

Genetic Algorithm for Integrated Models of Continuous Berth Allocation Problem and Quay Crane Scheduling with Non Crossing Constraint

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Abstract

Background/Objectives: This paper focused on integrated Continuous Berth Allocation Problem (BAPC) and Quay Crane Scheduling Problem (QCSP) by considering non-crossing constraint to make it more realistic. **Methods/Statistical analysis:** Genetic Algorithm (GA) is a metaheuristic method that has been used extensively in Berth Allocation Problem (BAP). Crossover and mutation are selected as operators in this paper. **Findings:** The integrated model is formulated as a Mix Integer Problem (MIP) with the objective to minimize the sum of the processing times. A vessel's processing time is measured between arrival and departure including waiting time to be berthed and servicing time. The new algorithm of GA are compatible with the integrated model and useful for finding near-optimal solutions. Three phase new algorithms of GA are proposed and provide a wider search to the solution space. **Application/Improvements:** Three phase of GA is another significant and promising variant of genetic algorithms in BAPC and QCSP. The probabilities of crossover and mutation determine the degree of solution accuracy and the convergence speed that GA can obtain. By using fixed values of crossover and mutation, the algorithm utilize the population information in each generation and adaptively adjust the crossover and mutation. So, the population diversity and sustain the convergence capacity is maintained.

Keywords: Continuous Berth Allocation, Genetic Algorithm, Non Crossing, Quay Crane Scheduling

1. Introduction

The efficient management of berth allocation and Quay Crane (QC) at container terminal systems give great impact on the operation's improvement and customer satisfaction. Berth scheduling and quay crane scheduling problems are the most important part of terminal operation because they are interfaces between landside and seaside. The efficient management systems in container terminals plays an importance role to raise up productivity and it is one of the complex problems encountered in transportation engineering¹.

The berth allocation problem in a terminal is defined

as a feasible solution of assigning ship to berthing position while minimizing the total processing times between arrival and departure of the ship. The terminal operators first determine a berth schedule based on estimate total berthing time of each vessel, then quay crane will be allocated based on holds within each vessel. A vessel's processing time is measured between arrival and departure of vessels. To enhance the productivity of the terminal, the processing time should be reduced. This paper concentrated on Integrated Continuous Berth Allocation Problem and Quay Crane Scheduling Problem (IBAPCQCSP) with non-crossing constraint.

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2. Related Works

There are more papers used metaheuristic methods compared to the other methods such as optimization algorithm iterative method and heuristic method. Although metaheuristic methods do not certain that a globally optimal solution can be found on some class of problems. By the way, compare to optimization algorithms, iterative methods, or simple heuristics, metaheuristics can find better solutions with less computational effort. The metaheuristic methods are useful approaches for optimization problems and gave a good performance in solving the IBAPCQCSP.

Some researchers choose Genetic Algorithm (GA) when deal with different situation/environment of BAP and QCSP. In² examined on stochastic arrival of vessel and container handling time. This study focused on the simultaneous model of berth allocation problem and quay crane scheduling. In this issue, QC in operation can be replaced with other QC after it task completed. A simulation based on genetic algorithm search procedure is used to generate robust berth and proactive QC schedule. In³ also formulated a simultaneous model for berth and crane allocation problem. By employing GA, an approximate solution for the problem is solved. The fitness value of a chromosome is obtained by QC scheduling.

While, in⁴ proposed stochastic environment for berth and quay crane allocation model. The model is capable of efficiently and dynamically allocating berths and quay cranes to calling containerships in real stochastic environments and reflects the risk preference of decision maker. The proposed Genetic Algorithm obtained satisfactory solutions, which is significantly improved by greedy algorithms.

In⁵ are applied a revised GA and a Branch-and-Bound method (B&B) to the solutions of upper and lower level problems. Bi-Level Programming (BLP) model is studied which is BAP is set as the upper-level programming problem and the QCSP as the lower-level problem. They found that, the first optimal berth allocation produced best result, having shortest berthing time for all incoming vessels.

In⁶ presented two phase solution for a dynamic BAPC and QCSP by using a hybrid Genetic Algorithm. At the first phase, vessels are allocated at berthing areas and QCs are assigned to vessels based on novel crane assignment heuristics. The solution process of the first phase is governed by the genetic algorithm that incorporates

heuristic procedures. In the second phase, the objective is to minimize the distance of QC's movement. The real data are used and tested by using GA. Computational testing indicated the impact of rising congestion levels on problem complexity as well as the ability of the proposed algorithm to solve large-scale problem instances within acceptable computational time.

