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New Scheduling Algorithm for Shipping Operation in Steel Works

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Abstract:

In steel works, products are carried by various kinds of machines, for example, overhead cranes, vehicles, forklifts and quay cranes. The operations of these machines affect each other and the situation makes the scheduling quite complicated. We have developed a new scheduling algorithm for shipping operations. The proposed algorithm is composed of two main steps to obtain efficient schedules and achieve short computation time. In the first step, shipping jobs are assigned to time windows which are created by dividing the scheduling horizon, and then the workload of machines is leveled. In the next step, the order and operating time of jobs are determined and a feasible schedule is developed. The scheduling algorithm was applied to practical data and compared with real operations. The result shows the high performance of the new algorithm.

1. Introduction

Steel makers expend huge sums to distribute products because steel coils, sheets and other products are heavy and difficult to handle, and special facilities and equipment are required for movement in the steel works. Since the use of these machines results in a complex operation, it is difficult to apply popular optimization algorithms for delivery operations to the scheduling problem of product distribution in a steel works.

Product shipping is completed through a series of operations involving various facilities, including warehouse cranes, forklifts, quay cranes, berths and cargo ships. Many scheduling algorithms for these machines were proposed in the past research on product distribution. For example, Imai et al.[1,2] and Buhrkal et al.[3] provide optimization techniques for berth allocation problems which determine the berth and service time for each ship so as to minimize the waiting time and operation cost. On the other hand, Rouwenhorst et al.[4] introduced many studies on planning and control of warehousing systems, and Xie, Zheng and Li[5] provide a technique for crane scheduling in a steel coil warehouse. However, because this past research focused on operations in only one stage, it is not sufficient to increase the efficiency of the total shipping operations in a steel works.

This paper proposes a new scheduling algorithm for the product shipping operation in a steel works, and presents computational results that compare actual operation and the results with the new algorithm.

2. Shipping Operation in Steel Works

Various types of shipping operations exist, corresponding to the characteristics of products and the locations of factories[6,7]. Therefore, this section introduces the common shipping operation in a steel works.

In a steel works, products are moved by specific machines for handling heavy cargos, namely, warehouse cranes, forklifts, quay cranes and vehicles. **Figure 1** shows one example of the shipping operation. After all the necessary manufacturing processes in the works are completed, products are transported to a warehouse near the shipping berth by using special vehicles and

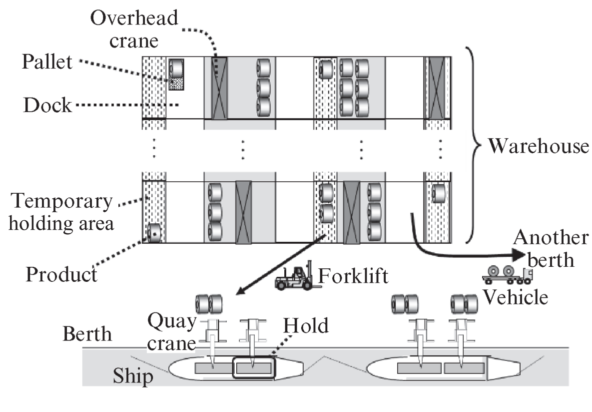

Fig. 1 Outline of shipping operation in steel works

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pallets, on which plural products can be loaded and received by a warehouse crane. A warehouse holds the received products for some days until instructions for product shipping are issued. When the product shipping time approaches, a warehouse crane moves the products to be shipped from the stockyard to a temporary product holding area. The products in the temporary holding area are carried to berths by forklifts, or if the berth is located far from the warehouse, the products are delivered by a vehicle. A quay crane picks up the products which have arrived at the berth and loads them into a ship.

One product is moved from the factory to the ship by using the above-mentioned machines, as required. Although machines of the same type can deal with different products in parallel, these characteristics of the shipping operation are likely to cause an overload in machine operation. For example, if one warehouse building contains many shipped products which are planned to be loaded by plural quay cranes during the same period, the required workload of the warehouse cranes is likely to exceed their capacity temporarily. Finally, this overload situation leads to a long waiting time for the quay cranes. This research aims to decrease overload, and evaluates the total efficiency of shipping based on the waiting time.

This paper focuses on a schedule for a warehouse building with plural cranes, which results in a quite complicated scheduling problem. Good schedules for the problem must distribute the workload to the cranes in the warehouse building and level the workload of the other machines simultaneously under various constraints.

3. Scheduling Model

In this research, a simplified model of the shipping operation was created because a precise model would be too complicated to develop schedules quickly. This section introduces the simple model of the shipping operation and summarizes the operation and restrictions.

In the proposed model, jobs are defined as follows, and the shipping schedule is created by deciding the order and execution time of the jobs under some restrictions.

[J1] Handling by warehouse crane
[J2] Handling by quay crane
[J3] Occupancy of dock by pallet
[J4] Delivery by forklift

In Jobs [J1] and [J2], cranes move products in warehouse buildings and berths, and job [J3] means one time window while one pallet is occupying the dock. In job [J4], products are delivered from a temporary holding area to a berth by forklifts. The schedule of these jobs should satisfy plural constraints. Four important types of constraints are the following.

