Developing a robust optimization model for seaside operations in container terminal under uncertainty environment

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Abstract. This paper discusses the robust optimization model development to integrate tactical decisions on seaside operations in container terminal, that is consist of Tactical Berth Allocation Problem and Specific Quay Crane Assignment Problem by considering the uncertainty of vessel arrival time and the number of containers to be discharged and loaded into the arrived vessels, which also affects the uncertainty of handling time required. The development of optimization model considers container terminal managers and shipping liner owners viewpoints. Thus, this optimization model has two objective functions, i.e. minimizing total costs of seaside operations and maximizing service levels for shipping liners. Since these two tactical decisions for seaside operations under uncertainty conditions are inter-related each other, the robust optimization model is solved by using exact method, which is applied to a numerical example in the small-scale problem for testing the effectiveness of the proposed method.

1. Introduction
Global containerized trade has increased rapidly at a rate of 3.1% in 2016, with a volume reaching 140 million TEUs. Based on the projected developments in world trade in 2017, according to UNCTAD in the Review of Maritime Transport, the estimated growth rate of containerized trade volume is 4.5% p.a. [1]. In line with the increasing of global containerized trade requirements, there has also been an increase in competition and the performance of container terminals. Port managers continually improve resources utilization to achieve operational cost efficiency while simultaneously meeting the service schedule requested by shipping liners.

The main container terminal area consists of seaside and landside. Resources on the seaside include berth and quay cranes, which require very high investment costs, maintenance costs and operational costs. In order to be able to survive and winning the global competition, terminal operators should develop appropriate and reliable berth management [2-5]. Berth management in seaside operations involves the decision of a tactical berth allocation planning and assignment of quay cranes [6]. The integrated planning between tactical berth allocation planning and quay crane assignment needs to be developed to obtain the optimal decisions because these both decisions on tactical level planning are interrelated. The berthing position and berthing time decisions of calling vessels in Tactical Berth Allocation Planning would be affected by the estimated vessels arrival times, and they also depend on the number of assigned quay cranes to serve each vessel. While the planning decision of the number of quay cranes assigned to each vessel, as a result of quay crane assignment decisions, depends on the number of containers to be discharged and loaded from the storage container yard and decision of vessels berthing positions [7, 8, 9].

Several factors that influence the integrated planning decisions in a container terminal are often found in uncertainty environment. These uncertainty conditions can occur in the vessel arrival at the container terminal, changes in the number of containers that must be discharging and loading from and to the vessels, the performance of quay cranes that affect their productivity, readiness of facilities and material handling equipment in the container terminal as well as external factors such as weather conditions and
so on. These uncertainty conditions can affect the performance of the container terminal in serving shipping liners [10, 11].

One of solution alternatives to overcome uncertainty conditions in decision making of integrated planning at container terminals is developing the optimal decisions for Tactical Allocation Planning and Quay Crane Assignment planning, which are robust against uncertainty factors. Several studies have developed robust optimization models for Berth Allocation Scheduling and Quay Crane Assignment decisions as in [12-15]. However, so far there are still few papers which discuss about development of robust optimization models in integrated planning involving Tactical Berth Allocation Planning decisions and Specific Quay Crane Assignment Planning that balancing the interests of container terminal managers and shipping liner owners. This paper discusses the development of robust optimization models for seaside operations in container terminals under uncertainty by considering viewpoints from terminal managers and shipping liner owners. The model development will include uncertainty factors at the vessel’s arrival times and changes in the number of containers that will have an impact on uncertainty in handling times.

Furthermore, the organization of this paper will be arranged as follows. Section 2 contains the results of related work to the development of robust optimization models in container terminal operations. Problem definitions and model development are discussed in Sections 3 and Section 4. This is followed by Section 5 which discusses the application of the model development and its results. The final section contains conclusions and further research opportunities.

