High-speed Automatic Planning Technology for Ship Cargo Handling Operations at Container Terminals Using Operations Research

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*Mitsubishi Logisnext Co., Ltd. (ML) has contributed to the operational efficiency of many container terminals by providing them with container handling equipment and an information management system TOS (**T**erminal **O**peration **S**ystem). On the other hand, the development of a means to solve the shortage of labor due to the decrease in the number of port workers caused by the declining birthrate and aging population, and the increase in the volume of export/import containers handled due to globalization has recently become an issue. This time, Digital Innovation Headquarters (DI Headquarters) of Mitsubishi Heavy Industries, Ltd. and ML have jointly developed a unique technology to automatically establish plans for ship cargo handling operations in a short time which are comparable to those established by experienced workers, by utilizing **o**perations **r**esearch (OR). This report outlines the technology, describes our unique technology used therefor, and explains its evaluation results.*

1. Introduction

Ship cargo handling operations represent a series of operations at container terminals that involve unloading containers from ships to shore (unloading operations) and loading containers from shore to ships (loading operations). Currently, the order of these operations and the placing locations of containers are manually determined by planners, taking into account various constraints such as the avoidance of interference of cargo handling equipment and the upper limit of loading weight so that the unnecessary movement of cargo handling equipment is minimized while maintaining a safe center of gravity balance for the sailing of the ship. However, satisfying these constraints depends on the planner's tacit knowledge and experience. In addition, when the number of containers to be handled is large, the planning process takes time and may not be able to address possible sudden changes sufficiently. Considering the declining birthrate and aging of the population and the shortage of labor due to the increasing volume of export/import containers handled in the future, these may hinder the smooth operation of terminals, so there is an urgent need to develop a means of planning ship cargo handling operations in a short period of time, regardless of the skill level of the planner.

On the other hand, one of the methods that can derive a solution to a real-world problem by replacing it with a mathematical model based on a mathematical theory is OR. DI Headquarters has worked for many years to use OR to solve various problems in Mitsubishi Heavy Industries Group, such as plant production planning[(1)] and calculation of material inventories[(2)].

This time, we have developed a technology that utilizes OR to replace the problem of establishing a ship cargo handling operation plan comparable to that established by an experienced worker with a mathematical model based on the aforementioned experience, and to automatically

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calculate the plan in a short time by using algorithms such as mathematical optimization and rule-based approaches.

2. Overview and issues of ship cargo handling operations

Ship cargo handling operations are carried out according to the procedure shown in **Figure 1**. First, when a ship arrives at the container terminal, handling of all containers to be unloaded is performed. Containers are transferred from the ship's carrying loading areas to trailers waiting near the ship using a gantry crane (GC), which is large-sized cargo handling equipment. When the number of containers is large, several GCs are used simultaneously, and the work proceeds in parallel. Then, the trailers loaded with containers move to a location close to the container yard, which is the pre-designated temporary storage area. There, a rubber tired gantry crane (RTG), which is another type of cargo handling equipment (**Figure 2**), unloads the containers into the container yard. After the unloading operations are completed, handling of all containers to be loaded is performed in the reverse order.

