# Delivery Scheduling System for Barge Transport in Tokyo Bay<sup>†</sup>

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#### Abstract:

An integrated delivery scheduling system for trucking has already been developed and in practical use. The scheduling system has been extended to marine transport in Tokyo Bay for more efficient product transfer. The marine transport scheduling was formulated as an optimization problem to obtain the most efficient routing and assignment of barges. The optimization problem was solved by using Mixed Integer Linear Programming (MILP).

## 1. Introduction

At East Japan Works, JFE Steel, direct delivery of products to domestic customers accounts for approximately half of the direct delivery ratio. Because trucks are mainly used in product deliveries, JFE Steel developed the Vehicle Routing Scheduler for Steel Products Delivery, which integrated the product delivery operations of three distribution bases of East Japan Works (Chiba and Keihin Districts and Tokyo Distribution Center) to realize high efficiency in deliveries by truck<sup>1, 2)</sup>.

On the other hand, due to the siting features East Japan Works, products are also delivered to customers along Tokyo Bay by bay ships and barges in parallel with trucks.

In this work, the Tokyo Bay barge delivery operations of the three distribution bases were integrated in the same manner as with the previously-developed Vehicle Routing Scheduler, and the Delivery Scheduling System for Barge Transport in Tokyo Bay, which optimizes barge routing, was developed<sup>3)</sup>. This has resulted in unification of land transport and marine transport in Tokyo Bay, and has made it possible to perform product delivery service to customers more quickly, flexibly and

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## 2. Product Delivery in East Japan Works

## 2.1 Overview of Product Delivery

Figure 1 shows an overview of product delivery in East Japan Works. Table 1 shows the scale of delivery,



Fig. 1 Overview of product delivery in JFE Steel East Japan Works

Table 1 Scale of delivery in JFE Steel East Japan Works

	Truck	Barge	Bay ship
Product (×1 000 tons/month)	250	60	30
Truck, Barge, Ship	300	20	1
Distribution base	5	5	4
Customer	150	40	4



<sup>2</sup> Staff Manager, Production Control Technology Sec., Production Control Dept., East Japan Works, JFE Steel the numbers of trucks, barges, bay ships, etc., the number of distribution bases, and the number of customers to whom deliveries are made.

Among the three main distribution bases, products produced by Chiba District and Keihin District are delivered from the respective districts, and products transported from West Japan Works by coastal vessels are delivered from the Tokyo Distribution Center.

#### 2.2 Integration of Product Delivery Operation

In conventional product delivery operation, the means of delivery (trucks, etc.) and products for delivery of each distribution base were managed individually, and many of the delivery plans were prepared by manual work. For this reason, preparation of delivery plans and management of their implementation were performed individually by each distribution base. However, this made it difficult to secure cargoes for return routes, and in many cases, trucks and other transport simply made return trips between the distribution base and a customer. This resulted in return trips to the base in which the truck or ship was empty, as well as long idling times.

Moreover, since delivery plans were prepared manually at many distribution bases, a long lead time was required in plan preparation, and when sudden changes in a plan or other problems occurred, this placed a heavy load on the person responsible for planning.

To solve these problems, JFE Steel constructed a database for integration of the delivery operations of each distribution base and integrated management of

(a) Conventional Delivery system Delivery schedule Delivery operation Truck/Barge (Manual) ↔ Customer Chiba DB ► Truck (Scheduler)/Barge (Manual) \leftrightarrow Customer Keihin DB TDC\* DB Truck/Barge (Manual) ↔ Customer DB: Database Tokyo Delivery Center Product wo delivery barges Product Keihin Customer2 Empty Chiba Chiba Waiting Keihin Two delivery trucks (b) Improvement Central Delivery Center Customer Chiba 🔾 Integrated Truck, Barge scheduler DB Keihin 🗡 🕻 Customer Make the integrated schedule TDC Customer One delivery barge Customer1 m Empty Keihin Customer? Chiba Chiba Vovage : One delivery truck

Fig. 2 Integrated delivery operation

products for delivery and the means of delivery, and developed a system which enables free selection of routes linking multiple distribution bases and customers by utilizing this infrastructure and optimization techniques (Fig. 2).

