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D N Prayogo[1], A Hidayatno[2,3], and Komarudin[2,4]

[1]Department of Industrial Engineering, University of Surabaya, Raya Kalirungkut, Surabaya, 60293, Indonesia
[2]Department of Industrial Engineering, University of Indonesia, Margonda Raya, Depok, 16424, Indonesia

Email: [1]dnprayogo@staff.ubaya.ac.id, [3]akhmad@eng.ui.ac.id, [4]komarudin74@ui.ac.id

Abstract. In this paper, we studied an integrated planning optimization model in container operations consisting of tactical and operational level decisions. At the tactical level decision, integration planning includes berth allocation problem, quay crane assignment problem and yard allocation planning. These tactical level decisions are integrated with quay crane scheduling which is an operational level decision at the container terminal. Integration of planning in container terminals is needed because the decision on berth allocation, namely berthing position and berthing time in seaport, is highly dependent on the decision of reserved sub-blocks positions in container yard allocation, the number of quay cranes assigned to each vessel and its scheduling on each vessel bays. This integrated planning decision optimization has two objective functions; namely: (i) minimizing total operational cost, and (ii) maximizing service level. Numerical experiments have been carried out to obtain total cost efficiency and maximum service level resulting from the proposed optimization model.

1. Introduction

In line with the rapid development of international trade in the past decade, the utilization of container terminals to support the efficiency of global transportation costs is very important. There are around 793.26 million TEUs managed by container ports around the world and have a growth rate of 4.7% in 2019 with 64% of the total container port traffic occurring in Asia. This is a huge challenge for container terminal managers to have a facility planning, i.e.: quay wharf and quay cranes in seaside ports, and at yard storage area in landside as container terminal resources in efficiently and effectively to increase the competitiveness of seaports.

Tactical level planning decisions in container terminal consists of Tactical Berth Allocation Problem (TBAP), Quay Crane Assignment Problem (QCAP), Specific Quay Crane Assignment Problem (SQCAP) and Tactical Yard Allocation Planning (TYAP). While operational level planning decisions includes Quay Crane Scheduling Problem (QCSP), Stowage Planning, Internal Transport Scheduling Problem (ITSP) and Yard Crane Scheduling Problem (YCSP).

TBAP decisions are berthing start and end time and berthing position, which are interrelated to the number of assigned QCs and the handling time of each vessel which are the decisions of QCAP and the location of reserved sub blocks for each vessel in the container yard storage area. However, intertwined tactical planning decisions of QCAP and TYAP also depend on the TBAP decisions, those are berthing time and position. Moreover, QCSP operational level decisions related to the sequence of tasks to be processed by each quay crane (QC) also depend on tactical decisions of TBAP and SQCAP. Therefore, solving the problem of tactical and operational planning at the container terminal should be carried out in integrated manner and considering the interests of all parties involved, namely container terminal managers and shipping liner owners.

In this study, we proposed a bi-objective optimization model for integration of tactical and operational planning decisions at container terminal operations. Furthermore, the organization of this paper has the following structure. Section 2 briefly discusses the literature review regarding various types of integration of container terminal planning. Explanation of problems related to the operational processes contained in container terminals at seaside and landside is described in Section 3. Section 4 describes the formulation of the bi-objective optimization model for the proposed integrated planning in container terminal operations. The solution method discussed in Section 5 and continues with the numerical experiments and analysis of the results of applying the integration model and the proposed solution method in Section 6. Finally, Section 7 presents the conclusion remarks and further research directions.

2. Literature Review

Several integration planning models of tactical and operational level at container terminal have been developed by researchers. The methods for solving the integration model can be classified into three categories, namely: (1) Sequential integration; an integration model is divided into several sub-problems and each sub-problem is solved in stages, where the optimization results from one stage will be input data for the next stage, such that the obtained results do not guarantee optimal overall; (2) Deep integration: the integration model is solved as a single model. If the integration model is a NP-Hard problem, then the optimal solution will hardly be obtained from the deep integration method, and (3) Functional integration: the integration model is divided into several sub-problems that are interrelated to each other, and solved by a mechanism feedback loop output from one sub-problem as an input parameter for another sub-problem. This mechanism is done iteratively until a convergent solution condition obtained in accordance with the specified requirements.

The most developed integration planning model at the container terminal were the integration model between TBAP and QCAP, which is solved by sequential integration as by Chan and Chung [1] using deep integration by Meisel and Bierwirth [2], Imai et al. [3], Zhang et al. [4], Giallombardo et al., [5], Meisel and Bierwirth [6], Liang et al. [7], Vacca et al. [8], Shang et al. [9], Iris et al. [10], [11], Wang et al. [12], Krimi et al. [13], Zheng et al. [14], Prayogo et al., [15], Wang et al. [16], Xie et al. [[17]. The integration models of TBAP, QCAP and SQCAP as had been done by Karam and Eltawil [18] using functional integration The integration models of TBAP, QCAP and QCSP had been proposed by Park and Kim [19], Agra and Oliveira, [20], Kasm et al. [21], and solved using sequential integration, functional integration was used by Li et al.[22], Meisel and Bierwirth [23], and Türkogulları et al. [24]. The integration models between TBAP and TYAP are Tao and Lee [25], Ma et al. [26]. The integration models between QCAP and QCSP as in the model from Fu et al. [27], Fu and Diabat [28], Theodorou and Diabat [29], and Alsoufi et al. [30]. The integration models of TBAP, QCAP and TYAP as had been done by Zhen et al. [31], Prayogo et al. [32], and Liu [33] and were solved by using functional integration.

This study proposed an integration model between tactical planning decisions, namely TBAP, TYAP, QCAP, and SQCAP, and QCSP as operational level decisions in container terminal operations. The optimization model of container terminal planning integration had been solved by using bi-objective optimization with point of views from all involved parties, those are container terminal manager and shipping liner owners, which objectives to minimize the total operating costs and maximize service level to increase customer satisfaction. This bi-objective optimization for integrated planning model is solved by applying the Fuzzy Multi-Objective Programming approach.

3. Problem Statement

This study solves problem related to berth allocation for every arrival of ships on quay wharf with continuous berth layout dynamically. Determination of berthing time and position of each vessel depends on the number of assigned QCs and specific QC assignment decisions aims to arrange the sequence of tasks to be processed by each quay crane in QC scheduling problems.

In this problem, we assumed a dynamic berth allocation problem, each vessel can arrive at any time within the planning horizon, but their feasible and expected arrival times are deterministic. Each vessel can moor at any position along the quay wharf, which is called as continuous berth allocation problem. The berth is divided into several berth segments with equal section length. Likewise, the time horizon, which is divided into several time steps in equal time interval. The integrated planning is cyclical berth and yard planning without service priorities.