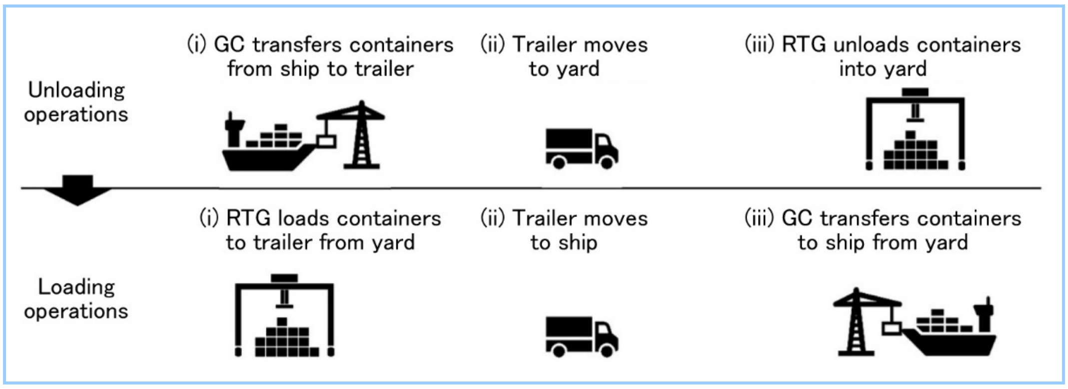

Figure 1 Flow of ship cargo handling operations

Figure 2 RTG sold by Mitsubishi Logisnext Co., Ltd.

To smoothly proceed with the aforementioned ship cargo handling operations, it is essential to prepare a lean plan for GCs and other cargo handling equipment in advance. A ship cargo handling work plan is divided into four phases as shown in **Figure 3**, depending on the timing and objective. The phase (1) allocates loading places (slots) for containers to be loaded onto the ship by port of discharge as much as possible to allow GC operations at the port of discharge to be smoother (however, the slots are specified by the ship's operator in some cases). This determines where all operations will be performed on the ship, including containers to be unloaded whose locations are known in advance. The phase (2) assigns a position in the slots allocated by port of discharge to each container to be loaded so as to keep the balance of the ship maintained from the state at the time of arrival. Then, the phase (3) determines the work order for containers to be unloaded by GC or loaded by RTG so as to allow such cargo handling equipment to operate smoothly. Finally, phase (4) works out a work schedule for the GCs that ensures that the GCs do not interfere with each other and that the work can be completed in the shortest possible time.

In fact, however, planners create plans by trial and error, making sure that the various different constraints are satisfied. Therefore, a technology to automatically create a plan that satisfies the constraints and meets the objectives is needed for each phase. The next chapter provides an overview of this technology.