2. Related Work

Based on the planning horizon, the problem of maritime transportation planning can be classified into strategic, tactical and operational planning [16, 17]. Berth Allocation Planning and designing yard template for temporary container stacking/storage included in tactical decisions. Furthermore, the scheduling of a tug boat when the vessel is berthing at the wharf, quay cranes operations for container loading and unloading from and to vessels, internal trucks to transport containers from and to the quay and yard area, scheduling yard cranes for stacking and taking containers from and to storage yards are operational decisions. Several scholars who have studied the seaside operations in container terminals, consisting of Strategic and Tactical Allocation Planning, Berth Allocation Scheduling and Quay Crane Assignment Planning, are Imai et al. [17, 18, 19].

Several studies have integrated Berth Allocation Planning and Quay Crane Assignment Problems, such as by applying Exact Algorithm [8], using Set partitioning models to obtain integrated planning decisions [20]. The use of Heuristics for integration of crane productivity in the berth allocation problem [21]. Whereas a study applied an evolutionary approach to a combined mixed programming model of seaside operations in container ports [22]. Iris et al. have proposed using an Adaptive Large Neighborhood Search heuristic for the integrated allocation and quay crane assignment problems [23]. An integrated Tactical Berth Allocation Planning decision, Specific Quay Crane Assignment and Yard Template Planning as an integrated tactical level planning in the terminal container [24].

The application of a bi-objective optimization model in container terminal operations problems has been discussed by He, with the aim for obtaining trade-offs between time-saving and energy-saving [25]. In addition, the bi-objective optimization model for the container terminal to have a turnaround time to meet the timetables from shipping liners, and to minimize the total distance in order to achieve terminal operational cost efficiency [26].

Several papers discuss the development of optimization models under uncertainty conditions in decision making at container terminals [12-15], by implementing the Robust Optimization Model which was proposed for the first time [27]. The comparison of the berth planning results between non-robust and robust is shown in figure 1.
In the following section, we will discuss the development of robust optimization models for individual operations in terminal containers under uncertainty environment.

3. Model Development

Development of a robust optimization model for seaside operations in terminal containers under uncertainty environment considering the balanced between terminal managers' interests and shipping liner owners. Therefore, a robust optimization model has two aims, (i) minimizing the expectations of total operational costs from viewpoint of terminal managers and (ii) to maximize the expected service levels for shipping liner owners. Uncertainty factors considered in decision making of integrated planning are vessel arrivals times and handling times, due to changes in the number of served containers for each vessel. The seaside operations include Tactical Berth Allocation planning and Specific Quay Crane Assignment planning by implementing continuous berth allocation and quay crane assignment in time variant. The following is discussed the development of a robust optimization model for seaside operations in seaport.

Indices:
\[ i \in V \]: set of all calling vessels to be served.
\[ k \in QC \]: set of available quay cranes in the port.
\[ t \in TP \]: set of time period in planning horizon
\[ s \in S \]: set of discrete scenarios based on the histories data

Model Parameters:
\[ l_i \]: the length of vessel \( i \) including the safe distance between the adjective vessels.
\[ NC_i \]: number of containers should be discharged and loading from and into vessel \( i \).
\[ a_i \]: the estimated arrival time of vessel \( i \) into a seaport.
\[ a_{is} \]: the actual arrival time of vessel \( i \) under scenario \( s \).
\[ bp_i \]: the desired berthing position of vessel \( i \).
\[ q_{min_i} \]: the minimum number of quay required simultaneously to serve vessel \( i \).
\[ q_{max_i} \]: the maximum number of quay crane required simultaneously to serve vessel \( i \).
\[ q_{ik} \]: is set to 1 if quay crane \( k \) is feasible to serve vessel \( i \), and set to 0 otherwise.
\[ d_i \]: the expected depart time of vessel \( i \).
\[ \alpha \]: interference exponent.
\[ \beta \]: berth deviation factor.
\[ M \]: a significant large positive number.
\[ Cd_i \]: the cost of berthing delay time of vessel \( i \) at a seaport.
\[ Cl_i \]: the cost of departure delay time of vessel \( i \) at a seaport.
\[ Cb_i \]: the cost of berthing delay position deviation from desired position of vessel \( i \).
\[ ps \]: the probability value of discrete scenario \( s \) where: \( \sum_{s \in S} p_s = 1 \)
\[ bp_i \]: berthing position of vessel \( i \) at a seaport.
\[ bt_i \]: berthing time of vessel \( i \) at a seaport.
\[ e_i \]: ending time of handling vessel \( i \).
\[ m_i = \left[ \frac{N}{p} \right] \]: quay crane productivity in TEUs per steps
\[ ht_i \]: handling time of vessel \( i \).
\[ h_{ts} \]: handling time of vessel \( i \) under scenario \( s \).
\[ q_{i0} \in \{0,1\} \]: decision to serve vessel \( i \) at time period \( t \).
\[ nq_{i0} \]: number of quay cranes assigned to vessel \( i \) at time period \( t \).
\[ st_{i0} \]: decision to set up quay crane for serving vessel \( i \) at time period \( t \).
\( u_{il} \in \{0,1\} \): set to 1 if there is changing the number of quay cranes assigned to vessel \( i \) between time period \( t \) and \( t+1 \).