In⁷ are extended the study of multiple quay cranes for the dynamic and continuous Berth Allocation Problem. GA is applied as solution method and a local search procedure is used to improvise the solutions produced by GA. In⁸ also extended study on dynamic but focus on discrete berth allocation bi-objective model. The model is to minimize daytime priorities and the delayed workloads in daytime and nights. A multi-objective of GA is developed to solve the bi-objective model. The sensitivity analysis is examined on the algorithmic parameters and tradeoffs between daytime priorities and delayed workloads. Another researchers focus on dynamic problem whether continuous or discrete and chose GA as solution method such as⁹⁻¹².

3. Problem Descriptions

There are various models for IBAPCQCSP based on their problem. However, the basic model is explained in this section to give a clear picture for the integrated model. The loading and unloading process of container at a berth is related to quay cranes schedule. First, a berth schedule using estimates of total berth time for each vessel need to determine, and then try to split cranes among the vessels planned to dock simultaneously. Terminal operators can develop a better operational plan if actual crane requirements are considered while determining berth schedules. The recent literature shown trend for integrated solution approaches for berth allocation problem and quay crane scheduling. The following assumptions are described for basic model of IBAPCQCSP:

This section proposed the assumptions of the model:

- Multiple vessels can moor at the berth and receive services as soon as possible.
- Vessel processing time depends on the number of QCs assigned to the vessel.
- A vessel is considered processed once a QC has completed the work on a set of holds identical.
- Vessels can arrive at the terminal during the planning process but cannot be handled before it's arrive time.

- Each vessel is divided along its length into holds 3 or 4 container rows.
- Work needs to continue on a hold until completion when it's started.
- A vessel can leave the port only after the proses of loading and unloading container is completed on every hold.
- Only one QC can work on a hold at a given time period.
- QCs are on the same tracks and cannot cross each other.
- QC can be shifted from hold to hold both within vessels and between vessels, as long as QCs are not cross one another.

4. Model Formulation

This section proposed mathematical formulation for IBAPCQSP. The study concentrated on the dynamic arrival where a set V of vessels with known arrival times, where $n = |V|$. For each vessel $k \in V$, the study defines:

- B: Set of berths equal size sections.
- Q: A set of identical quay cranes operating on a single set of rails.
- T: Time period of vessels.
- v: A set of vessels with known arrival time.
- M: A large positive scalar.
- i : Location of crane i at time period t .
- h_k : Number of holds of vessel k .
- p_k : Processing time of hold i of vessel k .
- p_{max}^k : Maximum hold processing time for vessel k ($p_{max}^k : \max_i p_k^i$).
- a_k : Arrival time of vessel k .
- b_k : Berthing position of vessel k .
- t_k : Berthing time of vessel k .
- c_k : The earliest time that vessel k can depart.
- t_k^i : Berthing time of vessel k .

$$x_{lk} = \begin{cases} 1 & \text{if vessel } k \text{ berth after vessel } l \text{ departs} \\ 0 & \text{otherwise;} \end{cases}$$

$$y_{lk} = \begin{cases} 1 & \text{if vessel } k \text{ berth completely above vessel } l \text{ on the time-space diagram} \\ 0 & \text{otherwise;} \end{cases}$$

$$z_{ki}^t = \begin{cases} 1 & \text{if vessel } k \text{ berth after vessel } l \text{ departs} \\ 0 & \text{otherwise;} \end{cases}$$

$$x_{lk} + x_{kl} + y_{lk} + y_{kl} \geq 1 \quad \forall k, l \in V \text{ and } k < l \quad (2)$$

$$x_{lk} + x_{kl} \leq 1 \quad \forall k, l \in V \text{ and } k < l \quad (3)$$

$$y_{lk} + y_{kl} \leq 1 \quad \forall k, l \in V \text{ and } k < l \quad (4)$$

$$t^i \geq c_k + (x_{kl} - 1)M \quad \forall k, l \in V \text{ and } k < l \quad (5)$$

$$b_l \geq b_k + h_k + (y_{kl} - 1)M \quad \forall k, l \in V \text{ and } k < l \quad (6)$$

$$t_k \geq a_k \quad \forall k \in V \quad \forall k \in V \quad (7)$$

$$t^i \geq tz_{ki}^t + (1 - z_{ki}^t)T \quad \forall k \in V \quad \forall i \in \{1, \dots, h_k\} \quad \forall t \in \{1, \dots, T\} \quad (8)$$

$$c_k \geq tz_{ki}^t + p_k^i \quad \forall k \in V \quad \forall i \in \{1, \dots, h_k\} \quad \forall t \in \{1, \dots, T\} \quad (9)$$