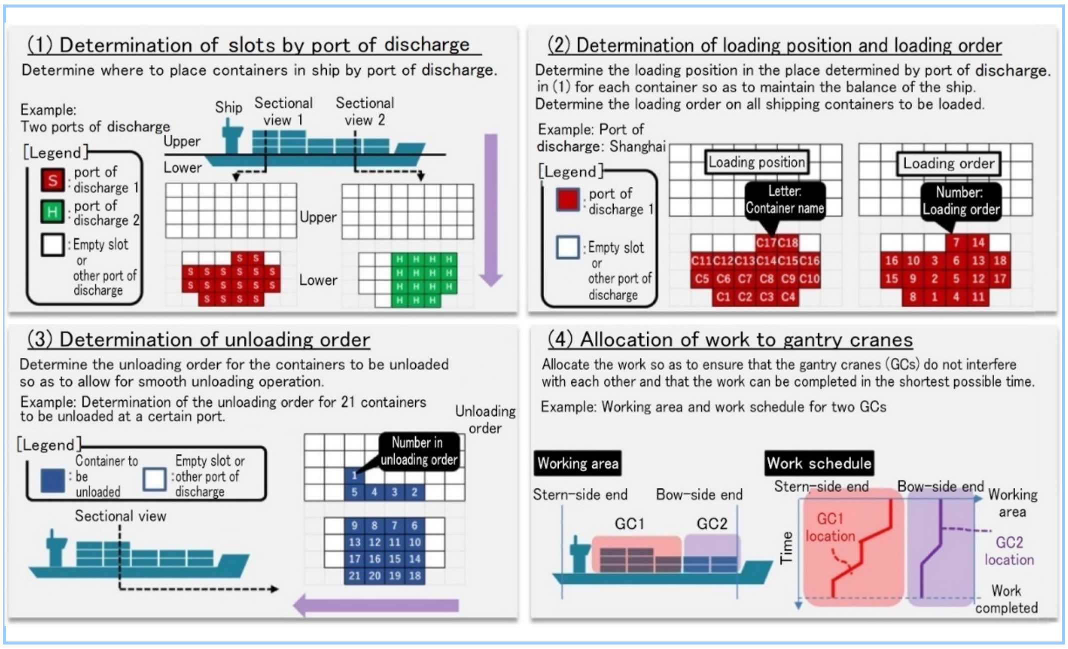

Figure 3 Plan phases

3. Optimization technology for ship cargo handling operations

3.1 Technology overview

This time, we have developed a technology that defines each of the four planning phases of ship cargo handling operations as a mathematical optimization problem, and automatically calculates them using optimization calculations and rule-based algorithms. This technology is capable of establishing plans in a short time which are comparable to those established by experienced workers while satisfying the constraints required in operating the plan at each phase. An overview of the problem at each phase is given below in (1) through (4), and the solution method is explained in sections 3.1.1 through 3.1.4.

(1) The problem of finding slots for each port of discharge so as to minimize the number of GC movements.

(2) The problem of finding each container position in the slot for each port of discharge in the ship so that the safety of the center of gravity balance is maintained with the constraints such as the maximum weight to be stacked satisfied.

(3) The problem of finding the work order which enables the unloading operations to proceed smoothly.

(4) The problem of finding the allocation of work to GCs that can complete the work in the shortest time possible without interference between GCs.

3.1.1 Method for finding slots for each port of discharge

This method finds slots that minimize the number of GC movements while satisfying the constraints (**Table 1**), such as the maximum number of bays to be used at each port of discharge. Specifically, the feature of this method is to efficiently derive slots that minimize the number of GC movements under the aforementioned constraints from a large number of candidates (candidates for placement in slots) using mathematical optimization technology (**Figure 4**). The solution method using mathematical optimization technology is described as follows. First, in STEP 1, the constraints (Table 1) and the objective function (minimization of the number of GC movements) required by the problem of finding slots for each port of discharge are replaced by mathematical formulas. **Figure 5** formulates the constraints No. 1 and No. 2 in Table 1. With these formulas as input, optimization calculations are performed by a commercial optimization solver (e.g., Gurobi) using various mathematical theories, such as the branch-and-bound and branch-and-cut methods.

Table 1 Constraint examples

No.	Constraint
1	The number of containers that can be stacked in the same height direction must not exceed the specified limit.
2	The GC must always move only once to the location where the slots for each port of discharge are allocated.
3	The total weight of containers that can be stacked in the same height direction must not exceed the specified limit.
4	The number of times a GC moves during loading operations for a same port of discharge must not exceed the specified limit.
5	The number of types of containers for a port of discharge that can be stacked in the same height direction must not exceed the specified limit.
6	The number of slots must match the number of containers to be loaded for each port of discharge.