- \( dh_{is} \): handling time deviations from the estimated time of vessel \( i \) under scenario \( s \).
- \( bt_{is} \): berthing time of vessel \( i \) under scenario \( s \).
- \( bp_{is} \): berthing position of vessel \( i \) under scenario \( s \).
- \( db_{i} \): berthing position deviation from the desired position of vessel \( i \).
- \( \nu_{i} \): deviation of berthing position from the desired position of vessel \( i \).
- \( \Theta_{s} \): deviation between total cost of all vessel under scenario \( s \) and its expected total cost.
- \( \beta_{s} \): satisfaction level of vessel \( i \) under scenario \( s \).
- \( \beta_{s} \): satisfaction level of all calling vessel under scenario \( s \).

\[

t_{i}^{X} \in \{0,1\} \): set to 1 if berthing position of vessel \( i \) is behind the berthing position of vessel \( j \).
\]

\[

t_{i}^{Y} \in \{0,1\} : \text{set to 1 if vessel } i \text{ is handling before vessel } j.
\]

\[

t_{i}^{X} \in \{0,1\} : \text{set to 1 if berthing position of vessel } i \text{ is behind the berthing position of vessel } j \text{ under scenarios}
\]

\[

t_{i}^{Y} \in \{0,1\} : \text{set to 1 if vessel } i \text{ is handling before vessel } j \text{ under scenario } s.
\]

- \( z_{i}^{+} \): positive deviation of berthing position of vessel \( i \) under scenario \( s \).
- \( z_{i}^{-} \): negative deviation of berthing position of vessel \( i \) under scenario \( s \).
- \( y_{i}^{+} \): positive deviation of berthing time of vessel \( i \) under scenario \( s \).
- \( y_{i}^{-} \): negative deviation of berthing time of vessel \( i \) under scenario \( s \).
- \( \mu_{s} \): delay time of depart time of vessel \( i \) under scenario \( s \).
- \( q_{k} \in \{0,1\} \) set to 1 if quay crane \( k \) assigned to vessel \( i \) at time period \( t \).

**Objective functions:**
The development of a robust optimization model for integrated planning in seaside operations at the container terminal takes into consideration the interests of the container terminal manager and the shipping liner owner. The first objective function is operational cost efficiency for the container terminal manager and the second objective function is to maximize the service level for the shipping liner owner. These two objective functions are stated as follows:

\[
\begin{align*}
M_{1} & = \sum_{s \in S} \left[ P \left( T \right) + \lambda \left[ I - \sum_{c} P \right] + 2\nu_{s} \right] + \omega \sum_{K} P \ u_{k} \right] \right) ; \quad \forall s \in S \\
M_{2} & = \sum_{s \in S} \left[ P \left( \beta - \lambda \left( \beta - \sum_{c} P \right) + 2\nu_{s} \right) \right] ; \quad \forall s \in S
\end{align*}
\]

