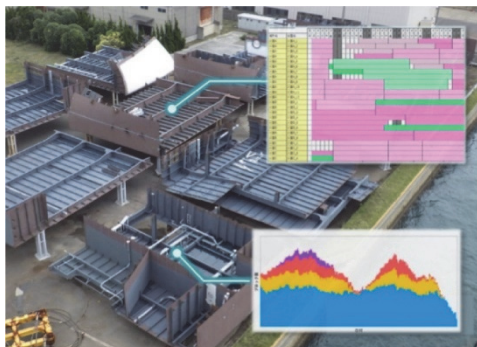


Block Storage Planning Using Mathematical Optimization for Enhancing Shipyard Construction Capacity



SHUHEI KONNO*1

MANABU KASANO*2

RYO KIMOTO*3

YASUTAKA KOBAYASHI*4

KEIGO TAKEMOTO*4

YOSHIKAZU MATSUOKA*4

Mitsubishi Shipbuilding Co., Ltd. is working to expand its shipbuilding capacity to increase the number of vessels built. As part of this effort, this report describes an automated block storage planning technology that leverages mathematical optimization. It was confirmed through comparative evaluation using past performance data that the cost of moving and storing blocks can be reduced by up to 42% compared to conventional manual planning, demonstrating that this technology can streamline the vessel construction process.

1. Introduction

Expanding vessel construction capacity in the shipbuilding business requires not only capital investment but also shorter lead time through optimized production planning and streamlined process management. Generally, in the shipbuilding process, a ship hull is divided into blocks of sizes suitable for the capacity of shipyard facilities. These blocks are processed and assembled in an assembly shop, and then sequentially erected on a berth or in a dock⁽¹⁾ (**Figure 1**). Because blocks completed in the assembly shop undergo on-ground work such as pre-outfitting and painting, and block erection takes a shorter time than shop assembly, it is difficult to erect blocks immediately after assembly. Therefore, these blocks must be stored in advance prior to erection. For this reason, shipyards often have storage sites (hereinafter referred to as “stockyards”) on the premises. Since the area of a stockyard is limited and the costs required for moving blocks and using locations vary by slot, an operation plan for blocks in a stockyard (hereinafter referred to as “block storage plan”) is required to determine the optimal combination of blocks and slots to minimize costs while adhering to the construction schedule. Currently, at Mitsubishi Shipbuilding Co., Ltd., this planning relies on experienced personnel, requiring a significant amount of time and labor. Furthermore, because the number of candidate combinations of blocks and slots is enormous, there are limits to manually deriving a rational plan that minimizes costs.

Therefore, a technology to define the block storage plan as a mathematical model and automatically generate it through optimization calculations, as well as a system for on-site utilization, have been developed⁽²⁾.



Figure 1 Blocks being assembled in shop (left) and being built in berth (right)

*1 Digital Intelligence R & D Department, Digital Innovation Headquarters, Mitsubishi Heavy Industries, Ltd.

*2 Manager, Factory Innovation Center, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.

*3 Manager, Shipbuilding & Repair Department, Mitsubishi Shipbuilding Co., Ltd.

*4 Shipbuilding & Repair Department, Mitsubishi Shipbuilding Co., Ltd.

2. Optimization technology for block storage planning

2.1 Overview of block storage planning

Figure 2 shows an example of a block storage plan. The daily storage status can be represented as a grid-like layout map of the stockyard slots. Plans are created according to the construction schedule. Blocks completed in the assembly shop are stored in one of the slots by the following day, while blocks to be erected are dispatched from the stockyard. In addition, after assembly, blocks may be processed in specialized shops depending on the work involved, such as a pre-outfitting shop. These blocks are moved according to the schedule of each process. (Strictly speaking, such factories are not stockyards, but they are treated in the same manner as other yards in this plan.) Furthermore, depending on the block, integration and grand assembly, which is a process of combining and joining multiple blocks assembled in the shop, may be performed immediately before erection. Therefore, a predetermined combination of blocks is aggregated and arranged in a predetermined slot according to the integration and grand assembly schedule. Although Figure 2 shows an example for a single day, in practice, a plan spanning several weeks to several months must be created to systematically secure the personnel and equipment needed for block movement.