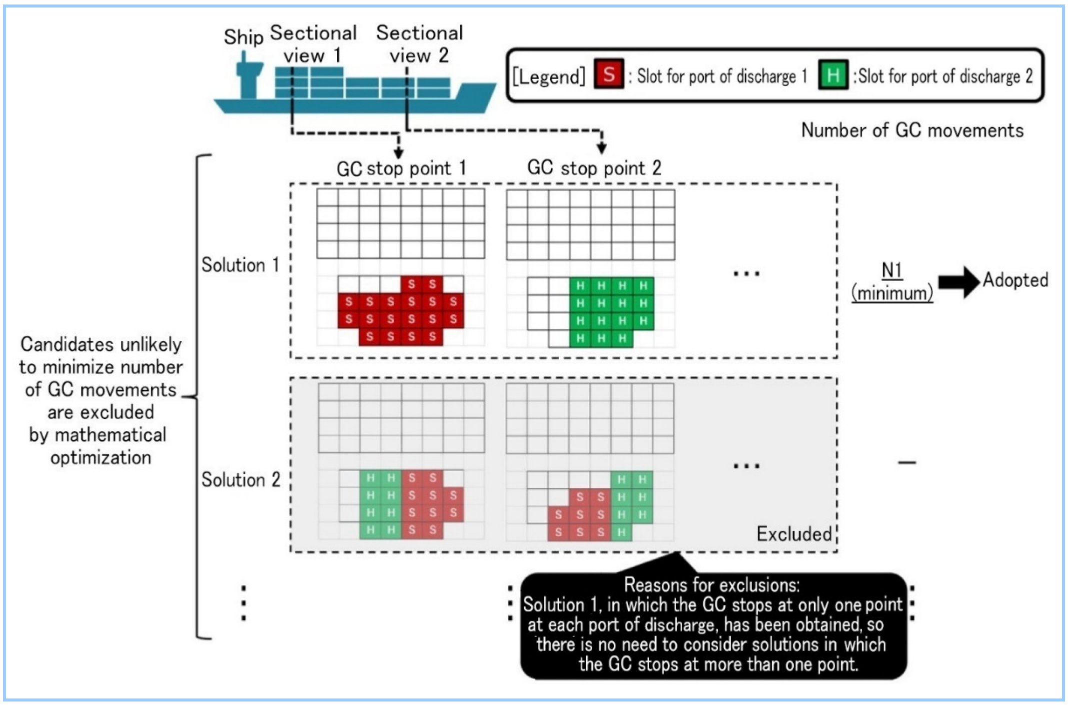

Figure 4 Overview of method for finding slots for each port of discharge

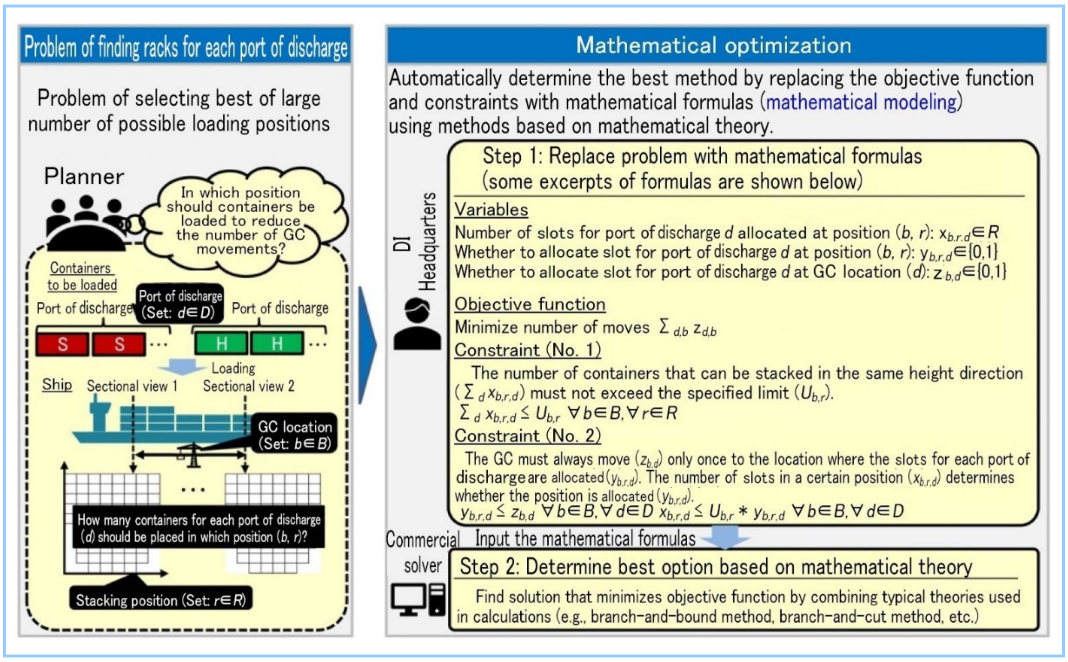

Figure 5 Solution method using mathematical optimization technology

3.1.2 Method for determining the loading position and loading order

This method finds the loading position and work order of each container in the slots for each port of discharge, while satisfying the constraints (**Table 2**), such as the restrictions on the loading position for each container type and the weight limit for stacking. The feature of this method is to efficiently derive loading positions in the ship and the work order of containers under the constraints described above using mathematical optimization technology so that the difference in the center of gravity from that at the time of arrival and the number of relocating operations of the RTG when it takes out containers from the yard are minimized. The calculation flow by the mathematical optimization technology is equivalent to that described in section 3.1.1 by replacing the constraints and objective function with those described in this section. The relocating operation by RTG is the temporary evacuation of containers stacked on top of the container to be loaded, which would not be necessary if the containers were stacked according to the loading order.

Table 2 Constraint examples

No.	Constraint
1	The total weight of containers that can be stacked in the same height direction must not exceed the specified limit.