The constraints to be considered are given as follows:

\[
\begin{align*}
T_{i} & \geq \sum_{s} C \ y_{i}^{+} + C \ u_{i}^{+} + C \ i\left( bp_{i} - b_{i}^{+} + 2\nu_{s} \right) ; \quad \forall s \in S \\
b_{i} + u_{i} & \leq y_{i}^{+} ; \quad \forall i \in V, \ s \in S \\
a_{i} & = u_{i} + d_{i} ; \quad \forall i \in V, \ s \in S \\
h_{i} & = h_{i} + d_{i} ; \quad \forall i \in V, \ s \in S \\
a_{i} & \leq m_{i} n_{i} ; \quad \forall i \in V, \ s \in S \\
b_{i} & \geq m_{i} n_{i} ; \quad \forall s \in V \\
\beta_{s} & \geq \sum_{s \in S} P \ - \beta_{s} ; \quad \forall s \in S \\
\beta_{s} & \leq \beta_{s} ; \quad \forall i \in V, \ s \in S
\end{align*}
\]

\[
\begin{align*}
\beta_{s} & = 1 - \frac{T_{i}}{h_{i}} ; \quad \forall i \in V, \ s \in S \\
T_{i} & \geq b_{i}^{+} + h_{i} - d_{i} ; \quad \forall i \in V, \ s \in S \\
T_{i} & \geq d_{i} - b_{i}^{+} - h_{i} ; \quad \forall i \in V, \ s \in S
\end{align*}
\]
\( b_L + h_L \uparrow |T| \leq u_i \); \( \forall i \in \mathcal{V}, s \in \mathcal{S} \) 
(11)

\( u_i \leq b_L \leq |T| \); \( \forall i \in \mathcal{V} \) 
(12)

\( u_i \leq b_L \uparrow |T| + 1 \); \( \forall i \in \mathcal{V} \) 
(13)

\( 0 \leq b_i + l_i \leq L \); \( \forall i \in \mathcal{V} \) 
(14)

\( b_i \leq b_i \uparrow \leq d_i \); \( \forall i \in \mathcal{V} \) 
(15)

\( b_i \uparrow - b_i \leq d_i \); \( \forall i \in \mathcal{V} \) 
(16)

\( b_L + l_i \leq L \); \( \forall i \in \mathcal{V}, s \in \mathcal{S} \) 
(17)

\( e_i \leq b_j + M(1 - z_i^j) \); \( \forall i, j \in \mathcal{V}, i \neq j \) 
(18)

\( b_i \leq h_j \leq b_j + M(1 - z_i^j) \); \( \forall i, j \in \mathcal{V}, i \neq j \) 
(19)

\( b_i \leq t_i \leq b_j + M(1 - z_i^j) \); \( \forall i \in \mathcal{V}, i \neq j \) 
(20)

\( z_i^+ + z_i^- + z_i^\uparrow + z_i^\downarrow \geq 1 \); \( \forall i \in \mathcal{V}, i \neq j \) 
(21)

\( b_i + h_i + y_i^j - y_i^\uparrow \leq b_j + y_i^j - y_i^\uparrow + M + (1 - z_i^j) \); \( \forall i, j \in \mathcal{V}, i \neq j, s \in \mathcal{S} \) 
(22)

\( b_i + l_i + x_i^\uparrow + x_i^\downarrow - x_i^\uparrow - x_i^\downarrow \leq b_j + x_i^\uparrow - x_i^\downarrow + M + (1 - z_i^j) \); \( \forall i, j \in \mathcal{V}, i \neq j, s \in \mathcal{S} \) 
(23)

\( 0 \leq b_i + l_i + x_i^\uparrow - x_i^\downarrow \leq L \); \( \forall i \in \mathcal{V}, s \in \mathcal{S} \) 
(24)

\( n_{\text{tot}} = \sum_{i \in \mathcal{Q}} q_i \); \( \forall i \in \mathcal{V}, k \in \mathcal{Q}, t \in T \) 
(25)

\( \Sigma_{\tau \in T} n_{q_0} = \text{m}_i \); \( \forall i \in \mathcal{V} \) 
(26)