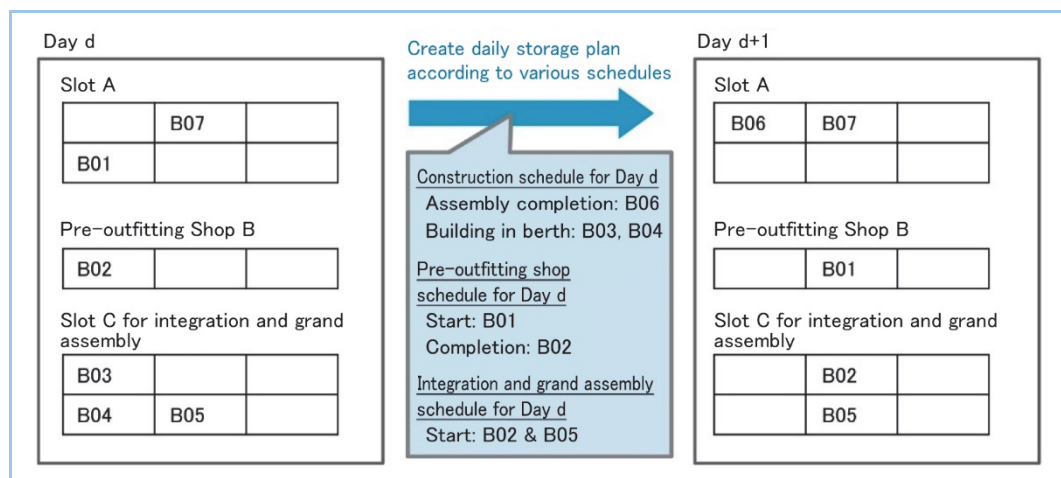


Figure 2 Example of block storage plan

2.2 Clarification of constraints in block storage planning

Table 1 shows the major constraints in block storage planning, which were clarified through interviews with personnel in charge of planning operations. Constraints 1 and 2 are intended to ensure logical consistency regarding block placement. Constraints 3 and onward are defined based on operational requirements.

Table 1 Major constraints in block storage planning

No.	Item	Description
1	Block placement	Always place in one of the placement positions from the start to the end of storage.
2	Maximum number of blocks per placement position	Each position can accommodate up to one block.
3	Prohibited placement positions	Certain placement positions are prohibited from storage depending on work area limitations and moving equipment capacity.
4	Consideration of work processes	Considering the chronological relationship of work processes, store the same block in the same position as much as possible.
5	Adjacent block pairs	Blocks subject to integration and grand assembly must be placed in adjacent positions.
6	Block size	The number of occupied positions varies depending on block size.

Figure 3 shows a conceptual diagram illustrating block operations and constraints 3 to 5 during a storage period. In block storage planning, as described in Chapter 1, storage locations are determined for the period from the day when assembly is completed in the assembly shop (the assembly completion date in the figure) to the erection date. For blocks involving work such as pre-outfitting or integration and grand assembly, the placement location must be determined according to the start and completion dates specified in the schedule of each process. For example, Block 1 may need to be placed in a predetermined location, such as a pre-outfitting shop, during Period 2

(Constraint 3). On the other hand, during Period 1 and Period 3, in which no work is performed, blocks are placed in any slot where storage is possible. At that time, if there is a vacancy in the slot before and after the work, continuing to store the block in the same location minimizes the number of relocations; therefore, placing blocks in the same position across consecutive periods is desirable (Constraint 4). In addition, multiple blocks subject to integration and grand assembly must be placed adjacent to each other (Constraint 5). The block example shown in Figure 3 involves only integration and no grand assembly; however, some other cases involve grand assembly, which is the work of further joining other integrated blocks after integration and before erection.