2	Loading positions must be selected in the slots for each port of discharge.
3	Containers must not be placed in locations that are restricted for each type of container. For example, freezer containers must not be placed anywhere other than where a power supply is available.
4	Containers containing dangerous goods must be placed at the specified distance from each other.

3.1.3 Method for determining the unloading order

This method determines the unloading order for containers to be unloaded in which the unloading operation can proceed smoothly. The feature of this method is to automatically assign the work order to the containers to be unloaded using a rule-based system based on planners' experience and intuition. The experience and intuition include, for example, that it is better to take out containers closer to the land, on which the GC is installed, first to avoid the necessity of movement to avoid containers, as shown in **Figure 6**.

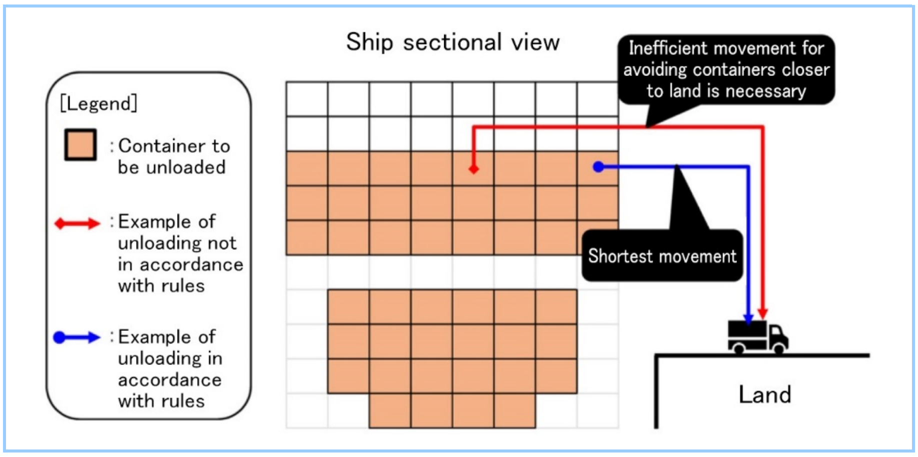

Figure 6 Example of determining effective unloading order based on planners' experience and intuition

3.1.4 Method for allocating work to GCs

This method works out the number of GCs and the work order that minimizes the work time while satisfying constraints such as avoiding interference between GCs. The feature of this method is to calculate the combination of unloading and loading work procedures that can complete the work in the shortest time among the GCs' unloading and loading work range division patterns and their traveling patterns (**Figure 7**).