$$c_k \geq tz_{ki}^t + p_{max}^k \quad \forall k \in V \quad (10)$$

$$\sum_{t=1}^T z_{ki}^t = 1 \quad \forall k \in V \quad \forall i \in \{1, \dots, h_k\} \quad (11)$$

$$\sum_{t=1}^T \sum_{i=1}^{h_k} \sum_{t=f_{p_k^i}+1}^t z_{ki}^t \leq Q \quad \forall t \in \{p_k^i, \dots, T\} \quad (12)$$

$$b_k \leq B - h_k + 1 \quad \forall k \in V \quad (13)$$

$$b_k \geq 1 \quad \forall k \in V \quad (14)$$

$$L_t^i \leq L_{i+1}^t - 1 \quad \forall k \in V \quad (15)$$

$$1 \leq L_t^i \leq B \quad \forall k \in V \quad (16)$$

$$x_{lk} \in \{0, 1\}, y_{lk} \in \{0, 1\}, \quad \forall k, l \in V \text{ and } k \neq l \quad (17)$$

$$z_{ki}^t \in \{0, 1\} \quad \forall k \in V \quad \forall i \in \{1, \dots, h_k\} \quad \forall t \in \{1, \dots, T\} \quad (18)$$

Constraints (2) through (4) guarantee that no vessel rectangles overlap. Constraints (5) and (6) ensure that the selected berthing times and berthing positions are consistent with the definitions of x_{lk} and y_{lk} , where M is a large positive scalar. Constraint (7) forces berthing to make sure no earlier than arrival time, and Constraint (8) forces hold processing to start after berthing. Constraint (9) ensures that vessels depart only after all holds are processed, and Constraint (10) is a valid inequality that provides a lower bound on c_k given t_k . Constraint (11) ensures that work starts on each hold of each vessel and Constraint (12) ensures that no more than Q quay cranes are used at any time period. Constraints (13) and (14) guarantee that all vessels fit on the berth. Constraint (15) and (16) ensure that cranes cannot cross over each other.

The objective $\sum_{k=1}^n (c_k - a_k) + \sum_{k=1}^n f_k(c_k - d_k)$ is to minimize the sum of processing time, where a vessel's processing time is measured between arrival and departure time including waiting times to be berthed and servicing time.

5. Genetic Algorithm

Genetic algorithms are based on population mechanisms. Every two parent solutions mate produced two child solutions which transferred a new combination of genes to form of new chromosomes¹³. To create the populations, chromosomes are generated randomly and proceeds for next generations.

Firstly, initial solution (L_{ρ}, B_{ρ}) is generated randomly

and evaluated. To produce next generation, the genetic operators of selection, reproduction and replacement is applied for parent one. The operators are independent from each other and can be implemented in a variety ways.

The paper applied crossover and mutation as operators. Single point crossover is randomly choose from a point in the first line of chromosome and employed for every vessels. The genes before that point are inherited from parent 1 and genes after that point are copied from parent 2.

Figure 1 shows the first phase of algorithm and there is containing second phase algorithm (Figure 2). In Figure 3, show the flow of third phase.

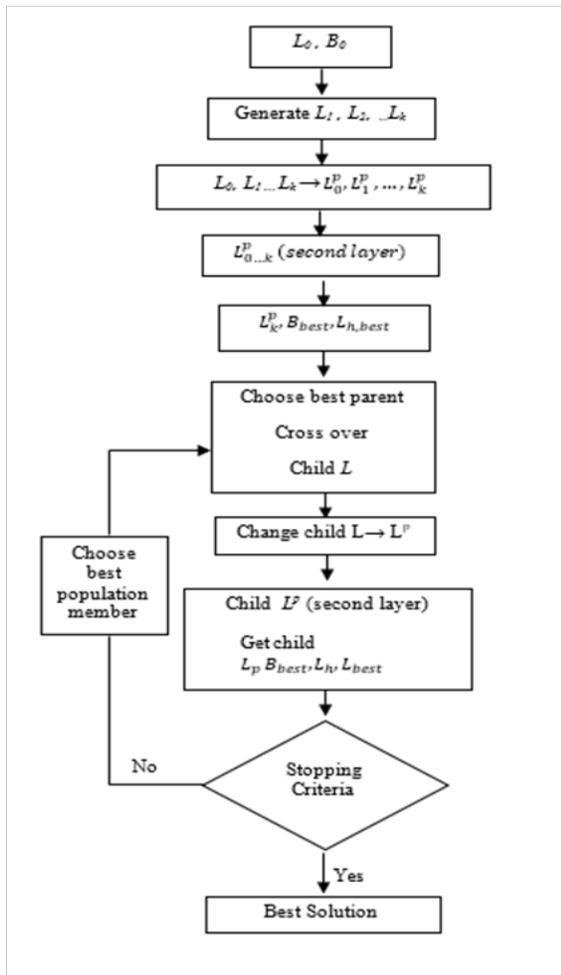


Figure 1. Flow chart algorithm (first phase).