In this problem also considered a time-variant assignment of quay cranes, which is, an assigned quay crane in a vessel could be moved to another vessel while the previous vessel was still being serving by other quay cranes if this resulted in a more efficient solution overall. The moving time of QCs from one vessel to another is not considered. QCs can move in bi-directional following a single track with safety margin between QCs and have an identical working rate. In QC assignment and scheduling, it's also considered the safety space among QCs and non-crossing constraints, such that QCs should be ordered from left to right along quay wharf.

For TYAP, consignment strategy is applied in yard allocation to cope of traffic congestion at container yard storage area. Yard storage areas are divided into transit, import and export container yard areas. Loading and unloading activities in the yard area consist of direct and indirect transhipment, import and export operations.

4. Mathematical Formulation

4.1. Notation

In the following sections, detailed indices, model parameters and decision variables were used to develop the integration of tactical planning and operational planning model in container terminal operations. The design of the integrated container terminal planning model had adopted from the models in [21], [27] [33], [34], and [35].

4.1.1. Indices

i, j: indices of vessels, $i, j \in V, i \neq j$, V: set of vessels
b: index of berth segments, $b \in B$, B: set of berth segments
q: index of quay cranes (QCs), $q \in Q$, Q: set of quay cranes
m, n: indices of bays, $m, n \in M, m \neq n$, M_i: set of bays in each vessel i
k: index of sub-blocks, $k \in K$, K: set of sub-blocks, $K = K^T \cup K^I \cup K^E$
K^T: set of transshipment sub-blocks in container yard area
K^I: set of import sub-blocks in container yard area
K^E: set of export sub-blocks in container yard area
n: index of neighborhood sub-block pairs in container yard area, $n \in N$, N: set of all the neighbor sub-block pairs in container yard area
g: index of all blocks, which each block consists of five sub-blocks in the export and transhipment container areas, $g \in G$, G: set of all the blocks in container yard area
t: index of time step, $t \in T$, which is $T = H + E$
H: length of planning horizon expressed in number of time steps
E: the longest handling time of all vessels

4.1.2. Model parameters

L: the quay wharf length in meters
l: a berth segment length in meters
l_i: vessel length i including safety distance between two adjacent mooring vessels
$[a_i^f, b_i^f]$: range of feasible service time for vessel i; $i \in V$ and $a_i^f, b_i^f \in T |\, t \leq H$
$[a_i^e, b_i^e]$: range of expected service time for vessel i; $i \in V$ and $a_i^e, b_i^e \in T |\, t \leq H$
f: Maximum start time step difference between two vessels conducting direct transhipment activity
v_{ij}^T: number of transshipment containers from vessel i to vessel j; $i, j \in V, i \neq j$
v_i^I: number of import containers should be unloaded from vessel i; $i \in V$
v_i^E: number of export containers should be loaded from vessel i; $i \in V$
m_i: total workload for vessel i; $i \in V$ in terms of QC – time steps, required for discharging and loading activities
Q_t: number of available quay cranes at time step t
λ: interference exponent for productivity loss the QCs
q_i^{min}: minimum number of QCs that should be assigned to vessel i; $i \in V$
q_i^{max}: maximum number of QCs that can be assigned to vessel i; $i \in V$
pq: productivity of the quay crane in TEUs per hour

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l_{im}: location of bay m in vessel i; $i \in V, m \in M_i$
w_{im}: workload (in QC-time steps) to be done for bay m in vessel i; $i \in V, m \in M_i$
u_{imt}: set to 1 if a QC is operating on bay m of vessel i at time step t; $\forall i \in V,\ m \in M_i, t \in T$
R: minimum of safety distance among quay cranes assigned in a vessel
s_i^T: number of transshipment sub-blocks in container yard area must be reserved for vessel i; $i \in V$
s_i^I: number of import sub-blocks in container yard area must be reserved for vessel i; $i \in V$
s_i^E: number of export sub-blocks in container yard area must be reserved for vessel i; $i \in V$
D_{bk}^U: distance between berth segment b and sub-block k for unloading activities; $b \in B, k \in K^T \cup K^I$
D_{kb}^L: distance between sub-block k and berth segment b for loading activities; $b \in B, k \in K^T \cup K^E$
$D_{b_i b_j}^D$: distance between berth segment of vessel i (b_i) and berth segment of vessel j (b_j) for direct transshipment activities; $i, j \in V,\ i \neq j,\ b_i, b_j \in B,\ b_i \neq b_j$
C_i^1: penalty cost for waiting of berthing start time of vessel i from its expected start service time; $i \in V$
C_i^2: penalty cost for tardiness of completion time of vessel i from its expected departure time; $i \in V$
C^T: transportation cost per container-meter in container yard area
M: a sufficiently large positive number

4.1.3. Decision variables
α_i: the berthing start time of vessel i; $i \in V$
β_i: the berthing end time of vessel i; $i \in V$
τ_i^{a+}: waiting time before berthing start time of vessel i; $i \in V$
τ_i^{a-}: earliness of berthing start time of vessel i; $i \in V$
τ_i^{b+}: tardiness of berthing end time of vessel i; $i \in V$
τ_i^{b-}: earliness of berthing end time of vessel i; $i \in V$
b_i: berthing position for vessel i; $i \in V$ and $bp_i \in [1, \dots, L]$
ω_{ib}: set to 1 if the middle point of vessel length i is located at berth segment b and 0 otherwise; $i \in V, b \in B$
ξ_{ib}: set to 1, if vessel i occupies berth segment b; $i \in V, b \in B$
π_{it}: set to 1, if the start berthing time of vessel i is $t = \alpha_i$ and 0 otherwise; $i \in V, t \in T \mid t \leq H$
θ_{it}: set to 1, if vessel i is berthing in time step t; $i \in V, t \in T$
ht_i: number of time steps for handling time of vessel i; $\forall i \in V$
δ_{ij}^x: set to 1, if vessel i is completed before vessel j starts service and 0 otherwise; $i, j \in V, i \neq j$
δ_{ij}^y: set to 1, if vessel i is berthed on the left-side of vessel j along the quay wharf and 0 otherwise; $i, j \in V, i \neq j$
s_b: the start time of berth segment b is occupied; $b \in B$
e_b: the finish time of berth segment b is occupied; $b \in B$
x_{ipt}: set to 1, if there is p QCs assigned to vessel i at time step t and 0 otherwise; $i \in V, p \in [0, q_i^{min}, \dots, q_i^{max}], t \in T$
nq_{it}: number of QCs should be assigned to vessel i at time step t; $i \in V, t \in T$
ρ_t: number of assigned QCs in time step t; $t \in T$
Z_{iqt}: set to 1, if QC q is assigned to vessel i at time step t and 0 otherwise; $i \in V, q \in Q, t \in T$
L_{iqt}: set to 1, if QC q is the leftmost QC assigned to vessel i at time step t and 0 otherwise; $i \in V, q \in Q, t \in T$
R_{iqt}: set to 1, if QC q is the rightmost QC assigned to vessel i at time step t and 0 otherwise; $i \in V, q \in Q, t \in T$
y_{imqt}: set to 1, if QC q is assigned to bay m of vessel i at time step t and 0 otherwise; $i \in V, m \in M_i, q \in Q_t, t \in T$
u_{imt}: set to 1 if bay bay m of vessel $i$is fully handled at time step t and 0 otherwise; $i \in V, m \in M_i, t \in T$
φ_{ik}: set to 1, if sub block k is assigned to vessel i and 0 otherwise; $i \in V, k \in K$