Prior to this, in 2009, JFE Steel started operation of the Vehicle Routing Scheduler for deliveries by trucks, and this is continuing to contribute to delivery service to customers by enabling speedy, flexible and accurate land transportation.

In the present work, the company developed the Delivery Scheduling System for Barge Transport in Tokyo Bay, which optimizes barge routes by integrating barge delivery operations in Tokyo Bay and applying optimization techniques to the preparation of plans for barge transport in the bay area by utilizing the constructed database for integrated management of the products for delivery and the means of delivery.

## 3. Delivery Scheduling System for Barge Transport in Tokyo Bay

## 3.1 Overview of Problems in Barge Delivery Planning

The problem of preparing the cargos to be loaded on trucks and barges and their delivery routes is common to both delivery planning for trucks and delivery planning for barges and ships. However, as shown in Table 2, there are also various problems which are unique to barge scheduling planning. For example, barge plans are prepared up to 10 days in advance, including barges which are currently on voyages, with daily rolling; in some cases, several days are required from the start of loading at the distribution base until completion of unloading at the delivery destination; there are restrictions on routing depending on the ship's registration; and sailing speed differs depending on the type of barge. For this reason, it is not possible to respond to barge planning by a simple extension of a truck routing problem. Thus, new modeling and a new solution algorithm are necessary.

Ship scheduling is one important field of scheduling problems, and research on a fusion of hierarchical build-

Table 2 Compare with barge scheduler and truck scheduler

	Barge scheduler	Truck sched- uler
Schedule period	10 days	1 day
Delivery time	1 to several days	Several hours
Registry constraints	Yse	No
Speed pattern	Several	1

ing block methods<sup>4</sup>), which is a framework that includes meta-heuristics methods, and column generation methods<sup>5</sup>), which is an approach to large-scale mathematical programming, etc. have been reported<sup>6</sup>).

#### 3.2 Modeling of Barge Scheduling Problem

The following describes modeling for formulation of the barge scheduling problem as an optimization problem.

The cargos to be delivered by barges are assembled in lots in advance in various product units, such as steel sheets, plates, pipes and so on, and the product type, dimensions, weight, loading port, unloading port, starting time of loading, loading time, starting time of unloading and unloading time are given.

Here, "operation from the start of loading of a cargo at the loading port to completion of unloading at the unloading port" is defined as a Job, and 1 cargo comprises 1 or more Jobs.

One important requirement for efficient voyages by as few barges as possible is a method for selecting a loading port where the next cargo to be delivered can be secured after completing unloading at the unloading port which is the delivery destination.

A simple schematic of the above-mentioned concept is shown in **Fig. 3**. Figure 3 shows the Job set at each loading port and the barge set which is available for use.

Focusing on Job 1 in Fig. 3, the Jobs that can be performed next after Job 1 are the Jobs from Job 2 to Job 6, as the Job starting times at each loading port are possible after completing Job 1. One of those Jobs is selected as the next Job to be performed (in the figure, Job 6 is selected). Also, because Job 1 and Job 6 must be delivered by the same barge, a barge that is capable of delivering both Job 1 and Job 6 is selected (in the figure, Barge 1 is selected).

In the model described above, the barge scheduling

problem can be formulated as a combinatorial optimization problem "Obtain the optimum barge corresponding to the selection of the optimum next job for all enumerated jobs," by giving the constraint conditions related to the Jobs that can be performed next, the barge that will perform the job, etc., and the objective function of minimizing the number of barges used, etc. The modeled problem was formulated as Mixed Integer Linear Programming (MILP).

#### 3.3 Barge Scheduler Engine

A barge scheduler engine was developed as a tool for solving problems formulated in MILP by using a general-purpose solver. The barge scheduling engine is operated by the algorithm shown in **Fig. 4**. The individual procedures are described below.

- (1) Read Input Data
  - The following data are read as inputs.
  - Cargo data: Data in connection with the dimensions, weight, loading port, unloading port, loading start time and unloading start time, including cargos in transit comprising lots by product type unit.
  - Barge data: Data concerning restrictions related to barge specifications such as maximum load weight and product type, cargo hold dimensions, ports where loading/unloading is impossible, barge speed, etc., barge layup period for periodic inspection, etc., and cargos in transit.
  - Loading port and unloading port data: Name and loading/unloading time of respective loading/ unloading ports.
  - Distance data:Data on the distance between loading and unloading ports.
- (2) Make Job Data

Job data are prepared for each cargo based on the read input data.



