheduling in a slab yard, where intermediate products called slabs are held temporarily. The purpose of this development was to realize high efficiency in logistics in the yard by optimization of the handling schedules of the overhead traveling cranes, which are the means of transport used in the slab yard.

2. Logistics in Slab Yard

2.1 Roles of Logistics in Slab Yard

Figure 1 is a schematic diagram showing a slab yard and slab logistics. Slabs are rectangular parallelepiped-shaped intermediate products with dimensions of approximately 2 000 mm × 10 000 mm × 250 mm which are cast in the continuous casting process. Slabs are transported by freight car to the slab yard, which is a temporary holding area for slab stock. The transported slabs are unloaded from the freight cars by an overhead traveling crane, which is installed in the slab yard, and stored by piling in the yard. The slab yard is divided into multiple yards, and entry by freight cars is limited to

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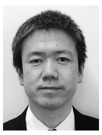
[*1] Senior Researcher Deputy Manager,
Instrument and Control Engineering Res. Dept.,
Steel Res. Lab.,
JFE Steel



[*2] Senior Researcher Manager,
Instrument and Control Engineering Res. Dept.,
Steel Res. Lab.,
JFE Steel

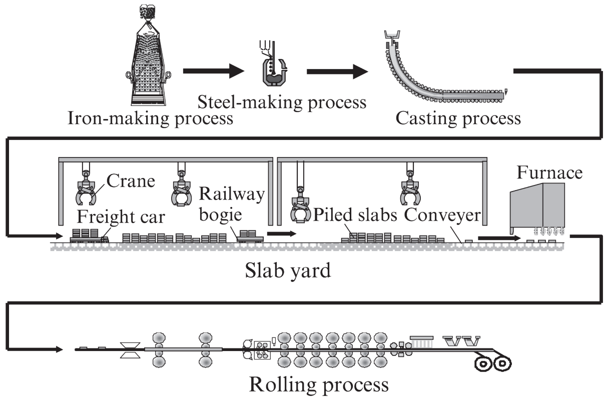


Fig. 1 Slab logistics in slab yard

only two yards. There are several 100 slab holding areas in each yard, and from several slabs to 20 slabs are piled in one slab holding area. Transfer of the slabs between holding areas in a yard is performed by several overhead traveling cranes, while transfer between yards is performed by railway bogeys. The slab yard is connected directly to the heating furnace of the hot rolling process, which is the next process. Each slab is placed flat without piling-up on the transport route in the rolling sequence, and are then charged one by one into the heating furnace of the hot rolling process at the pitch specified in the rolling schedule.

The purposes of slab logistics are to hold the slabs which are carried by the freight cars in the slab yard, and to arrange the slabs in the holding area in front of the heating furnace in the sequence in the rolling schedule in advance, so that the correct slab can be conveyed to the heating furnace at the correct timing.

2.2 Crane Handling Operation

The roles of the overhead traveling cranes installed in the slab yard are to unload slabs from freight cars into the yard, to transfer slabs from one holding area to another holding area, to unload slabs from railway bogeys, and to pile the slabs flat without piling-up in the transportation route.

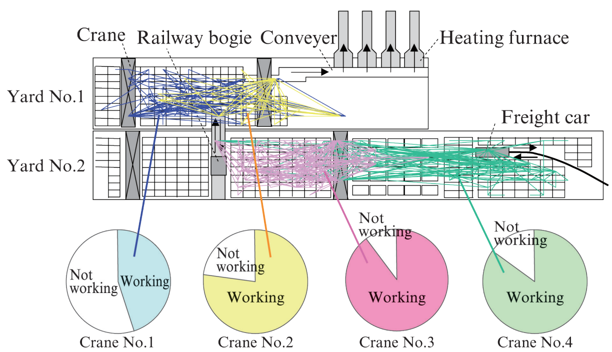


Fig. 2 Trajectory of 4 cranes in slab yard and the rate of operation

Figure 2 shows the trajectories of 4 cranes during a certain time period and the rates of operation of the cranes at this time by color. The operation rates of Crane No. 3 and Crane No. 4 reach the 80% level, which indicates a tight crane operation condition. The reason for this is because the slabs which are transferred from the previous process are piled in the order of as-transferred, and as a result, when the slabs are transferred to the following process, as much as half of the handling work is reshuffling work, that is, digging out a slab that are buried in a slab pile by unpiling the upper slabs.