γ_{ikt}: set to 1, if sub block k is assigned to vessel i at time step t and 0 otherwise; $i \in V, k \in K, t \in T$

v_{ij}^{D}: set to 1, if there is direct-transhipment activity from vessel i to vessel j and 0 otherwise; $i, j \in V, i \neq j$

v_{ij}^{I}: set to 1, if there is indirect-transhipment activity from vessel i to vessel j and 0 otherwise; $i, j \in V, i \neq j$

ψ_{jkib}: set to 1, if there is indirect transshipment activities from vessel i at berth segment b to vessel j which has reserved sub block k and 0 otherwise, $i, j \in V,\ i \neq j, k \in K^T, b \in B$

κ_{ibk}: set to 1, if vessel i at berth segment b and reserved sub block k and 0 otherwise, $i \in V$, $b \in B, k \in K$

$\varpi_{ib_ijb_j}$: set to 1, if bething position of vessel i at berth segment b_i and berthing position of vessel j at berth segment b_j and 0 otherwise; $i, j \in V,\ i \neq j,\ b_i, b_j \in B,\ b_i \neq b_j$

θ_{ib}^{L}: set to 1, if berth segment b is on the left side of vessel i and 0 otherwise; $i \in V, b \in B$

θ_{ib}^{R}: set to 1, if berth segment b is on the right side of vessel i and 0 otherwise; $i \in V$, $b \in B$

ι_{ij}^{L}: set to 1, if vessel i has berthing start time before berthing start time of vessel j and 0 otherwise; $i, j \in V, i \neq j$

ι_{ij}^{R}: set to 1, if vessel j has berthing start time before berthing start time of vessel i and maximum allowance time of difference start times f and 0 otherwise; $i, j \in V, i \neq j$

4.2. Objective functions

This integrated planning model has two objective function, those are OBJ_1, that minimize the total operational cost, consist of cost of delay in berthing start time, penalty cost of tardiness of berthing completion time, QCs operation costs and total transportation cost of import, export and transit containers in container yard areas.

$$Obj_1 = Min\ TC = \sum_{i \in V} c_i^1\, \tau_i^{a+} + c_i^2 \tau_i^{b+} + C^q \sum_{i \in V} \sum_{t \in T} nq_{it} + c^T \sum_{i \in V} \sum_{\substack{j \in V \\ j \neq i}} \sum_{b \in B} \sum_{k \in K} v_{ij}^{T}\, \frac{D_{bk}^{U} \psi_{jkib} + D_{kb}^{L} \kappa_{jbk}}{s_j^T} + c^T \sum_{i \in V} \sum_{b \in B} v_i^I\, D_{bk}^{U} \omega_{ib} + c^T \sum_{i \in V} \sum_{k \in K} \sum_{b \in B} v_i^E\, \frac{D_{kb}^{L} \kappa_{ibk}}{s_i^E} \quad (1)$$

The second objective function (Obj_2) is to find the maximize of minimum service level among all vessels.

$$Obj_2 = Max\ SL \quad (2)$$

Service level of each vessel is correlated to delay completion time of its expected service end time as presented in constraint (3)

$$SL \leq 1 - \frac{\tau_i^{b+}}{b_i^e - a_i^e} \qquad \forall i \in V \quad (3)$$

4.3. Constraints

Constraints of the tactical and operational planning model at the container terminal were divided into three sub problems, those are the constraints related to the integration models: (1) TBAP, QCAP and SQCAP; (2) TBAP and TVAP, and (3) SQCAP and QCSP which would be explained in detail as follows.

TBAP, QCAP and SQCAP related constraints:

Constraints (4) guarantee that the middle point of each vessel length is positioned at a berth segment

$$\sum_{b \in B} \omega_{ib} = 1 \qquad \forall i \in V \quad (4)$$

Constraints (5) and (6) ensure that berthing position of vessel i should be located within the range $[l \times (b-1), l \times b - 1]$ on the quay wharf.

$$l. \sum_{b \in B} (b-1). \omega_{ib} \leq b_i \qquad \forall i \in V \quad (5)$$

$$b_i \leq l. \sum_{b \in B} b. \omega_{ib} - 1 \qquad \forall i \in V \quad (6)$$

Constraint (7) ensures that for any two vessels i and j, if $\delta_{ij}^{y} = 1$, then the leftmost berthing position of vessel j is not less than the rightmost berthing position of vessel i.

$$b_i + l_i/2 \leq b - l_j/2 + M\left(1 - \delta_{ij}^{y}\right) \qquad \forall i,j \in V, i \neq j \tag{7}$$

Constraint (8) defines that for any two vessels $i$and j, if $\delta_{ij}^{x} = 1$, then the end time of vessel i must less than the start time of vessel j.

$$\beta_i \leq \alpha_j + M\left(1 - \delta_{ij}^{x}\right) \qquad \forall i,j \in V, i \neq j \tag{8}$$

Constraint (9) defines that there is no overlap for any two vessels in berth plan graph.

$$\delta_{ij}^{x} + \delta_{ji}^{x} + \delta_{ij}^{y} + \delta_{ji}^{y} \geq 1 \qquad \forall i,j \in V, i \neq j \tag{9}$$

Constraint (10) ensures that the rightmost berthing position of vessel i should be within the quay wharf.

$$b_i + l_i/2 \leq L \qquad \forall i \in V \tag{10}$$

Constraint (11) defines that each vessel is scheduled to start handling at a time step in planning horizon.

$$\textstyle\sum_{t=1}^{H} \pi_{it} = 1 \qquad \forall i \in V \tag{11}$$

Constraint (12) relates the start time-step α_i and binary variable π_{it} for each vessel i .

$$\alpha_i = \textstyle\sum_{t=1}^{H} t.\pi_{it} \qquad \forall i \in V \tag{12}$$

Constraint (13) connects the start and end time-steps of each vessel.

$$\alpha_i + \textstyle\sum_{t \in T} \theta_{it} - 1 = \beta_i \qquad \forall i \in V \tag{13}$$

Constraint (14) shows the total handling time of each vessel.

$$ht_i = \textstyle\sum_{t \in T} \theta_{it} \qquad \forall i \in V \tag{14}$$

Constraints (15) and (16) relate variables π_{it} and θ_{it}, θ_{it} and Z_{iqt}.