\( \text{m}_i \leq M \cdot q_0 \); \( \forall i \in \mathcal{V}, t \in T \) 
(27)

\( \Sigma_{\tau \in T} q_i = e_i - b_i \); \( \forall i \in \mathcal{V} \) 
(28)

\( (1 + \beta)q_i \leq e_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(29)

\( t \cdot q_i + (1 - (1 - q_i)) \geq b_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(30)

\( \Sigma_{k \in \mathcal{Q}, q_i \neq 1} \Sigma_{\tau \in T} \Delta t_i^k \cdot q_i \geq (1 + \beta) \cdot \text{m}_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(31)

\( \Sigma_{\tau \in T} q_i \leq 1 \); \( \forall k \in \mathcal{Q}, t \in T \) 
(32)

\( q_i \geq q_0 + \beta \); \( \forall i \in \mathcal{K}, k \in \{1 \mid q_i = 1\}, t \in T \) 
(33)

\( q_i \leq q_0 \); \( \forall i \in \mathcal{V}, k \in \mathcal{Q}, t \in T \) 
(34)

\( q_i \leq q_0 \); \( \forall i \in \mathcal{V}, k \in \mathcal{Q}, t \in T \) 
(35)

\( \Sigma_{\tau \in T} q_i \leq M \cdot q_0 \); \( \forall i \in \mathcal{V}, t \in T \) 
(36)

\( \Sigma_{\tau \in T} q_i \leq \Sigma_{\tau \in T} q_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(37)

\( \Delta t_i^k \leq \Sigma_{\tau \in T} q_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(38)

\( \Sigma_{\tau \in T} q_i + \Sigma_{\tau \in T} q_i \leq |Q| \); \( \forall i \in \mathcal{V}, \mathcal{T} \setminus \{T\} \) 
(39)

\( \Sigma_{\tau \in T} q_i \geq \Sigma_{\tau \in T} q_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(40)

\( \Sigma_{\tau \in T} q_i \geq 1 - M(1 - u_i) \); \( \forall i \in \mathcal{V}, t \in T \) 
(41)

\( \Sigma_{\tau \in T} q_i \geq \Sigma_{\tau \in T} q_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(42)

\( \Sigma_{\tau \in T} q_i \geq \Sigma_{\tau \in T} q_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(43)

\( \Sigma_{\tau \in T} q_i \geq \Sigma_{\tau \in T} q_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(44)

\( s_{\text{tot}} \leq M \cdot u_i \); \( \forall i \in \mathcal{V}, t \in T \) 
(45)

\( x_i^\uparrow, x_i^\downarrow, y_i^\uparrow, y_i^\downarrow, \mu_i, \beta_i, \Delta t_i^k \geq 0 \); \( \forall i \in \mathcal{V}, s \in \mathcal{S} \) 
(46)

\( u_i, s_{\text{tot}}, q_i, t_i, e_i, \Delta t_i^k \geq 0 \); \( \forall i \in \mathcal{V}, i \neq j, k \in \mathcal{Q}, t \in T \) 
(47)

\( b_i \leq b_i \uparrow \leq b_i \leq b_i \uparrow \); \( \forall i \in \mathcal{V} \) 
(48)

The first objective function is to minimize the expectation of the total cost of handling all vessels in the container terminal (1). The second objective function aims to maximize the expectations of linear shipping liner satisfaction level with respect to the services provided by the terminal operator (2). Equation (3) describes the total cost of handling the entire vessel during the planning horizon under scenario s, with the deviation of berthing position of the vessel i to its desired berthing position. Constraint (4) is the maximum limit of total cost deviation under scenario s against the expectation of total cost of handling all vessels in all scenario conditions. Constraints (5) - (8) describe the maximum delay time for a vessel i start berthing in scenario s with the arrival of vessel i under scenario s and the maximum delay time of vessel i departs in scenario s. Constraints (9) and (10) to ensure berthing time of vessel i can only be done after the arrival of vessel i for all scenarios. The maximum deviation from
the level of service satisfaction in the scenario s to the expected service satisfaction level of all scenarios is shown in constraint (11).