Because crane operators were not given adequate information to judge which slab should be moved to which position next in order to optimize efficiency, inventories of slabs in the yard increased, and slab holding areas became occupied. In this situation, operators had to focus their efforts on arranging the slabs for the rolling schedule in the immediate future, and it was difficult to create efficient slab piles from the long-term viewpoint.

If the average value and deviations of the logistics lead time from casting until hot rolling increase, deliveries of slabs to the hot rolling process, which is the following process, will be delayed. This is not desirable, as may become impossible to keep the hot-rolling production schedule. As an additional concern, if freight car unloading work is delayed, the freight car turnover rate will decrease, and deliveries from the preceding process will also be delayed. Moreover, because products in steel manufacturing are frequently tied to a customer's order on a 1-to-1 basis from the stage of the slab, which is an intermediate product, smooth movement of slabs is also desirable for ensuring final on-time delivery to the customer.

3. Optimization of Crane Handling Scheduling

3.1 Aims of Crane Handling Scheduling Guidance

In order to minimize reshuffling work, in which it is necessary to dig out slabs buried in slab piles, the authors proposed a guidance system which shows an efficient crane handling schedule to the crane operator.

Figure 3 shows the concept of the guidance system. Conventionally, how slab stock was piled (hereinafter, piling) had been left to the judgment of the crane operators. However, in the proposed method, a scheduling operator is newly assigned to plan piling on a full-time basis. The guidance system calculates crane handling so as to minimize reshuffling work, and provides the provisional calculated handling schedule and future slab piling information to the scheduling operator. The scheduling operator then revises the schedule as he considers

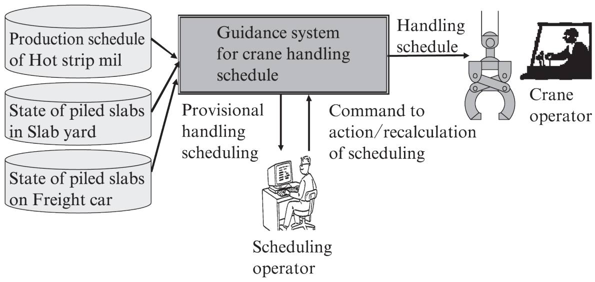


Fig. 3 Guidance system for crane handling scheduling

appropriate and sends the crane handling schedule to all cranes. The information sent to the cranes is a crane handling schedule which shows the slab to be moved, the original slab pile location and the target slab pile location arranged in time series. The crane operators transport slabs in accordance with the crane handling schedule shown on their hand terminals.

When changes in the production operation occur, the guidance system must recalculate the schedule before the start of the next crane handling. Since the average crane handling times is approximately 30 seconds per crane handling operation, response on the order of 10 seconds is required in the guidance system.

In order to implement a system with the above-mentioned functions, it must be possible to access in real time various types of information (Status of piled slabs in slab yard, Crane handling information, Production schedule of hot strip mill, Status of piled slabs on freight cars). The necessary information infrastructure for this was already in place as a result of the Sheet Production Management Re-Engineering Project launched in March 2006[2].

3.2 Crane Handling Optimization Problem

The problem of deciding crane handling schedules is defined as the following optimization problem.

One crane handling operation is defined by the timing when a certain slab is moved to a certain pile by a certain crane. The sequence of these crane handling operations in time series is called a crane handling schedule and is considered to be the solution of a crane handling optimization problem.