$$\pi_{it} \geq \theta_{it} - \theta_{it-1} \qquad \forall i \in V, t \in T | t \leq H \tag{15}$$

$$\theta_{it} \geq Z_{iqt} \qquad \forall i \in V, q \in Q_t, t \in T | t \leq H \tag{16}$$

The following four constraints (17) - (20) show the relation between $\zeta_{ib}$and b_i. and

$$b_i - l_i/2 \leq s.b - 1 + M.\theta_{ib}^{L} \qquad \forall i \in V, b \in B \tag{17}$$

$$b_i - l_i/2 \geq s.b - M\left(1 - \theta_{ib}^{L}\right) \qquad \forall i \in V, b \in B \tag{18}$$

$$b_i + l_i/2 \geq s.(b-1) - M.\theta_{ib}^{R} \qquad \forall i \in V, b \in B \tag{19}$$

$$\beta_i + l_i/2 \leq s.(b-1) - 1 + M\left(1 - \theta_{ib}^{R}\right) \qquad \forall i \in V, b \in B \tag{20}$$

Constraint (21) guarantees that if both $\theta_{ib}^{L} = 0$ and $\theta_{ib}^{R} = 0$, then $\zeta_{ib} = 1$.

$$\zeta_{ib} \geq 1 - \theta_{ib}^{L} - \theta_{ib}^{R} \qquad \forall i \in V, b \in B \tag{21}$$

Constraints (22) and (23) define start and end time berth b occupied by vessels.

$$s_b \leq \alpha_i + M(1 - \zeta_{ib}) \qquad \forall i \in V, b \in B \tag{22}$$

$$e_b \geq \beta_i - M(1 - \zeta_{ib}) \qquad \forall i \in V, b \in B \tag{23}$$

Constraints (24) guarantees that the time window of berth b are occupied by vessels within the planning horizon.

$$e_b - s_b + 1 \leq H \qquad \forall b \in B \tag{24}$$

Constraint (25) relates nq_{it} and θ_{it}

$$nq_{it} \leq M.\theta_{it} \qquad \forall i \in V, t \in T | t \leq H \tag{25}$$

Constraints (26) and (27) enforce that the number of used QCs in each time step should not exceed the available QCs in the cyclical berth planning.
Constraints (26) and (27) ensure that in cyclical berth planning, the number of QCs used in each time step does not exceed the number of available QCs in container terminal.

$$\textstyle\sum_{i \in V} nq_{it} \leq Q_t \qquad \forall t \in T | E + 1 \leq t \leq H \tag{26}$$

$$\textstyle\sum_{i \in V} nq_{it} - \sum_{i \in V} nq_{it+H} \leq Q_t \qquad \forall t \in T | t \leq E \tag{27}$$

Constraint (28) – (30) ensure vessel operation carry out to completion.

$$X_{i0t} + \textstyle\sum_{c=q_i^{min}}^{q_i^{max}} X_{ict} = 1 \qquad \forall i \in V, t \in T | t \leq H \tag{28}$$

$$\textstyle\sum_{c=q_i^{min}}^{q_i^{max}} c.X_{ict} = nq_{it} \qquad \forall i \in V, t \in T | t \leq H \tag{29}$$

$$\textstyle\sum_{t=1}^{H} \sum_{c=q_i^{min}}^{q_i^{max}} c^{\lambda} X_{ict} \geq m_i \qquad \forall i \in V \tag{30}$$

Constraint (31) ensures that each QC can only serve maximum one vessel at every time step.

$$\sum_{i\in V} Z_{iqt} \leq 1 \qquad \forall q \in Q_t, t \in T | t \leq H \tag{31}$$

Constraint (32) and (33) and (34) and (35) define L_{iqt} and R_{iqt} , respectively.

$$1 - \left(Z_{iqt} - Z_{iq-1,t}\right) \leq M\left(1 - L_{iqt}\right) \qquad \forall i \in V, q \in Q_t, t \in T | t \leq H \tag{32}$$

$$Z_{iqt} - Z_{iq-1,t} \leq ML_{iqt} \qquad \forall i \in V, q \in Q_t, t \in T | t \leq H \tag{33}$$

$$1 - \left(Z_{iqt} - Z_{iq+1,t}\right) \leq M\left(1 - R_{iqt}\right) \qquad \forall i \in V, q \in Q_t, t \in T | t \leq H \tag{34}$$

$$Z_{iqt} - Z_{iq+1,t} \leq MR_{iqt} \qquad \forall i \in V, q \in Q_t, t \in T | t \leq H \tag{35}$$

Constraints (36) – (38) define the leftmost and rightmost QCs, that are assigned to a vessel.

$$\sum_{q=1}^{Q_t} L_{iqt} = \theta_{it} \qquad \forall i \in V, t \in T | t \leq H \tag{36}$$

$$\sum_{q=1}^{Q_t} R_{iqt} = \theta_{it} \qquad \forall i \in V, t \in T | t \leq H \tag{37}$$

$$\sum_{q=1}^{Q_t} Z_{iqt} = \theta_{it} \qquad \forall i \in V, t \in T | t \leq H \tag{38}$$

Constraints (39) and (42) enforce each vessel must be served within its feasible service time window.

$$\alpha_i \geq a_i^f \qquad \forall i \in V \tag{39}$$

$$\beta_i \leq b_i^f \qquad \forall i \in V \tag{40}$$

$$a_i^e - \alpha_i = \tau_i^{a+} - \tau_i^{a-} \qquad \forall i \in V \tag{41}$$

$$\beta_i - b_i^e = \tau_i^{b+} - \tau_i^{b-} \qquad \forall i \in V \tag{42}$$

TBAP and TYAP related constraints:

Constraints (43) guarantees that each sub-block can be reserved for maximum one vessel.

$$\sum_{i\in V} \varphi_{ik} \leq 1 \qquad \forall k \in K \tag{43}$$

Constraints (44) defines number of sub-blocks are reserved for vessel i.

$$\sum_{k\in K} \varphi_{ik} = s_i \qquad \forall i \in V \tag{44}$$

Constraints (45) shows the relation among $\psi_{jkib}, \varphi_{jk}$ and ω_{ib} as follow

$$\psi_{jkib} = \varphi_{jk} + \omega_{ib} - 1 \qquad \forall\, i,j \in V, i \neq j, k \in K^T, b \in B \tag{45}$$

Constraints (46) defines the relation among κ_{jkb}, φ_{jk} and ω_{jb} as follow.

$$\kappa_{jkb} = \varphi_{jk} + \omega_{jb} - 1 \qquad \forall j \in V, k \in K^I \cup K^E \cup K^T, b \in B \tag{46}$$

If there is a transhipment activity, then this transhipment task must be carried out in either direct-transhipment or indirect-transhipment as presented in constraint (47).

$$v_{ij}^D + v_{ij}^I = A_{ij}^T \qquad \forall\, i,j \in V, i \neq j \tag{47}$$

Constraints (48) and (49) ensure that the number of sub-blocks in yard transhipment area should be reserved for the vessel whose carry out indirect-transhipment activity.

