Instance Generation for Computational Experiments

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For our computational experiments, we generated problem instances based on the characteristic of the operational data of Keppel Shipyard in Singapore, renowned as one of the world's leading shipyards. This shipyard features 5 graving dry docks ranging in length from 300 to 400 meters, alongside 3 floating dry docks. On average, approximately 33 ships are serviced monthly across all types of dry docks. The instances we generate are based on the 5 graving dry docks.

Configuration details of the five graving dry docks, including their lengths, widths, and drafts, are provided in Table 1. Each dock is outfitted with three main pumps and several auxiliary pumps. Drainage relies on main pumps with an average efficiency of 24000m^3/h, the raining time of dry dock k is thus estimated as $P_k = \lceil V_k/24000/3 \rceil$, where V_k represents the volume of dock k calculated from its dimensions. Flooding occurs naturally, with flooding time of each dry dock k set at $Q_k = \lceil P_k/2 \rceil$. Accordingly, the draining and flooding times for each dry dock are detailed in the last two columns of Table 1.

Table 1 **Dry dock data in the shipyard**

Dock No.	Length (m)	Width (m)	Draft (m)	Draining time (h)	Flooding time (h)
1	400	64	13.6	5	3
2	350	66	13.7	5	3
3	301	52	14.4	4	2
4	350	60	12.0	4	2
5	300	60	12.0	3	2

The ships served in the Keppel Shipyard in Singapore are classified into four different types based on the ship size, denoted by W. Table 2 shows the statistics on the ship data, including the proportion and the range of length, width, draft, and service time for each type $w \in W$ of ships.

Table 2 Statistics of ship data

Ship type	Proportion (%)	Length (m)	Width (m)	Draft (m)	Service time (h)
Small	15	[60, 99]	[10.0, 19.5]	[3.0, 6.5]	[48, 72]
Regular	35	[100, 199]	[20.0, 28.5]	[7.0, 9.5]	[72, 120]
Large	30	[200, 299]	[25.0, 35.5]	[10.0, 12.0]	[120, 192]
Mega	20	[300, 380]	[40.0, 56.5]	[12.0, 13.5]	[144, 240]

Based on the statistics on the ship data, we consider 7 types of block layout in our experiments, each tailored to accommodate ships within specific length ranges. The length of each type of block layout is determined by the maximum length of the suitable ships, with an additional 20-meter safety clearance. The block placement time is related to the length of the block layout L_z, i.e., $\lceil L_z/100 \rceil$. Hence, the setup time associated with placing block layout z in dock k is defined as $U_z^k = P^k + \lceil L_z/100 \rceil + Q^k$, where P^k and Q^k represent the draining and flooding times for each dock k as indicated in Table 1.

Table 3 Block layout data in the shipyard

Layout No.	Ship Length (m)	Layout No.	Ship Length (m)
1	[60, 99]	5	[250, 299]
2	[100, 149]	6	[300, 339]
3	[150, 199]	7	[340, 380]
4	[200, 249]		

We generate five sets of instances based on the docks in the Keppel Shipyard in Singapore for a planning period of one month, with each time unit equivalent to one hour. Specifically, the dry docks $\mathcal{K}$ are generated based on Table 1 for all instances. The monthly total number of ships served in the dry docks $\mathcal{K}$, i.e., $|\mathcal{I}|$, is set at 15, 20, 25, 30, and 35 for each instance set, reflecting practical demand scales. We randomly generate five instances for each set, resulting in a total of 25 test instances.

For each instance, in order to form the ship set $\mathcal{I}$, we determine the quantity of various ship types according to the given $|\mathcal{I}|$ and the proportions outlined in Table 1. Subsequently, the length, width, and draft of each ship are uniformly generated from the designated intervals corresponding to their specific ship type. The service time of each ship is generated follows the same method proposed by Jia et al. (2024). Specifically, for each ship i categorized under type $w \in W$, its nominal service time in dry dock k, i.e., $\bar{R}_{ik}$, is drawn from the interval $[e_\omega, d_\omega]$, as detailed in Table 2. Each $r \in T_\omega = \{[e_\omega, d_\omega] \cap \mathbb{N}\}$ is selected with a probability of $\frac{\beta_\omega - |r-\alpha_\omega|}{\sum_{r \in T_\omega} \beta_\omega - |r-\alpha_\omega|}$, where $\beta_\omega = d_\omega - e_\omega + 1$ and $\alpha_\omega = \frac{e_\omega + d_\omega}{2}$. Its maximum deviation of service time $\hat{R}_{ik}$ for each k is randomly picked from $[0, \min\{d_\omega - \bar{R}_{ik}, \bar{R}_{ik} - e_\omega\}]$. The arrival time of ship i is uniformly selected from $[0, 720 - \max_{k \in \mathcal{K}}\{\bar{R}_{ik} + \hat{R}_{ik}\}]$

and the desired departure time is set as $D_i = A_i + \lceil (1+\varepsilon_i) \cdot \max_{k\in\mathcal{K}}\{\bar{R}_{ik} + \hat{R}_{ik}\}\rceil$, where ε_i is uniformly generated from $[0, 0.5]$.

For each ship i, it can be serviced in dock k if 1) its draft, and the length and width of its requited block layout z_i, do not exceed those of the dock k, denoted by set K_i; 2) the equipment of dry dock k should meet the services required by ship i. As such, we assume that each dry dock is capable of servicing ships with specific sets of block layouts. Correspondingly, we can obtain the ship set $\mathcal{I}_k = \{i \in \mathcal{I} : k \in \mathcal{K}_i\}$ that can be served by dry dock k. The block layouts $\mathcal{Z}_k$ is then generated based on $\mathcal{I}_k$ and the data listed in Table 3.

To define the cost parameters, we set the unit time costs for draining and flooding as 1 and 0, respectively, to represent the expenses mainly tied to water pumps in these operations. Therefore, the fixed batch operational cost of dry dock k, encompassing draining and flooding operations, is expressed as $f_k = P_k$. For each setup operation in dock k, in addition to the draining and flooding expenses, there is a labor cost associated with block placement. We assume the labor cost for each setup operation in dry dock k to be $\lceil \frac{\bar{L}_k}{100} \rceil$. This cost is estimated by setting a unit time labor cost of 1 and considering a maximum working time of $\lceil \frac{\bar{L}_k}{100} \rceil$, where $\bar{L}_k$ represents the length of dry dock k and 100 indicates a working efficiency of 100m/h. Thus, the setup cost for dock k is given by $c_k = P_k + \lceil \frac{\bar{L}_k}{100} \rceil$. Moreover, the unit tardiness cost of each ship i is set as $C_i = 1$ if ship i is a small or regular ship, $C_i = 2$ if ship i is a large ship, and $C_i = 3$ if ship i is a mega ship, so as to reflect the service priorities of different types of ships.

Finally, we define the uncertainty budget for each dry doc $k \in \mathcal{K}$ as $\Delta_k = \lceil \mu \times \sum_{i\in\mathcal{I}_k} \hat{R}_{ik} \rceil$. The specific value of μ is explained in different experiments.

References

Jia, S., Li, C.L., Meng, Q., 2024. The dry dock scheduling problem. Transportation Research Part B: Methodological 181, 102893.