Fig. 3 Modeling of barge scheduler



Fig. 4 Algorithm of barge scheduler

(3) Make Constraints Data

Combinatorial data for possible Jobs and available barges are prepared by combining the next possible Job, based on the input data and the prepared Job data.

(4) Run General Purpose Solver (Solve MILP)

The combination of the barge with the optimum navigation route is obtained by solving an optimization problem based on the input data and prepared constraints data and the defined objective function.

(5) Prepare Barge Scheduling Plan Data (Make Schedule Data for Display)

Data for plan display are prepared based on the obtained combinatorial data for the barge correspond-

ing to the obtained optimum navigation route.

## 4. Verification of Effects by Simulation

A simulation for verification of the effects of the developed barge scheduler engine was performed by using actual ship scheduling result data. An example of the simulation results is shown in **Fig. 5**. Figure 5 shows the improvement ratio in comparison with the existing (conventional) condition for (a) average idling time of barges and (b) average loading weight of barges.

With the actual barge scheduling result data, idling



Fig. 5 Simulation results



TDC: Tokyo Delivery Center

Fig. 6 Integrated delivery system

time could be reduced by 23.4% and loading weight could be increased by 7.3% in comparison with the results of conventional scheduling as a result of applying the barge scheduler engine to the existing condition of barge scheduling.

In addition, a simulation was carried out under the condition that the delivery lot preparation method was reviewed, and simultaneously with this, barge operation plans were also reviewed, for example, by shifting products for delivery to group companies to bay ships, etc. As a result, the possibility of improvements of 31.9% in idling time and 20.1% in loading weight in comparison with the existing scheduling results could be confirmed.

Based on the results described above, the barge scheduler engine was installed in the integrated delivery system shown in **Fig. 6**, and was incorporated in the actual process as the Delivery Scheduling System for Barge Transport in Tokyo Bay.

## 5. Conclusion

In this work, the barge scheduling operations for three distribution bases on Tokyo Bay were integrated in the same manner as the Vehicle Routing Scheduler for Steel Products Delivery, which was developed previously, and a barge scheduler engine which optimizes the navigation routes of barges was developed and applied in the Delivery Scheduling System for Barge Transport in Tokyo Bay.

This system was put into operation in 2011 and is used in daily barge scheduling planning work. This system and the previously-developed Vehicle Routing Scheduler have made it possible to integrate land transport and marine transport in Tokyo Bay, and to perform product delivery service to customers more speedily, flexibly and accurately.

#### References

- Yoshinari, Y.; Kishda, T. Vehicle routing scheduler of coil products. CAMP-ISIJ. 2010, vol. 23, p. 1048.
- Yamaguchi, O.; Yoshinari, Y.; Tomiyama, S. Applications of Optimization and Simulation Technologies to Scheduling Systems in Steel Manufacturing and Logistics. JFE Giho. 2011, no. 28, p. 23–28.
- 3) Yoshinari, Y.; Kishda, T. Delivery scheduling system for barge

transport in Tokyo bay. CAMP-ISIJ. 2013, vol. 26, p. 239.

- 4) Kubo, M.; Miyamoto, Y. A New Framework of Meta-heuristics —The Hierachical Buildings Block Method—. The transactions of the Institute of Electrical Engineers of Japan. C, A publication of Electronics, Information and System Society, 2001-06-01, vol. 121, no. 6, p. 976–981.
- Kobayashi, K.; Kubo, M.; Kano, T. Ship scheduling problem for a fleet of chemical tankers in Japan. Conference proceedings. The Japan Society of Naval Architects and Ocean Engineers, 2007, p. 7–8.
- 6) Kubo, M.; Kobayashi, K. A Unified Framework of the Hierarchical Building Block and Column Generation Methods and its Application to Transportation and Ship Scheduling. Journal of the Society of Instrument and Control Engineers. 2008, vol. 47, no. 6, p. 519–524.