$$\sum_{k\in K^T} \varphi_{jk} \geq s_j^T - M\left(1 - \sum_{\substack{i\in V \\ i\neq j}} v_{ij}^I\right) \qquad \forall\, j \in V \tag{48}$$

$$\sum_{k\in K^T} \varphi_{jk} \leq s_j^T + M\left(1 - \sum_{\substack{i\in V \\ i\neq j}} v_{ij}^I\right) \qquad \forall\, j \in V \tag{49}$$

The following three constraints (50) – (52) guarantee that for direct or indirect transhipment activity from vessel i to vessel j are presented as follow.

$$\alpha_j \geq \alpha_i - M\left(1 - \iota_{ij}^L\right) \qquad \forall i,j \in V, i \neq j \tag{50}$$

$$\alpha_j \leq \alpha_i + f - 1 + M\left(1 - \iota_{ij}^R\right) \qquad \forall\, i,j \in V, i \neq j \tag{51}$$

$$v_{ij}^I \geq A_{ij}^T\left(2 - \iota_{ij}^L - \iota_{ij}^R\right) \qquad \forall i,j \in V, i \neq j \tag{52}$$

Constraint (53) defines the links among variables ξ_{ikt} to φ_{ik} and θ_{it} for each sub-block in yard export area.

$$\xi_{ikt} \geq \varphi_{ik} + \theta_{it} - 1 \qquad \forall i \in V, k \in K^E, t \in T \tag{53}$$

Constraint (54) shows the links between variables ξ_{jkt} to φ_{jk}, θ_{jt} and v_{ij}^I for each sub-block in yard transhipment area.

$$\xi_{jkt} \geq \varphi_{jk} + \theta_{jt} + \sum_{\substack{i\in V \\ i\neq j}} v_{ij}^I - 2 \qquad \forall\, j \in V, k \in K^T, t \in T \tag{54}$$

Constraints (55) and (56) define that at most only one sub-block in each adjacent sub-block pairs can carry out loading containers to vessels at each time step in yard export area and transhipment area.

$\sum_{k\in n}\sum_{i\in V}\xi_{ikt}+\sum_{k\in n}\sum_{i\in V}\xi_{ikt+H}\le 1 \quad \forall t\in T|t\le E, n\in N \quad (55)$

$\sum_{k\in n}\sum_{i\in V}\xi_{ikt}\le 1 \quad \forall t\in T|E+1\le t\le H, n\in N \quad (56)$

Constraints (57) and (58) ensure that at most one sub-block in each block can carry out loading containers to vessels at each time step in yard export area and transhipment area.

$\sum_{k\in g}\sum_{i\in V}\xi_{ikt}+\sum_{k\in g}\sum_{i\in V}\xi_{ikt+H}\le 1 \quad \forall t\in T|t\le E, g\in G \quad (57)$

$\sum_{k\in g}\sum_{i\in V}\xi_{ikt}\le 1 \quad \forall t\in T|E+1\le t\le H, g\in G \quad (58)$

SQCAP and QCSP related constraints:

Constraints (59) and (60) ensure that each QC can only be placed in a single bay at any time and only one QC can be placed in a bay at any time.

$\sum_{i\in V}\sum_{m\in M_i}y_{imqt}\le 1 \quad \forall q\in Q_t, t\in T \quad (59)$

$\sum_{q\in Q_t}y_{imqt}\le 1 \quad \forall i\in V, m\in M_i, t\in T \quad (60)$

Constraint (61) defines that number of operating QCs must less than the number of available QCs at any time step.

$\sum_{i\in V}\sum_{m\in M_i}\sum_{q\in Q_t}y_{imqt}\le Q_t \quad \forall t\in T \quad (61)$

Constraint (62) is a QC non-crossing constraint with the location in increasing order from left to right and minimum safety space R bays

$\sum_{i\in V}\sum_{m\in M_i}l_{im}.y_{imq+1,t}-\sum_{i\in V}\sum_{m\in M_i}l_{im}.y_{imqt}\ge R \quad \forall q\in Q_t, t\in T \quad (62)$

Constraint (63) ensures that all containers are handled in the planning horizon.

$\sum_{q\in Q_t}\sum_{t\in T}y_{imqt}= w_{im} \quad \forall i\in V, m\in M_i \quad (63)$

Constraint (64) defines the value of binary variable u_{imt} is set to 1 if all containers in bay m of vessel i are completed.

$\frac{\sum_{q\in Q_t}\sum_{h=1}^{t}y_{imqh}}{w_{im}}\ge u_{imt} \quad \forall i\in V, m\in M_i, t\in T \quad (64)$

Constraint (65) ensures that a vessel is finished served after the task for every bay of vessel i is completed.

$u_{imt}\ge \theta_{it} \quad \forall i\in V, m\in M_i, t\in T \quad (65)$

Constraint (66) links the berthing status to the service status. A vessel remains berthed until the required service is finished handled.

$M.\theta_{it}\ge \theta_{it}-1-\sum_{m=1}^{M_i}w_{im}\left(1-\sum_{p=1}^{t}\pi_{ip}\right)+\sum_{m=1}^{M_i}w_{im}-\sum_{m=1}^{M_i}\sum_{h=1}^{t-1}u_{imp} \quad \forall i\in V, t\in T \quad (66)$

Constraint (67) enforces that before the vessel starts berthing there are no quay cranes operating.

$u_{imt}\le \sum_{p=1}^{t}\pi_{ip} \quad \forall i\in V, m\le M_i, t\in T \quad (67)$

Constraint (68) guarantees that no quay crane will be assigned to vessel that is not moored

$\sum_{m=1}^{M_i}u_{imt}\le M.\theta_{it} \quad \forall i\in V, t\in T \quad (68)$

Constraint (69) ensures that all containers are finished handled

$\sum_{t\in T}u_{imt}=w_{im} \quad \forall i\in V, m\le M_i \quad (69)$

Constraint (70) ensures that the position between the quay cranes meets the safety clearance distance requirements

$\sum_{a=m}^{m+R}u_{iat}\le 1 \quad \forall i\in V, m\le M_i-R, t\in T \quad (70)$

Constraint (71) ensures that the number of QCs operating on vessel i does not exceed the number of QCs assigned to vessel i as resulting in QCAP.

$\sum_{m=1}^{M_i}u_{imt}\le nq_{it} \quad \forall i\in V, t\in T \quad (71)$

Each decision variable domain is stated in (72) – (81).