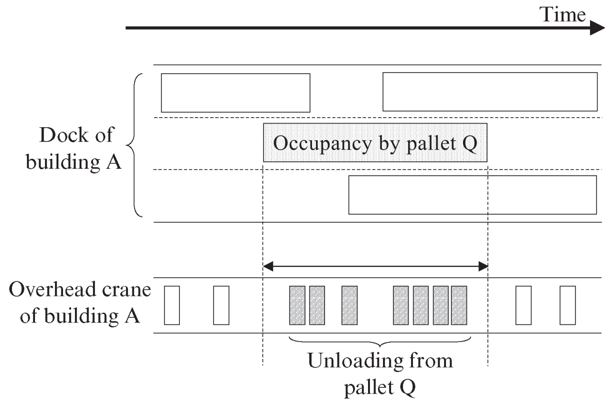

Fig. 2 Constraint on pallet and crane

(C1) Time constraints between pallet occupancy and crane handling
(C2) Finish-start precedence constraints on movement of one product
(C3) Dock capacity constraints on pallet
(C4) Warehouse, temporary holding area and berth capacity constraints on product

Both constraints (C3) and (C4) mean the maximum numbers of pallets and products which the areas can store simultaneously. (C1) are constraints between the starting time and finish time of [J1] and [J3]. If one crane receives some products on a pallet in a warehouse, the following constraints should be satisfied. **Figure 2** shows one example of the constraints. Constraint (C1) should be satisfied if a warehouse crane moves products onto a pallet.

- The starting time of [J3], occupancy by the pallet, is earlier than the earliest starting time of jobs [J1], receiving products on the pallet.
- The finish time of [J3] is later than the latest finish time of jobs [J1]

Furthermore, constraints (C2) are finish-start precedence constraints among jobs which deal with the same product. Let α denote the name of a product, which must be received by the warehouse, moved to the temporary holding area by the warehouse crane, delivered to the berth by the forklift and loaded into the ship during the scheduling horizon. To meet this requirement, the following four jobs concerning product α must be completed.

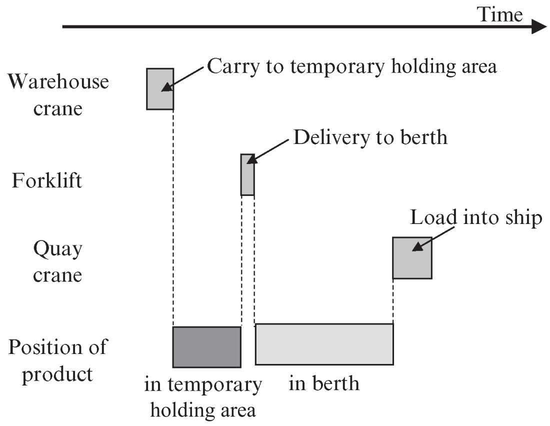

Fig. 3 Relation between jobs of one product

- Receiving product α by warehouse crane [J1]
- Moving product α to temporary holding area by crane [J1]
- Delivering product α to berth by forklift [J4]
- Loading product α into ship by quay crane [J2]

These four items should be processed in order from top to bottom, and conflicting time is not allowed. Therefore, these jobs are assigned to the schedule satisfying the finish-start constraints. Because the warehouses, temporary holding areas, and berths have respective capacity restrictions, early entry of products into an area is sometimes prohibited. **Figure 3** illustrates the lower three of the four items and the relationship to the product positions. The shipped product is held in the temporary holding area until delivery by the forklift starts. After the forklift arrives at the berth, the product is kept at the berth until it is loaded into the ship. The shipping schedule should satisfy the above constraints and minimize the total waiting time of quays, which is an important criterion for the shipping operation.

4. Scheduling Algorithm

Because the shipping operation is affected by various disturbances, it is difficult to follow the shipping schedule continuously. Therefore, frequent schedule updating is required in order to adjust to changes. In this research, a new scheduling algorithm was developed for the shipping model mentioned in the previous section. The algorithm simultaneously realizes a short computation time and short waiting time of quay cranes. This section explains the features of the new algorithm.

A list of the operational information used by the algorithm is summarized as follows. This information is given in advance and is necessary in order to create the schedule.

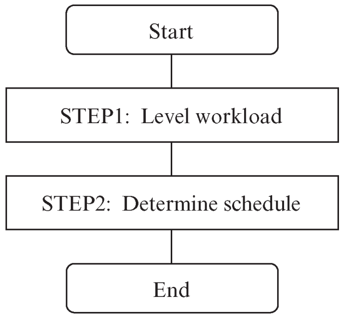

Fig. 4 Two main steps of proposed algorithm

(I1) Schedule of vehicle delivery between factories and warehouses
(I2) Berth schedule
(I3) Information on shipped products
(I4) Inventory information

(I1) is information about the deliveries between factories and warehouse buildings and includes the arrival time of vehicles and the requirements of each product delivery. The berth schedules (I2) are composed of assigned places for ship loading, quay cranes and time slots in which ships are prepared for loading and products are loaded. Information about the shipped products is included in (I3). Therefore, (I1) is information on the product movements before products are moved into warehouses, while (I2) and (I3) are information after the products are moved from the warehouses. (I4) is information on products which remain in the warehouses at the beginning of the scheduling horizon. The scheduling algorithm creates data for the jobs and constraints mentioned in the previous section based on these types of information.