Constraint (12) states that the satisfaction level of container terminal services in scenario s is the lowest service satisfaction level of all vessels under scenario s. Constraints (13) - (15) indicate the satisfaction level of container terminal services for vessel i in scenario s is the fraction of on time service of estimated handling time for vessel i with the delay in service completion time for vessel i under scenario s. Constraint (16) states the excess time of service completion time of vessel i under scenario s from the end of planning horizon cycle time. Constraint (17) ensures the start time for berthing time for vessel i can only be done after the vessel's arrival time and before the end of the planning horizon cycle time. The completion time of handling vessel i after the vessel arrival time of and before the start time for the next planning horizon (18). Constraint (19) ensures berthing position of each vessel i within the wharf limit at the container terminal and the deviation of berthing position of vessel i from its desired position is shown in Constraints (20) - (21). Constraint (22) states the excess length of the berthing position of vessel i under scenario s from the end of the wharf. Constraints (23) - (25) show whether the start time of berthing time of vessel j after vessel i is finished served and whether the berthing position of the vessel j in front of the berthing position of the vessel i. Constraints (26) ensures that there is no overlapping in terms of the location of vessels on the wharf and the service time at a container terminal. Constraints (27) - (29) state that vessel j is served after vessel i has been served under scenario s with berthing position vessel j in front of vessel i and positive and negative deviation from berthing position of vessel i in scenario s to length of wharf.

Constraints (30) –(36) state the number of quay cranes and the allocation of quay cranes assigned to the vessel i over the time period t and during the service time, starting from berthing time to completion time. Quay crane assignment takes into account the desired berthing position of vessels and efficiency of setup time between vessel transfers, that show in constraints (37) – (42). Constraint (43) indicates that the total number of quay cranes assigned to serve vessel i simultaneously at each time period t in the feasible range q_{min}, q_{max}. Constraint (44) ensures that the total number of quay cranes assigned to service the entire vessels and in the setup position does not exceed the number of quay cranes available. Constraints (45) - (50) describe the number of quay cranes in a setup position which the difference in the number of quay cranes is assigned at times t and t + 1. Domain of decision variables show in (51) and (53). This model development is a bi-objective robust optimization model that would be solved using the Pre-emptive Goal Programming approach with the first priority on the objective function of minimizing the total expected cost in container terminal, followed by maximizing the expectation of service level.

4. Result and Discussion

The bi-objective robust optimization for seaside operations in container terminal under uncertainty conditions has been applied into a numerical illustration, consist of 10 vessels, 12 available quay cranes with similar productivity rate, those are 30 TEUs per hour. The coefficient of interference exponential is 0.1 and the berth position deviation factor is 0.9. The container terminal has a wharf length of 240 meters (partitioned in 10 meters berth segments). Planning horizon of 120 hours is divided into time step of 8 hours. Data related to length of vessels, number of containers, desired berthing position, estimated vessel arrival time, feasible range of quay crane and cost components are shown in table 1 as follows.

| Vessel | l | NCi | hp | ai | q_{min} | q_{max} | ai | Cd | Cl | Ch |
|--------|---|-----|----|----|--------|--------|----|----|----|----|
| Vessel 1 | 3 | 960 | 20 | 8 | 1 | 4 | 9 | 3 | 2 | 9 |
| Vessel 2 | 5 | 1440 | 2 | 10 | 1 | 5 | 13 | 3 | 1 | 9 |
| Vessel 3 | 4 | 1680 | 8 | 3 | 1 | 4 | 5 | 1 | 1 | 6 |
| Vessel 4 | 6 | 1920 | 10 | 12 | 2 | 5 | 16 | 1 | 2 | 6 |
| Vessel 5 | 5 | 1440 | 12 | 2 | 2 | 4 | 4 | 2 | 1 | 9 |
| Vessel 6 | 4 | 1200 | 10 | 9 | 1 | 4 | 12 | 2 | 2 | 6 |
| Vessel 7 | 5 | 2160 | 14 | 7 | 2 | 4 | 10 | 3 | 3 | 6 |
| Vessel 8 | 6 | 1440 | 4 | 7 | 2 | 5 | 9 | 3 | 2 | 6 |
| Vessel 9 | 4 | 1200 | 17 | 1 | 1 | 4 | 4 | 1 | 3 | 6 |
| Vessel 10 | 6 | 960 | 18 | 12 | 1 | 4 | 14 | 3 | 1 | 6 |
The assignment of quay cranes for each vessel is carried out in a feasible range of quay cranes based on the desired berthing position of each vessel determined according to the location of the containers to be loaded from the storage yard area to the vessels or vice versa. The feasible range of quay crane assignments for each vessel is shown in Table 2.