$b_i,\alpha_i,\beta_i,\tau_i^{a+},\tau_i^{a-},\tau_i^{b+},\tau_i^{b-},s_b,e_b,\rho_t\ge 0\ \&\ integer \quad \forall i\in V, b\in B, t\in T \quad (72)$

$\omega_{ib},\varphi_{ik},\xi_{ikt},\zeta_{ib}\in\{0,1\} \quad \forall\, i\in V, b\in B, k\in K^I\cup K^E\cup K^T, t\in T \quad (73)$

$\pi_{it},\theta_{it}\in\{0,1\} \quad \forall\, i\in V, t\in T \quad (74)$

$\delta_{ij}^x,\delta_{ij}^y,v_{ij}^D,v_{ij}^I\in\{0,1\} \quad \forall\, i,j\in V, i\ne j \quad (75)$

$\psi_{jkib}\in\{0,1\} \quad \forall\, i,j\in V, i\ne j, k\in K^T, b\in B \quad (76)$

$\kappa_{jkb}\in\{0,1\} \quad \forall j\in V, k\in K^I\cup K^E\cup K^T, b\in B \quad (77)$

$\varpi_{ib_ijb_j} \in \{0,1\}$ $\quad \forall i,j \in V, i \neq j, b_i, b_j \in B, b_i \neq b_j$ (78)

$\theta_{ib}^L, \theta_{ib}^R, \iota_{ij}^L, \iota_{ij}^R \in \{0,1\}$ $\quad \forall i,j \in V, i \neq j, b \in B$ (79)

$u_{imt} \in \{0,1\}$ $\quad \forall i \in V, m \in M_i, t \in T$ (80)

$y_{imqt}\{0,1\}$ $\quad \forall i \in V, m \in M_i, \mathrm{q} \in Q_t, t \in T$ (81)

5. Solution method

In this study, the tactical and operational decisions of integration model at the container terminal consists of integration models for tactical level planning, namely: TBAP, TYAP, QCAP, and SQCAP, and QCSP at the operational level planning. The integrated planning models for container terminal were solved using a combination of functional integration with feedback loop structure and deep integration methods. Functional integration method had been used to solve the integration model of TBAP, QCAP and SQCAP, as well as the integration model between TBAP and TYAP. While deep integration was used to solve the integration model between SQCAP and QCSP. The proposed procedure for solving the integration model of tactical and operational planning at container terminal is shown in Figure 1. The solution method for bi-objective optimization model uses a fuzzy multi-objective programming approach to obtain a tradeoff between the interests of the container terminal manager to achieve total operational cost efficiency and the interests of the shipping liner owners to maximize service level in order to improve customer satisfaction.

The following model is a fuzzy multi objective programming that was used to solve the integrated planning model at the container terminal [36].

$$Max. \lambda \quad (82)$$

S.t: $\mu_1 \leq \lambda$ (83)

$$\mu_2 \leq \lambda \quad (84)$$

$$\mu_1 = \frac{f_1^- - f_1}{f_1^- - f_1^+} \quad (85)$$

$$\mu_2 = \frac{f_2 - f_2^-}{f_2^+ - f_2^-} \quad (86)$$

$$0 \leq \lambda \leq 1 \quad (87)$$

Where: λ: fuzzy membership function

μ_1: Membership function of objective function minimization-mode Obj_1

μ_2: Membership function of objective function maximization-mode Obj_2

f_1: Objective function value of Obj_1

f_2: Objective function value of Obj_2

f_1^+: the best value of objective function Obj_1

f_1^-: the worst value of objective function Obj_1

f_2^+: the best value of objective function Obj_2

f_2^-: the worst value of objective function Obj_2

6. Numerical Experiments

The proposed bi-objective optimization model of integrated planning in container terminal was applied to 12 cases which the model parameters are combination of number of calling vessels, length of quay wharf, number of available QCs, number of sub-blocks in yard area as shown in Table 1. Quay wharf is divided into intervals of berth segment with a length of 50 meters. Planning time horizon is divided into time steps for 4 hours and carried out of periodic planning in 1 week. Each sub-block has length of 50 meters and contains of 240 containers. For each case, we generated randomly 10 datasets. For each instance, three vessel types consist of Feeder vessels, Medium vessels and Jumbo vessels are generated with composition of 90%, 30% and 10%, respectively. The vessel length and the number of containers for each vessel type, as well as the composition of the number of transit, import and export containers; and number of bays in each vessel follow the distribution of model parameters in [33] and [27]. Python programming was applied to Gurobi optimization to solve proposed bi-objective optimization model of integrated planning in container terminal and using the Fuzzy Multi Objective Programming approach.

Table 1. shows the average of minimum total operational costs and maximum service levels for each case that consist of 10 instances.

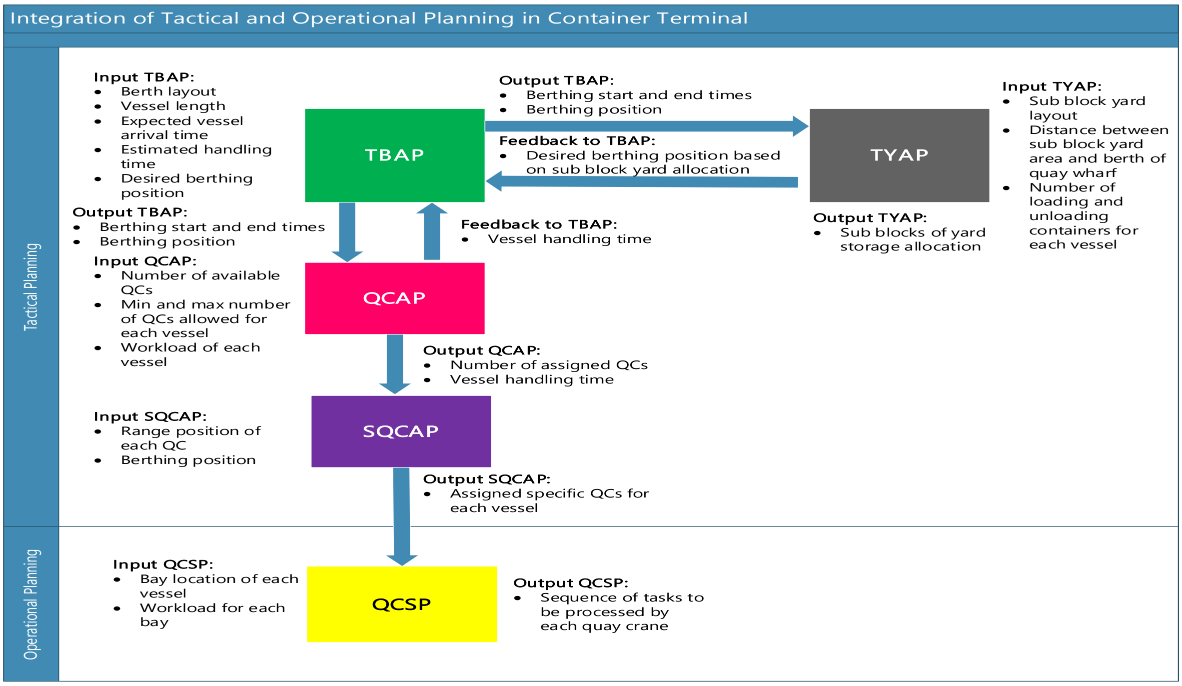

Figure 1. Solution method for integrated planning model in container terminal operations.