The proposed algorithm has two main steps, which consist of some computation processes. In the first step, a rough shipping schedule is created in order to level the workload of machines, and then in the second step, the feasible schedule is determined based on the rough schedule (**Fig. 4**).

First, STEP 1 creates an initial quay crane schedule which does not include waiting time and assigns the jobs to the other cranes and forklifts and the time windows obtained by dividing the scheduling horizon. The assignment process tries to minimize the delay of arrivals of shipped products at quays. However, the first step does not determine the order and start time of jobs within one time window, but only the time windows within which the jobs are to be processed.

This paper focuses on the scheduling problem for shipping facilities which include warehouse buildings with plural overhead cranes, where the travel of cranes interferes with that of other cranes. It is difficult to develop efficient schedules considering the cooperation

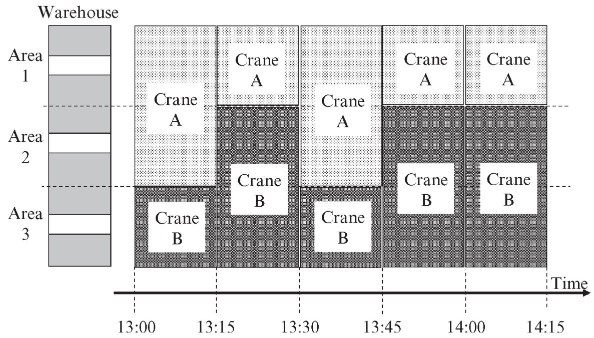

Fig. 5 Assignment of two cranes to areas

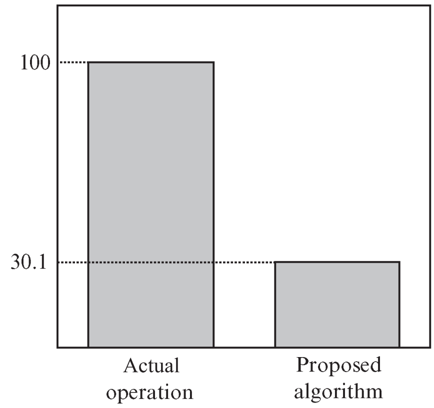

Fig. 6 Waiting time of quay cranes

of warehouse cranes because the interference of warehouse cranes produces the complex constraints of the problem. Furthermore, the delay of one crane is likely to affect the operations of other cranes and decrease the efficiency of operations. The proposed algorithm develops the shipping schedule according to the following policies to avoid this difficulty and simplify the scheduling process.

- The algorithm divides the travelling area of one building into some areas which are assigned to the warehouse cranes.
- The assignment of areas is updated in a fixed cycle.

Figure 5 illustrates one example of the areas assigned to two cranes, A and B, and the assignment is updated in a 15 minute cycle. This restriction on working areas eliminates the mutual influence of cranes, and the updating process adjusts the assignments to the time-variant workloads.

STEP 2 determines the order and operating time of the jobs in the scheduling window and finally produces a feasible shipping schedule to satisfy constraints (C1) to (C4). The second step starts the scheduling process from the earliest time window and deals with the jobs with stricter constraints on a priority basis. This two-step scheduling algorithm only needs a short computation time for scheduling, because the searching process deals with the small number of possible schedules restricted by STEP 1.

5. Computation Results

The proposed algorithm was applied to practical operational data, and its performance was evaluated based on the waiting time of quay cranes. In this numerical experiment, the jobs of five warehouse cranes in three buildings and six quay cranes are scheduled, and the scheduling horizon is 40 hours.

Figure 6 shows the waiting time in the actual loading operation and in the computation results by the new algorithm. The waiting times are indexed to the value in the actual operation as 100. The chart shows that the proposed algorithm decreases the waiting time by approximately 70 %. Furthermore, the proposed algorithm aims to achieve a short computation time because frequent rescheduling is required in response to various kinds of disturbances. A standard personal computer requires less than one minute to create a schedule with a horizon of 40 hours using the proposed algorithm, which suggests that the performance of the algorithm is sufficient to create a new schedule when necessary to adapt to frequent disturbances.

The decrease in the waiting time of quay cranes leads to a shorter cycle time of ships and thus contributes to efficient shipping operation. Moreover, the algorithm also increases the efficiency of vessel navigation because it enables accurate estimation of ship loading time. In the future, we plan to examine the detailed specifications of the scheduling system for implementation of the new algorithm.

6. Conclusion

The contents of this paper are summarized as follows.

- This paper proposes a new scheduling algorithm for total deliveries of products for shipment in a steel works.
- The proposed algorithm is composed of two main steps and creates schedules which quickly satisfy all constraints of the shipping operation.
- The computation results show that the algorithm successfully decreases the waiting time of quay cranes by 70%.
- The total computation time for a scheduling problem with a horizon of 40 hours is less than one minute.

Acknowledgement

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