The evaluation function for judging whether a crane handling schedule is efficient or not is defined as the sum of the time margins for delivery of each slab. The case of delivery delay is defined as the penalty of the second power of the delay time (minus value). According to this definition, the solution with the shortest margin without incurring a time delay is evaluated as the optimal solution.

The following constraints exist in crane handling.

- Maximum slab thickness which can be lifted in 1 crane handling operation.
- Upper limit of piling gap of crane handling.
- In slab piling, piling of 2 slabs with extremely different lengths is prohibited to prevent slab hanging.
- Maximum height of slab pile.
- Maximum loads of railway bogeys and freight cars.

Since the slab yard contains several hundred slab holding areas and several thousand slabs, the number of handling schedules is practically infinite, and a solution would not be possible in a realistic time if the entire yard is searched as-is. In particular, the problem of deciding the sequence of movements for piled slabs is known to be a problem for which optimization calculations are difficult. In the field of artificial intelligence, this type of problem is called block world planning[3].

Moreover, as numerous constraints on slab yard cranes must also be considered, including piling constraints and the like, existing algorithms cannot be applied in a simple manner. Therefore, a new algorithm for slab yard handling optimization is necessary.

3.3 Optimization Algorithm for Crane Handling Scheduling

Figure 4 shows the processing procedure of the proposed optimization algorithm for crane handling scheduling. The purpose of the algorithm is to calculate an efficient handling schedule for transporting slabs which are scheduled to be charged into the heating furnace to pile in front of the heating furnace, while also satisfying the handling constraints.

(1) Read Input Data

Pile information data, rolling schedule data and data

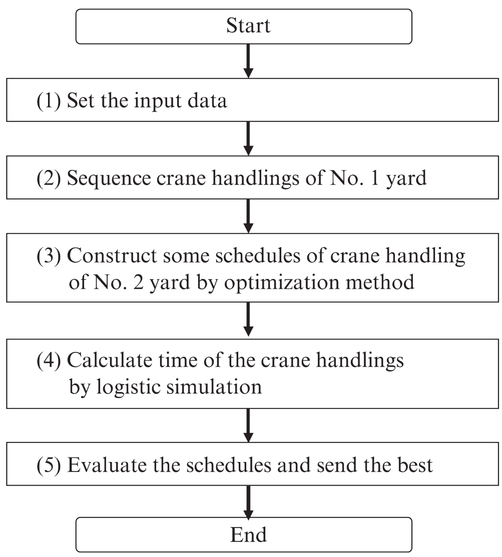


Fig. 4 Proposed optimization algorithm of crane handling schedule

related to slabs on freight cars are read into the system.

(2) Prepare Crane Handling Schedule for No. 1 Yard

A crane handling schedule is prepared for transfer of slabs from railway bogeys to a holding pile in front of the transportation route and transfer to the transportation route in No. 1 yard in accordance with the sequence of the rolling schedule, while considering the constraint conditions.

(3) Prepare Multiple Rough Crane Handling Schedules for No. 2 Yard

Multiple candidate schedules, in which the No. 2 yard cranes load slabs scheduled for rolling onto railway bogeys while the crane circulates around the yard, are prepared. In cases where the slabs scheduled for rolling are scattered in various places around the yard, circulation of the crane carrying the slabs in the sequence of the rolling schedule is not necessarily efficient in terms of slab transfer time and the number of transfer operations. Therefore, multiple candidate circulation patterns which seem to be efficient are calculated by a genetic algorithm. A genetic algorithm is one type of algorithm which gives approximate solutions of optimization problems by simulating biological evolution and has been widely applied in industry[4)].

In order to shorten the calculation time, the following constraint reductions are performed.

- Slab piles are divided into large areas containing a number of individual holding areas, as shown in **Fig. 5**; these spaces are called Areas. Slab transfer is regarded as transfer between these larger areas. When transfer between areas is the same, the transfer time is regarded as the same.
- In case a slab which is to be transferred is buried in a slab pile, reshuffling is regarded as proportional to the number of slabs which are later than that slab in the rolling schedule.