Table 1. Parameters and optimal solutions for each case.

Case	V [a]	L [b]	QC [c]	K [d]	H [e]	SL [f]	TC [g]	Run-time (s)
C6-600-80	6	600	8	80	42	100.00%	52.35	0.66
C9-600-80	9	600	8	80	42	97.93%	245.29	0.74
C12-600-80	12	600	8	80	42	93.03%	523.64	2.57
C15-1000-120	15	1000	16	120	42	97.83%	358.12	3.15
C18-1000-120	18	1000	16	120	42	92.69%	477.06	6.74
C21-1000-120	21	1000	16	120	42	95.57%	561.49	8.03
C24-1400-160	24	1400	24	160	42	96.13%	285.30	12.72
C27-1400-160	27	1400	24	160	42	94.07%	829.74	33.12
C30-1400-160	30	1400	24	160	42	90.78%	1175.89	68.68
C33-1800-200	33	1800	30	200	42	95.69%	742.54	84.48
C36-1800-200	36	1800	30	200	42	94.92%	909.93	97.57
C40-1800-200	40	1800	30	200	42	91.72%	1510.49	176.10

a. V: number of vessels
b. L: length of quay wharf in meters
c. QC: number of available quay cranes
d. K: number of sub-blocks in yard area
e. H: number of planning horizon in time step.
f. SL: average of maximize service level
g. TC: average of minimize total service cost in container terminal

Based on the optimal solutions in Table 1, shown that the increasing in number of vessel arrivals at the case of the same quay wharf length, the number of QCs availability and the number of sub-blocks in yard area have an effect on increasing total costs and decreasing service level. Runtime is proportionally increasing with respect to the number of calling vessels, berths segments, and sub-blocks in yard storage area.

7. Conclusions and Further Research Direction

This study has developed a bi-objective optimization integration model of tactical and operational planning in container terminal operations that consist of tactical berth allocation problem, specific quay crane assignment problem, tactical yard allocation planning and quay crane scheduling problem. The optimization model has two objective functions, namely minimization of the total operational cost and maximization of the overall service level. The integration model had solved using the Fuzzy Multi Objective Programming approach. As a solution method, we had developed solution method by using functional integration with feedback loop structure for solving the integration model of TBAP, QCAP and SQCAP and integration of TBAP and TYAP. The deep integration was used to solve the integration of QCAP and QCSP using Python Programming.

For further research, it might be considered uncertainty environment in container terminal operational planning such as vessel arrival times, handling times of each vessel and productivity rate of quay cranes. In addition, for solving the integration model effectively, the development of metaheuristic algorithms could be considered to solve large scale problems.

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References

[1] Ma H, Chan FT, Chung S. A fast approach for the integrated berth allocation and quay crane assignment problem. *Proc Inst Mech Eng B J Eng Manuf*. SAGE Publications; 2014 Aug 14;229(11):2076–87. doi.org/10.1177/0954405414544555

[2] Meisel F, Bierwirth C. Integration of Berth Allocation and Crane Assignment to Improve the Resource Utilization at a Seaport Container Terminal. *Oper. Res. Proc. 2005*. Springer Berlin Heidelberg; 105–10. doi.org/10.1007/3-540-32539-5_17.

[3] Imai A, Chen HC, Nishimura E, Papadimitriou S. The simultaneous berth and quay crane allocation problem. *Transp. Res. Part E. Logist. Transp. Rev*. Elsevier BV; 2008 Sep;44(5):900–20. doi.org/10.1016/j.tre.2007.03.003

[4] Zhang C, Zheng L, Zhang Z, Shi L, Armstrong AJ. The allocation of berths and quay cranes by using a sub-gradient optimization technique. *Comput. Ind. Eng.* Elsevier BV; 2010 Feb;58(1):40–50. doi.org/10.1016/j.cie.2009.08.002.

[5] Giallombardo G, Moccia L, Salani M, Vacca I. Modeling and solving the Tactical Berth Allocation Problem. *Transp. Res. Part B Methodol.* Elsevier BV; 2010 Feb;44(2):232–45. doi.org/10.1016/j.trb.2009.07.003.

[6] Meisel F, Bierwirth C. Heuristics for the integration of crane productivity in the berth allocation problem. *Transp. Res. Part E. Logist. Transp. Rev*. Elsevier BV; 2009 Jan;45(1):196–209. doi.org/10.1016/j.tre.2008.03.001.

[7] Liang C, Huang Y, Yang Y. A quay crane dynamic scheduling problem by hybrid evolutionary algorithm for berth allocation planning. *Comput. Ind. Eng.* Elsevier BV; 2009 Apr;56(3):1021–8. doi.org/10.1016/j.cie.2008.09.024

[8] Vacca I, Salani M, Bierlaire M. An Exact Algorithm for the Integrated Planning of Berth Allocation and Quay Crane Assignment. *Transp. Sci.* Institute for Operations Research and the Management Sciences (INFORMS); 2013 May;47(2):148–61. doi.org/10.1287/trsc.1120.0428

[9] Shang XT, Cao JX, Ren J. A robust optimization approach to the integrated berth allocation and quay crane assignment problem. *Transp. Res. Part E. Logist. Transp. Rev*. Elsevier BV; 2016