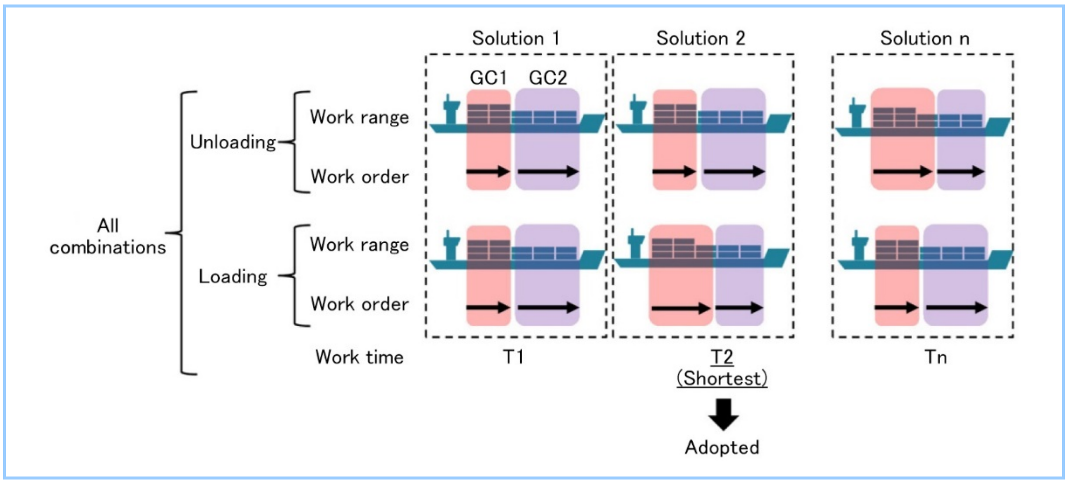

Figure 7 Overview of work assigning method for GCs

3.2 Evaluation result

To confirm the effectiveness of the technology described in (1) to (4) in section 3.1, we calculated a ship cargo handling operation plan for a ship of the largest size assumed based on the records of an actual container terminal, and quantitatively evaluated the time required for the calculations. The number of containers to be unloaded and loaded for this calculation target ship was set to 1,000 each, and several patterns with different distribution of container weights were prepared.

As a result, compared to the case of an experienced planner, the time required to create a cargo handling plan with the same safety of center of gravity balance and number of relocating operations was reduced by about 75%, confirming the effectiveness of the developed technology (**Figure 8**).

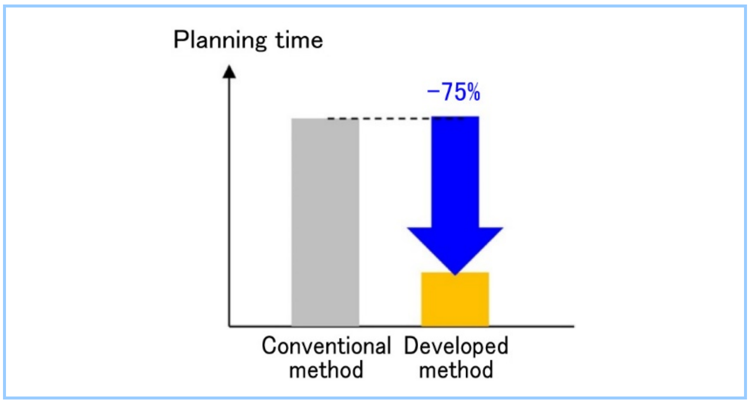

Figure 8 Confirmation of effectiveness of ship cargo handling operation plan optimization technology on planning time

4. Conclusion

This report presented a technology to automatically determine the efficient work order of cargo handling equipment and the loading location of containers on a ship while maintaining the center of gravity balance for safe operation of the ship using a mathematical algorithm to reduce the time required for creating ship cargo handling operation plans, and confirmed that, compared to the case of an experienced planner, this technology can significantly reduce the time required to create a plan comparable to that created by him/her. We have already incorporated the technology into the TOS(3) sold by ML, and will in the future sequentially deploy it at container terminals in Japan (scheduled to start operations in fiscal 2024). We will also work on automating other planning processes related to ship cargo handling operations, such as container placement in a yard and RTG work schedules, to contribute to the realization of more efficient operations at the terminal as a whole.

Acknowledgments

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