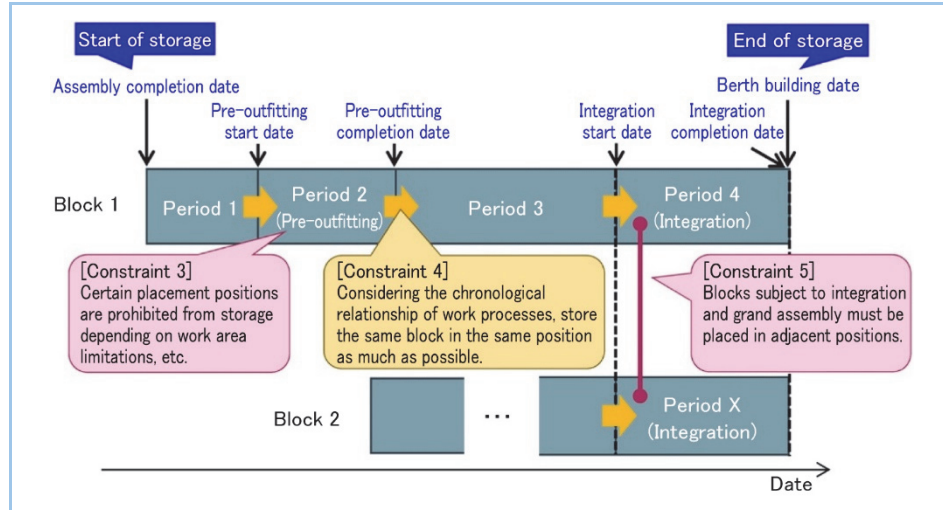


Figure 3 Blocks and work processes

2.3 Construction of mathematical optimization model

Based on input data regarding blocks and stockyards, a mathematical optimization model was devised. This model represents decision-making elements of storage planning formulation using 0-1 integer variables, and consists of mathematical formulas expressing the constraints shown in Section 2.2 (constraint equations) and a function expressing plan evaluation indicators such as costs required for moving and storing blocks (the objective function). An overview of the devised model is outlined below. Note that the following description is partially simplified to make the concept and structure of the model easier to understand. In the implemented model, input data and constraint equations based on various operational constraints are added, and modeling techniques to enhance computational efficiency are also incorporated.

(1) Variables

Table 2 provides examples of variables in this model. According to the representation of blocks and periods shown in Figure 3, block storage planning determines where to store each block b during period $t(b)$ corresponding to that block. Therefore, decision variable x is defined using position number j that identifies each location. In addition, variable y is defined to determine whether there is a change in the storage position between two consecutive periods.

Table 2 Examples of variables

Variable name	Description
$x(b, t(b), j)$	A 0-1 integer variable that takes a value of 1 if block b is stored at location j during period $t(b)$, and 0 otherwise.
$y(b, t(b), j)$	A 0-1 integer variable that takes a value of 1 if block b continues to be stored at location j between period $t(b)$ and period $t(b)+1$ and the storage position does not change, and 0 otherwise.

(2) Constraint equations

Table 3 shows examples of constraint equations. The constraints shown in Table 1 are defined in the form of inequalities using variables.

Table 3 Examples of constraint equations

Constraint equation	Description
For any block b and period $t(b)$, $\sum_{j=1}^{ J } x(b, t(b), j) = 1$	Every block b is always placed in one of all placement locations $J = \{1, \dots, J \}$ during period $t(b)$. Corresponds to Constraint 1.
For any day d during the planning period and any location j , $\sum_{b, t(b) \in \text{Stored}(d)} x(b, t(b), j) \leq 1$	At each date and location during the planning period, the number of placed blocks is at most one (0 or 1). Corresponds to Constraint 2. "Stored(d)" represents the set of blocks b and periods $t(b)$ that must be stored on Day d .
For any block b and period $t(b)$, $2y(b, t(b), j) \leq x(b, t(b), j) + x(b, t(b) + 1, j)$	An equation for defining variable y , which defines the logical relationship: "If $y(b, t(b), j) = 1$, then $x(b, t(b), j) = x(b, t(b) + 1, j) = 1$ ".

(3) Objective function

A part of the objective function (minimization function) is defined as follows, using the cost ("cost") required to move and store block b at location j , and a coefficient α representing the cost reduction rate for continuous storage in the same location:

Objective function

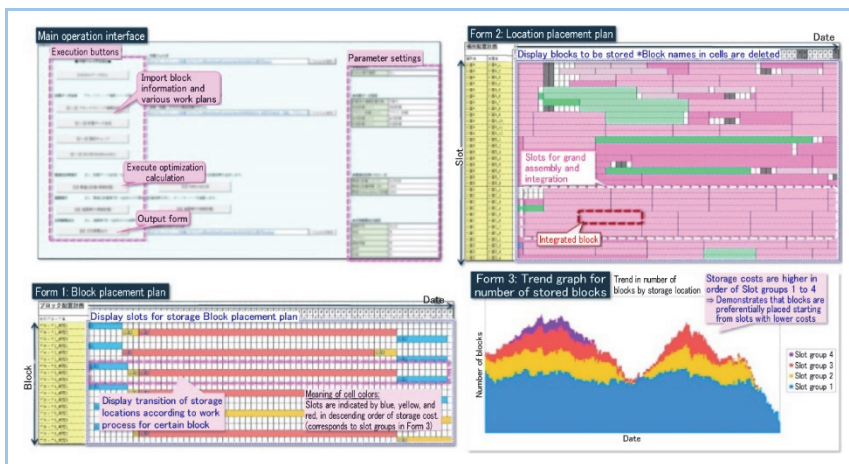
$$= \sum_b \sum_{t(b)} \sum_j \text{cost}(b, j) \cdot x(b, t(b), j) - \sum_b \sum_{t(b)} \sum_j \alpha \cdot \text{cost}(b, j) \cdot y(b, t(b), j)$$

the first term represents the total cost when block b is moved to and stored at location j during period $t(b)$. Minimizing this term suppresses placement in locations far from the shop or building berth, which would increase movement costs, thereby aiming to reduce movement costs. The second term means that if the storage position does not change after period $t(b)$ for block b , that is, if $y = 1$, the cost for one movement of the block is canceled out. Consequently, this objective function accounts for the reduction in cost when stored at the same position.

2.4 Development of block storage planning optimization system

By performing calculations with a general-purpose mathematical optimization solver using the model described in Section 2.3, a system was developed to automatically formulate an optimized block storage plan. **Figure 4** shows the main operation interface of this system and planning sheets obtained from the optimization calculation results. Because data that serve as input for planning and data regarding block storage plans that serve as system output are often managed in Excel tabular format, all operations, including importing and editing input data, executing optimization calculations by the solver, and outputting various forms, can be easily executed within a single Excel interface.

By using this system, in addition to the conventional form generation shown in Figure 2, it has become possible to collectively create plans for over a year, which was difficult with manual planning. This enables the estimation of long-term trends of storage locations and the required periods for slots to be rented during peak seasons.

**Figure 4 Examples of system interface**

3. Verification using actual data

The effectiveness of the developed technology was verified using the system described in Section 2.4. In the verification, actual data regarding block information and various schedules, such as erection schedules at a certain point in the past, as well as the slots and positional relationships of the stockyard, were prepared. An optimization calculation was then performed within the maximum allowable time required for operations to create a plan.

Figure 5 shows the results of estimating and comparing the costs required for movement and storage between the plan generated by the developed technology and the actual operational performance. It was confirmed that this technology can reduce handling and storage costs by up to 42% by realizing an operational plan that minimizes the number of movements between processes, particularly to distant locations far from the shop where movement costs are high, thereby demonstrating that the vessel construction process can be made more efficient.

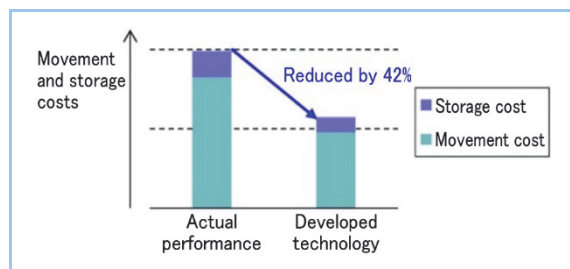


Figure 5 Comparison results of movement and storage costs

4. Conclusion

This report presented a technology that defines the block operation plan in a stockyard (block storage plan) as a mathematical model and automatically formulates it through optimization calculations, as well as a system developed for on-site application, both for expanding the vessel construction capacity of shipyards. Effectiveness verification using past performance data confirmed that the proposed approach can reduce handling and storage costs by up to 42% compared to actual operational performance.

In the future, Mitsubishi Shipbuilding Co., Ltd. aims to further advance optimization and automation by applying technologies such as mathematical optimization to other manually planned processes, including block assembly in upstream operations. Furthermore, by integrating these systems, the company will enhance operational efficiency across the entire shipbuilding process, thereby contributing to the expansion of vessel construction capacity toward increasing the number of vessels built.

References

- (1) Y Okumoto, Shipbuilding Technology & Production System, seizando-shoten Publishing Co., Ltd., (2009) (in Japanese)
- (2) Konno, S., A Mixed-Integer Programming Model for Optimizing Block Storage Planning in Shipyards, 24th Conference of the International Federation of Operational Research Societies (IFORS2026), (2026)