Oct;94:44–65. doi.org/10.1016/j.tre.2016.06.011
[10] Iris Ç, Pacino D, Ropke S, Larsen A. Integrated Berth Allocation and Quay Crane Assignment Problem: Set partitioning models and computational results. *Transp. Res. Part E. Logist. Transp. Rev*. Elsevier BV; 2015 Sep;81:75–97. doi.org/10.1016/j.tre.2015.06.008
[11] Iris Ç, Pacino D, Ropke S. Improved formulations and an Adaptive Large Neighborhood Search heuristic for the integrated berth allocation and quay crane assignment problem. *Transp. Res. Part E. Logist. Transp. Rev*. Elsevier BV; 2017 Sep;105:123–47. doi.org/10.1016/j.tre.2017.06.013
[12] Wang T, Wang X, Meng Q. Joint berth allocation and quay crane assignment under different carbon taxation policies. *Transp. Res. Part B Methodol*. Elsevier BV; 2018 Nov;117:18–36. doi.org/10.1016/j.trb.2018.08.012
[13] Krimi I, Benmansour R, el Cadi AA, Duvivier D, Elhachemi N, Deshayes L, et al. The integrated multi-quay Berth Allocation and Crane Assignment Problem: Formulation and case study. 2018 *7th Int. Conf. Ind. Technol. Manag.* (ICITM). IEEE; 2018 Mar; doi.org/10.1109/icitm.2018.8333938
[14] Zheng F, Li Y, Chu F, Liu M, Xu Y. Integrated berth allocation and quay crane assignment with maintenance activities. *Int. J. Prod. Res.* Informa UK Limited; 2018 Nov;57(11):3478–503. doi.org/10.1080/00207543.2018.1539265
[15] Prayogo DN, Hidayatno A, Komarudin. Developing a robust optimization model for seaside operations in container terminal under uncertainty environment. *IOP Conf. Ser. Earth Environ Sci.* IOP Publishing; 2019 Feb 20;235:012067. doi.org/10.1088/1755-1315/235/1/012067.
[16] Hu H, Li M, Wang T. Berth allocation and quay crane-yard truck assignment considering carbon emissions in port area. *Int. J. Shipp. Transp. Logist.* Inderscience Publishers; 2019;11(2/3):216. doi.org/10.1504/ijstl.2019.10020672..
[17] Xie F, Wu T, Zhang C. A Branch-and-Price Algorithm for the Integrated Berth Allocation and Quay Crane Assignment Problem. *Transp. Sci.* Institute for Operations Research and the Management Sciences (INFORMS); 2019 Sep;53(5):1427–54. doi.org/10.1287/trsc.2019.0894.
[18] Karam A, Eltawil AB. Functional integration approach for the berth allocation, quay crane assignment and specific quay crane assignment problems. *Comput. Ind. Eng.* Elsevier BV; 2016 Dec;102:458–66. doi.org/10.1016/j.cie.2016.04.006.
[19] Park Y-M, Kim KH. A scheduling method for Berth and Quay cranes. *Contain. Termin. Autom. Transp. Syst. Logist. Control Issues Quant. Decis. Support*. Springer-Verlag; 159–81. doi.org/10.1007/3-540-26686-0_7
[20] Agra A, Oliveira M. MIP approaches for the integrated berth allocation and quay crane assignment and scheduling problem. *Eur. J. Oper. Res.* Elsevier BV; 2018 Jan;264(1):138–48. Available from: http://dx.doi.org/10.1016/j.ejor.2017.05.040.
[21] Abou Kasm O, Diabat A, Cheng TCE. The integrated berth allocation, quay crane assignment and scheduling problem: mathematical formulations and a case study. *Ann. Oper. Res*. Springer Science and Business Media LLC; 2019 Jan 2;291(1-2):435–61. doi.org/10.1007/s10479-018-3125-3
[22] Li F, Sheu J-B, Gao Z-Y. Solving the Continuous Berth Allocation and Specific Quay Crane Assignment Problems with Quay Crane Coverage Range. *Transp. Sci.* Institute for Operations Research and the Management Sciences (INFORMS); 2015 Nov;49(4):968–89. doi.org/10.1287/trsc.2015.0619
[23] Meisel F, Bierwirth C. A Framework for Integrated Berth Allocation and Crane Operations Planning in Seaport Container Terminals. *Transp. Sci*. Institute for Operations Research and the Management Sciences (INFORMS); 2013 May;47(2):131–47. doi.org/10.1287/trsc.1120.0419
[24] Türkoğulları YB, Taşkın ZC, Aras N, Altınel İK. Optimal berth allocation, time-variant quay crane assignment and scheduling with crane setups in container terminals. *Eur. J. Oper. Res.* Elsevier BV; 2016 Nov;254(3):985–1001. doi.org/10.1016/j.ejor.2016.04.022
[25] Tao Y, Lee C-Y. Joint planning of berth and yard allocation in transshipment terminals using

multi-cluster stacking strategy. *Transp. Res. Part E. Logist. Transp. Rev*. Elsevier BV; 2015 Nov;83:34–50. doi.org/10.1016/j.tre.2015.08.005

[26] Ma HL, Chung SH, Chan HK, Cui L. An integrated model for berth and yard planning in container terminals with multi-continuous berth layout. *Ann. Oper. Res.* Springer Science and Business Media LLC; 2017 Jul 13;273(1-2):409–31. doi.org/10.1007/s10479-017-2577-1.

[27] Fu Y-M, Diabat A, Tsai I-T. A multi-vessel quay crane assignment and scheduling problem: Formulation and heuristic solution approach. *Expert Syst. Appl.* Elsevier BV; 2014 Nov;41(15):6959–65. doi.org/10.1016/j.eswa.2014.05.002

[28] Fu Y-M, Diabat A. A Lagrangian relaxation approach for solving the integrated quay crane assignment and scheduling problem. *Appl. Math. Model.* Elsevier BV; 2015 Feb;39(3-4):1194–201. doi.org/10.1016/j.apm.2014.07.006.

[29] Theodorou E, Diabat A. A joint quay crane assignment and scheduling problem: formulation, solution algorithm and computational results. *Optim. Lett.* Springer Science and Business Media LLC; 2014 Sep 20;9(4):799–817. doi.org/10.1007/s11590-014-0787-x.

[30] Alsoufi G, Yang X, Salhi A. Combined quay crane assignment and quay crane scheduling with crane inter-vessel movement and non-interference constraints. *J. Oper. Res. Soc.* Informa UK Limited; 2018 Jan 17;69(3):372–83. doi.org/10.1057/s41274-017-0226-3.

[31] Zhen L, Chew EP, Lee LH. An Integrated Model for Berth Template and Yard Template Planning in Transshipment Hubs. *Transp. Sci.* Institute for Operations Research and the Management Sciences (INFORMS); 2011 Nov;45(4):483–504. doi.org/10.1287/trsc.1100.0364.

[32] Prayogo DN, Hidayatno A, Komarudin. Development of integrated tactical level planning in container terminal. *Int. Conf. Ind. Eng. Eng. Manag.* IEEE; 2017 Dec; doi.org/10.1109/ieem.2017.8290045

[33] Liu M, Lee C-Y, Zhang Z, Chu C. Bi-objective optimization for the container terminal integrated planning. *Transp. Res. Part B Methodol*. Elsevier BV; 2016 Nov;93:720–49. doi.org/10.1016/j.trb.2016.05.012

[34] Wang K, Zhen L, Wang S, Laporte G. Column Generation for the Integrated Berth Allocation, Quay Crane Assignment, and Yard Assignment Problem. *Transp. Sci*. Institute for Operations Research and the Management Sciences (INFORMS); 2018 Aug;52(4):812–34. doi.org/10.1287/trsc.2018.0822

[35] Liu C. Iterative heuristic for simultaneous allocations of berths, quay cranes, and yards under practical situations. *Transp. Res. Part E Logist. Transp. Rev.* Elsevier BV; 2020 Jan;133:101814. doi.org/10.1016/j.tre.2019.11.008.

[36] Mohamed RH. The relationship between goal programming and fuzzy programming. *Fuzzy Sets Syst.* Elsevier BV; 1997 Jul;89(2):215–22. doi.org/10.1016/s0165-0114(96)00100-5