**Table 2. Feasible range of quay crane assignment**

| Vessel | QC 1 | QC 2 | QC 3 | QC 4 | QC 5 | QC 6 | QC 7 | QC 8 | QC 9 | QC 10 | QC 11 | QC 12 |
|--------|------|------|------|------|------|------|------|------|------|-------|-------|-------|
| Vessel 1 | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1      |       |       |
| Vessel 2 | 1    | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0      |       |       |
| Vessel 3 | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    | 0      |       |       |
| Vessel 4 | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1      |       |       |
| Vessel 5 | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 0    | 0      |       |       |
| Vessel 6 | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 0      |       |       |
| Vessel 7 | 0    | 0    | 0    | 1    | 1    | 1    | 1    | 1    | 0    | 0      |       |       |
| Vessel 8 | 0    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 0      |       |       |
| Vessel 9 | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 1      |       |       |
| Vessel 10 | 0   | 0   | 1   | 1   | 1   | 1   | 0   | 0   | 0   | 0      |       |       |

The uncertainty of vessel arrivals and handling times which depend on changes in the number of containers that should be discharged and loaded into each vessel are shown as the six scenarios in Table 3. Each scenario has the same probability value.

**Table 3. Vessel arrival times and handling times for each scenario**

| Vessel | $a_{is}$ | S1 | S2 | S3 | S4 | S5 | S6 |
|--------|----------|----|----|----|----|----|----|
| Vessel 1 | 3        | 4  | 5  | 4  | 5  | 7  | 7  |
| Vessel 2 | 8        | 6  | 4  | 6  | 6  | 5  | 5  |
| Vessel 3 | 1        | 1  | 1  | 5  | 5  | 2  | 2  |
| Vessel 4 | 4        | 2  | 4  | 2  | 5  | 2  | 2  |
| Vessel 5 | 1        | 1  | 3  | 4  | 1  | 3  | 3  |
| Vessel 6 | 8        | 6  | 8  | 8  | 7  | 7  | 7  |
| Vessel 7 | 7        | 9  | 8  | 10 | 8  | 10 | 10 |
| Vessel 8 | 7        | 4  | 4  | 6  | 7  | 5  | 5  |
| Vessel 9 | 4        | 4  | 3  | 6  | 3  | 6  | 6  |
| Vessel 10 | 10      | 9  | 9  | 12 | 11 | 8  | 8  |

The optimal solution generated from the exact method are the minimum expected total operational cost of 73.4833 and the maximum expected satisfaction level of 87.4%, with detailed of the both objective values for each scenarios as stated in Table 4.

**Table 4. Total operational cost and service level for each scenario**

| Scenario, s | S1 | S2 | S3 | S4 | S5 | S6 |
|-------------|----|----|----|----|----|----|
| $TC_s$      | 70 | 77 | 82 | 68 | 64 | 76 |
| $\bar{s}_s$ | 1  | 1  | 1  | 1  | 0.667 | 0.667 |