The evaluation scores of the candidate solutions are calculated in accordance with the definitions in Section 3.2. One hundred solutions are then selected from the solutions with the best estimated evaluation scores.

(4) Logistics Simulation

The individual crane handling times of the 100 candidate solutions are estimated by a logistics simulation while simulating the rising/lowering of the crane tongs and transfer movements.

If a slab is buried under other slabs at the area where transfer is originated, reshuffling handling to remove the interfering slabs is added to the handling schedule.

The cranes responsible for each crane handling operation are assigned in accordance with the predetermined areas served by each crane. Although the possibility of waiting or deadlock due to interference between pairs of cranes is a concern, interference between cranes is not considered in this algorithm. This is because it is not easy to solve crane non-interference problems for more than 3 cranes, and it is possible to warn the crane operators by guidance about schedules where crane interference is a concern, and allow the operators to judge crane waiting at their own discretion.

(5) Decision of Optimal Solution

The solution with the smallest evaluation score among the 100 candidate solutions is selected. A separate analysis was also performed to confirm that the solution with the smallest evaluation score is the solution with the smallest number of crane handling operations.

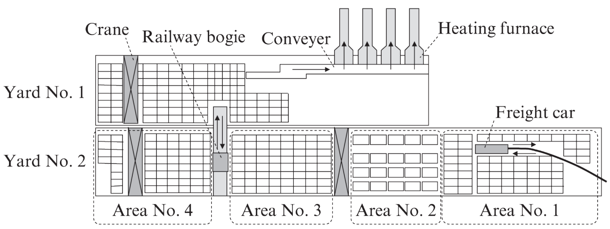


Fig. 5 “Area” of the slab yard

4. Simulation Results and Discussion

Figure 6 shows the results of a simulation comparing the actual operation by operators and the schedule calculated by the algorithm. The figure shows histograms counting the number of slabs by number of handling

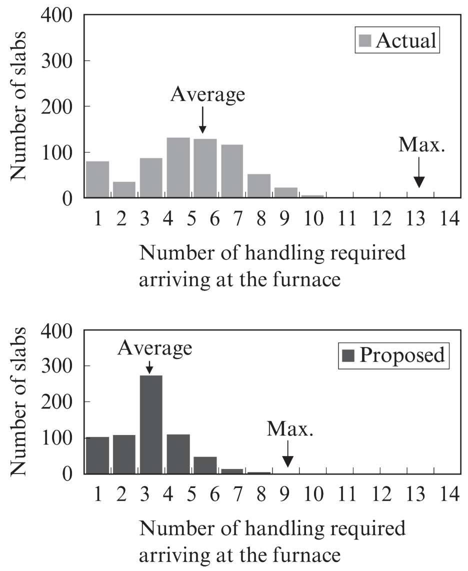


Fig. 6 Comparison between the number of the actual handlings and the proposed handlings

operations required up to the holding pile in front of the transportation route. The horizontal axis shows the number of handling operations required up to the holding pile in front of the transportation route, and the vertical axis shows the number of slabs. The upper graph in this figure shows the actual results by the operator, and the lower graphs shows the results by the developed algorithm. An average of 4.3 handling operations is required in operator operation, but in contrast to this, slabs can be transported to the target holding area with an average of 2.9 operations by the proposed method, which is a 30% reduction in handling. As the maximum number of handling operations is also reduced from 13 to 8, it can be said that this method enables efficient crane operation.

Two factors are conceivable as reasons for the decrease in the number of handling operations in comparison with operation by operators, namely, an increase in the number of slabs transported in one handling operation and a decrease in reshuffling work. Therefore, verifications were performed to support this assumption.

The first was a comparison of the number of slabs transported in one handling operation. **Figure 7** shows the results. The vertical axis shows the number of slabs transported in one handling operation, and the horizontal axis shows the time of day during a two-day period. The upper figure shows the actual results of operation by the operator, and the lower figure shows the results of a simulation by the proposed algorithm. The simulation starts at 7:30 on the *X*th day. The average number of slabs per one handling operation is 1.1 in the actual results and 1.5 by the proposed method. Thus, the number of slabs transported per handling operation increases by 38% with the proposed method.