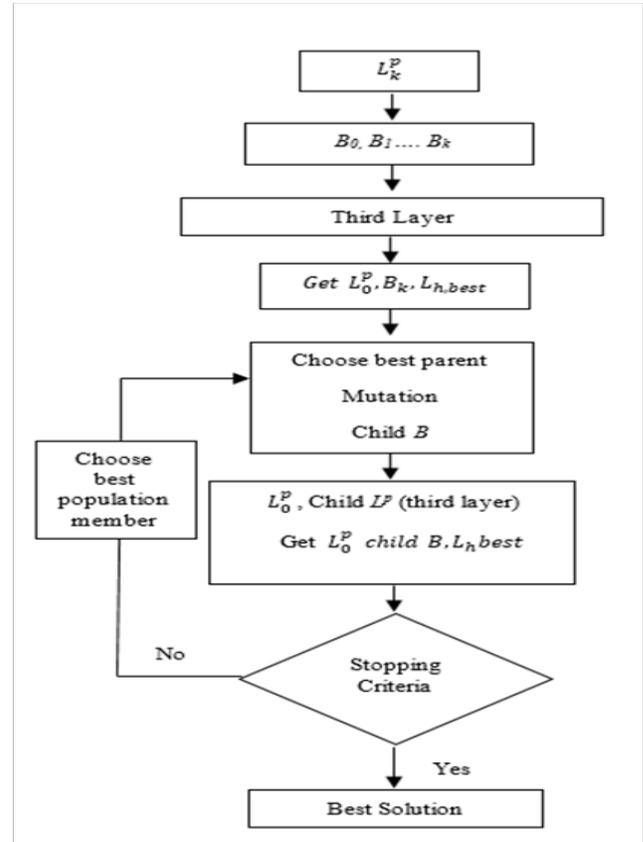


Figure 2. Flow chart algorithm (second phase).

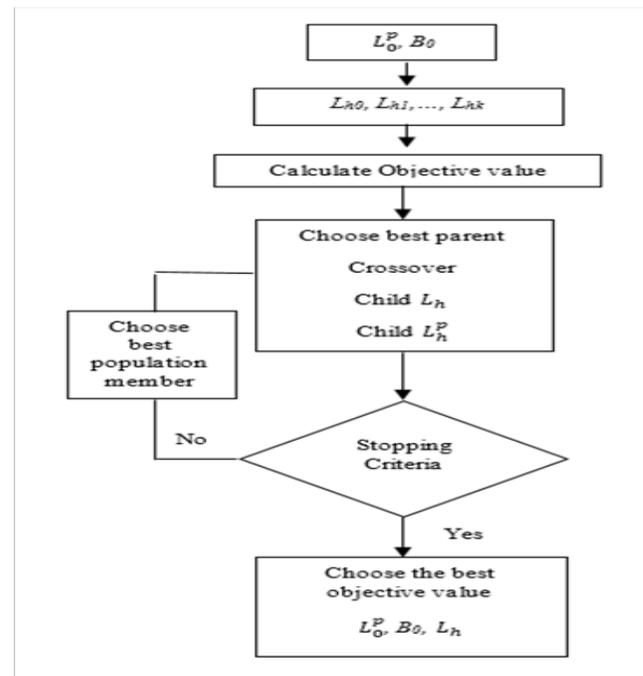


Figure 3. Flow chart algorithm (third phase).

These three phase algorithm of GA is significant and produced new GA in BAPC and QCSP. In order to maintain the population diversity and sustain the convergence capacity, the value of cross over and mutation are fixed. The population information in each generation are used and the adaptively adjust for cross over and mutation.

6. Numerical Example

The small problem in Table 1 is used for the model, where $B = 7$ and $Q = 4$. Commercial software, LINGO 14.0 was adopted in this research for validation process. In this problem, each vessel is divided into equal size sections that we call holds. The length of a vessel can be represented by the number of holds it has. Furthermore, the length of a hold is also set equal to the length of a berth section, and it is assumed that the berth is B holds in total length. Each hold consists of 3 or 4 container rows. Multiple vessels can moor at the berth and receive service simultaneously but only one QC can work on a hold at a given time period. Each hold requires a known processing time to allocate QC for every hold. A vessel can leave the port only after loading and unloading process is completed on every hold.