The optimal handling times based on the number of handled containers, berthing positions, berthing times, and completion times for each vessel as shown in Table 5 below.
Table 5. The optimal results for the integrated planning decisions

| Vessel | $h_i$ | $b_{pi}$ | $b_{ti}$ | $e_i$ |
|--------|-------|----------|----------|-------|
| Vessel 1 | 1     | 20       | 8        | 11    |
| Vessel 2 | 3     | 2        | 10       | 15    |
| Vessel 3 | 2     | 8        | 3        | 7     |
| Vessel 4 | 4     | 10       | 12       | 15    |
| Vessel 5 | 2     | 12       | 2        | 5     |
| Vessel 6 | 3     | 10       | 9        | 12    |
| Vessel 7 | 3     | 14       | 7        | 11    |
| Vessel 8 | 2     | 4        | 7        | 9     |
| Vessel 9 | 3     | 17       | 3        | 7     |
| Vessel 10 | 2    | 18       | 12       | 15    |

Figure 2. Berth template resulting from robust optimization.

Figure 3. Specific Quay crane assignment from Robust Optimization result

5. Conclusion and Further Research
In this paper, a robust optimization model of integrated planning for seaside operations in terminal containers under uncertainty environment has been carried out. A robust optimization model has two objective functions to balance the interests of the terminal managers and shipping liner owners. Integrated planning consists of Tactical Berth Allocation Problems and Specific Quay Crane Assignment Problems, taking into account the uncertainty of vessels arrival times and changes in the number of containers handled of each vessel. The optimization model has been solved by using Pre-emptive Multi-Objective Programming and applied in a small scale problem. For the development of further research, meta-heuristics algorithm approaches and simulation based optimization methods could be applied to get a reasonable computation time for solving large scale problems.
References

[1] United Nations Conference On Trade And Development 2017 Review of Maritime Transport (New York and Geneva: UNCTAD).
[2] Carlo H J, Vis I F A and Roodbergen K J 2015 Seaside operations in container terminals: literature overview, trends, and research directions J. Flex. Serv. Manuf. 27 224–262.
[3] Bierwirth C and Meisel F 2010 A survey of berth allocation and quay crane scheduling problems in container terminals Eur. J. Oper. Res. 202 615–627.
[4] Bierwirth C and Meisel F 2015 A follow-up survey of berth allocation and quay crane scheduling problems in container terminals Eur. J. Oper. Res. 244 675–689.
[5] Moorthy R and Teo C P 2006 Berth management in container terminal: the template design problem OR Spectr. 28 495–518.
[6] Meisel F and Bierwirth C 2006 Integration of berth allocation and crane assignment to improve the resource utilization at a seaport container terminal Oper. Res. Proc. 20 105–110.
[7] Vacca I, Salani M, Bierlaire M, Salani M and Bierlaire M 2013 An exact algorithm for the integrated planning of berth allocation and quay crane assignment an exact algorithm for the integrated planning of berth allocation and quay crane assignment J. Transp. Sci. 47 148–161.
[8] Iris Ç, Pacino D, Ropke S and Larsen A 2015 Integrated berth allocation and quay crane assignment problem: set partitioning models and computational results J. Transp. Res. Part E Logist. Transp. Rev 81 75–97.
[9] Zhen L, Lee L H and Chew E P 2011 A decision model for berth allocation under uncertainty Eur. J. Oper. Res. 212 54–68.
[10] Zhen L 2015 Tactical berth allocation under uncertainty Eur. J. Oper. Res. 247 928–944.
[11] Changchun X and Lixin M 2017 A bi-objective robust model for berth allocation scheduling under uncertainty Transp. Res. Part E 106 294–319.
[12] Zhen L and Chang D F 2012 A bi-objective model for robust berth allocation scheduling Comput. Ind. Eng. 63 262–273.
[13] Golias M, Portal I, Konur D, Kaisar E and Kolomvos G 2014 Robust berth scheduling at marine container terminals via hierarchical optimization Comput. Oper. Res. 41 412–422.
[14] Ting X, Xin J and Ren J 2016 A robust optimization approach to the integrated berth allocation and quay crane assignment problem Transp. Res. Part E 94 44–65.
[15] Christiansen M, Fagerholt K, Nygreen B and Ronen D 2015 Optimization of Maritime Transportation (Norway: NTNU).