Next, reshuffling handling was compared. As used here, reshuffling handling means handling in which slabs which are later in the rolling sequence are piled on a slab which is earlier, in other words, handling in which

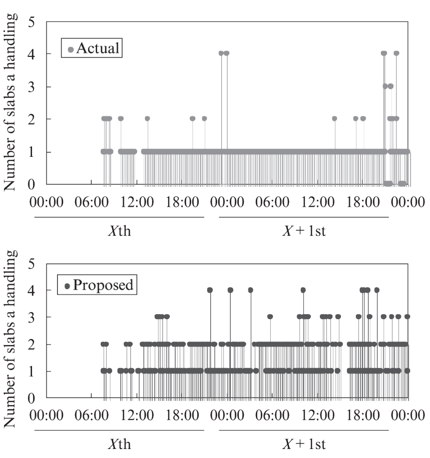


Fig. 7 Comparison between the number of slabs with an actual handling and a proposed handling

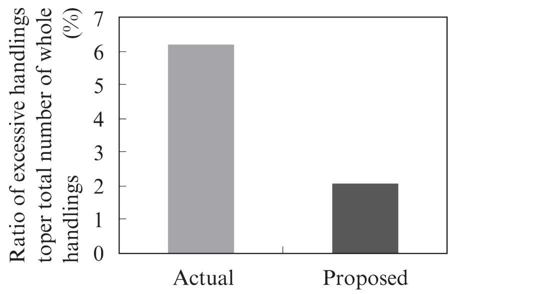


Fig. 8 Comparison between the ratio of actual handlings for reshuffling and the proposed handlings for reshuffling

reshuffling is necessary after the original piling. **Figure 8** shows the results of a comparison of the actual operator operation and the results with the developed algorithm. The vertical axis shows the ratio of the number of reshuffling handling operations to total handling. The ratio of 6.2% with the conventional technique has been reduced to 2.1%, or 1/3 of the conventional result. From this, it can be said that the proposed technique realizes efficient slab piling which looks into the future manufacturing schedule.

5. Guidance Screenshot

Figure 9 shows an example of the guidance screenshot of the prototype system. The screen is broadly divided into five parts, with the crane schedule calculated by the algorithm displayed in time series in the upper left screen. Colored areas are intended to encourage attention, for example, when crane interference is a concern, etc. The upper right part of the screen shows the movement of the crane when following this schedule. Because this algorithm does not consider crane interference, this allows the crane operator to check crane movements in which crane interference is possible in advance. The bottom two parts show the heights of slab piles in each holding area in the yard. The window in the center of the screen shows the slab piling status of

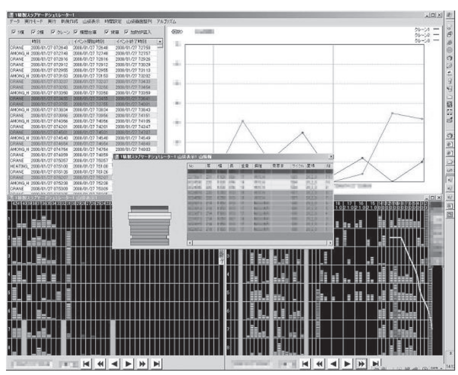


Fig. 9 Guidance screen shot

a certain holding area, and makes it possible for the operator to check the size and steel grade of each slab.

6. Conclusion

This paper has introduced an example of research and development in which optimization techniques were applied to crane handling scheduling in a slab yard. The results of a simulation showed that a 30% reduction in the number of crane handling operations is possible in comparison with operation by the crane operators. Practical application of the developed system in the future is underway. The developed system can contribute to customer satisfaction through a reduction of lead time by higher efficiency in slab transportation.

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