Table 1. A small instance for IBAPCQSP

K	1	2	3	4	5
a_k	2	1	3	2	1
h_k	2	3	3	4	4
p_k^1	3	2	2	3	3
p_k^2	4	2	4	1	2
p_k^3	-	2	1	0	2
p_k^4	-	-	-	1	4

Initial solution is randomly generated (Figure 4). Each vessel can be selected only once and quay crane will be allocated based on holds within each vessel. In this problem, quay crane is allowed to move from one hold of a vessel to another with the condition all works in initially assigned hold is completed. The ordered list \mathcal{L} for the initial solution is (2,5,1,4,3) and B is (1,1,1,3,4). From Table 2, the objective function values of initial solution is 31 hours.

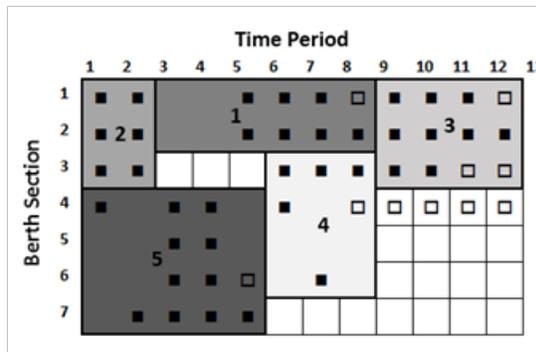


Figure 4. Initial solution of IBAPCQSP on time space diagram.

Time space diagram in Figure 4 represented processing time for vertical axis and berth section for horizontal axis. The location of cranes in any holds illustrated using a solid and empty square. Solid square means crane in processing activities (loading or unloading) and empty square means cranes in idle situation.

Table 2 shows the optimal solution for this problem. The ordered list is $\mathcal{L} = (2,4,1,3,5)$ and $B = (1,1,5,4,1)$. The objective function values of the optimal solution is 26 hours. Figure 5 shows time space diagram for optimal solution of the problem.

Table 2. Optimal solution for IBAPCQSP

k	1	2	3	4	5
b_k	1	1	5	4	1
t_k	3	1	5	2	7
c_k	7	3	9	5	11

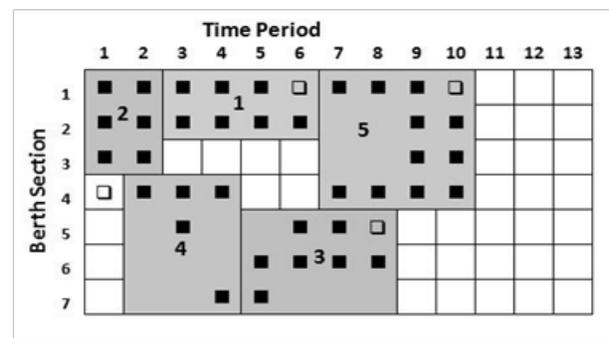


Figure 5. Optimal solution of IBAPCQSP on time space diagram.

This model considered non crossing constraint. As illustrated in Figure 6, the lines belonging to a QC should not crossover line other QCs and each berth section

handled by one QC. In this problem, the travel time of a QC not considered.

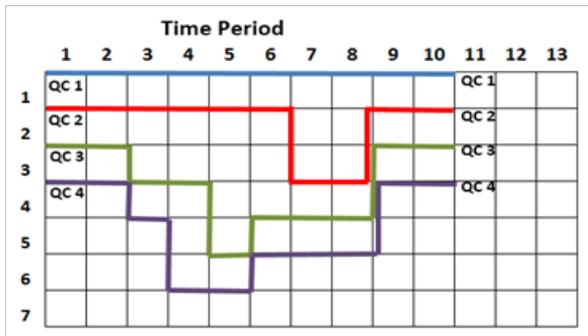


Figure 6. Space time diagram for quay crane in optimal solution of IBAPCQSP.

This integrated model showed that the BAPC and QCSP can be solved simultaneously and become more practical. The efficient utilization of this technical equipment will minimize vessel handling times. Hence, well planned QC operations are important for terminal efficiency. Solving these two problems separately may cause the terminal operators need to solve BAPC first and then solve QCSP later. Two different problems need to model for solving the BAPC and QCSP and it may cause inefficiency situation.

7. Conclusion

In this paper, the mathematical formulation is presented for IBAPCQSP. This integrated model developed by considering non crossing constrain to make it more realistic. The new approach of GA is able to maintains a rapid convergence and obtain near-optimal solutions in lower computational times. For future work, we propose to focus on realistic assumptions to the formulation, such as safety distance between vessels and the traveling time of cranes during scheduling process. Sensitivity Analysis for mathematical model also something important to explore.

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