# Research on Multi-Objective Co-operation Optimization of Shipyard Berth Allocation System

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***Abstract*** **— Berth allocation indicates the arrangement of a berth position for a ship according to pier berth availability and physical conditions when the ship arrives at the anchorage or pier. This paper analyzes pier berth allocation system according to actual requirements of ship enterprises. It builds a mathematical model for berth allocation, creates the multi-objective co-operation optimization method, combines heuristic rules with genetic algorithms, seeks integrated and synchronized optimization for minimum in-factory time, shortest berth shifting distance and lowest production cost, and finally verifies the validity of the model and algorithms with examples.**

***Keywords - berth scheduling system; Multi-Objective; Co-operation; Optimization***

## I. INTRODUCTION

Berth allocation indicates the arrangement of a berth position for a ship according to pier berth availability and physical conditions when the ship arrives at the anchorage or pier. The goal of berth position arrangement is optimal working berth, which will maximally ensure that a ship can finish its work tasks in a planned period. The optimization process of ship scheduling is actually the process of optimizing pier production resource configuration. Berths are key resources as well as scarce resources of a pier. Therefore, rational berth allocation plan has significant impact on the improvement of pier manipulative level.

Researchers mainly focus on how to build relevant mathematical models for pier scheduling. They further develop intelligent optimization algorithms based on conventional methods and also have system simulation. These approaches, to some extent, reflect actual requirements of pier operations and are of theoretical and practical significance.

Pasquale Legato shortened ship stay time and improved berth utilization [1] by building the ship arrival queueing mod-el using Visual Slam language. Edomal studied pier berth allocation and planning, solving berth allocation [2] with the queueing theory model. Legato studied the impact of ship arrival time and departure time on berth allocation, built the queueing network model for berth allocation accordingly, and solved berth allocation optimization [3]. Imai et al. built the nonlinear integer programming model, of which the objective function is minimum ship waiting period [4]. Yavuz B. Türkog˘ulları built a new binary integer linear programming model to resolve berth allocation and quay crane operation [5]. Nishimura et al. resolved berth scheduling [6] in various depths with the genetic algorithm.

This paper creates the multi-objective berth co-operation optimization method, builds the multi-objective co-operation berth allocation model, and seeks optimization of berth allocation by introducing scheduling rules into NsGAII to generate the initial population.

## II. MULTI-OBJECTIVE CO-OPERATION OPTIMIZATION

There are numerous objectives in berth scheduling, such as the shortest berth repair period, the shortest shipyard repair period, maximum production profit, and the shortest operating time[7]. It is, however, impossible to reach optimal results of all these targets because these targets are often mutually exclusive. In practice, the groove of a pier scheduling system is a balance between various production activities to maintain the order of production. A scheduling model is often aimed at optimization based on multi-objective comprehensive consideration. A representative result in the multi-objective optimization algorithm is NsGA Ⅱ[8]. A major part of the algorithm is to select the initial population in search space. Generally, the initial population is generated randomly to reach diversity of initial solutions. Solution quality in the algorithm is, to a great extent, based on initial solutions. Though NsGAⅡ is capable of global search, search process may see "precocity" and end at a local optimal solution due to the impact of randomness.

In practice of berth scheduling, scheduling personnel concluded scheduling rules that meet actual production requirements according to their rich experience. Full use of the knowledge will greatly reduce solution space, accelerate solution speed, improve solution quality, and provide a new solution method integrating human thought and computing methods to solve complicated issues like berth scheduling.

### A. Problem Description and Optimization Rules

Berth layout in shipyards is two dimensional. There is no physical partitioning of berths. Any ship can berth as long as there is space.

The optimization of water frontage berth scheduling system is actually the optimization of system control. It is to seek optimal operational indexes of a specific objective function with existing pier resources. An objective function is generally the shortest in-factory time, minimum production cost, etc.

A scheduling rule is an instruction to or decision of the next step in a system. According to shipyard operational features, the following rules and principles are to be followed in berth allocation for ships:

Principle of First Come First Served: Optimal working berths are arranged according to the sequence of ship arrival. It can be represented by the following mathematical model.

$$Z_i = T_i \tag{1}$$

Ti is the arrival time of ship i.

Principle of Engineering Period: Prioritize the arrangement of optimal working berths for those ships with shorter engineering periods. It can be represented by the following mathematical model.

$$Z_i = t_{ai} - T_i \tag{2}$$

Tai is the moment when ship i berths at its optimal working berth.

Principle of Priority for Shorter Relaxation Period: Relaxation period is the gap between the period from the current time t to the end of the engineering period of ship i and the remaining working time of it. It can be represented by the following mathematical model.

$$Z_i = d_i - t - \sum_{q=j+1}^{n_i} P_{iq} \tag{3}$$

Piq is the remaining working time of ship i. This principle is an ODD principle when t=0.

EDD Rule: Prioritize those ships with earliest delivery dates. It can be represented by the following mathematical model.

$$Z_i = d_i \tag{4}$$

Rule of Priority for Shortest Waiting Time:

$$Z_i = t_{ai} - T_i \tag{5}$$

Similar Model Ships Berth at Different Shifts of a Berth: It can be represented by the following mathematical model.

$$b_{ik1} = b_{jk2} \tag{6}$$

bkn represents different shifts of a berth. n=1, 2, …

### B. Problem Description and Optimization Rules

#### 1) Model Formulation

S: the set of all vessels, S={1,2,3,…,s};

C: the set of berthing positions, C={1,2,3,…,c};

L: the length of the wharf (m);

li: the length of vessel i (m), $i \in S$;

mcmin: minimum hoisting capacity near berth c ;

mcmaxn: maximum hoisting capacity near berth c ;

tai: the estimated arrival time of vessel i, $i \in S$;

pi: the berthing position with the lowest cost for vessel i, $i \in S$;

qi: decision variable, the berthing order of vessel i, $i \in S$;

bi: decision variable, the berthing position of vessel i, $i \in S$;

zij: dependent variable, if vessel i is berthed on the left of vessel j on the wharf, zij=1, otherwise zij=0， $i, j \in S$;

θij: dependent variable, if vessel i is berthed before vessel j in time, θij=1, otherwise θij =0, $i, j \in S$;

tbi: dependent variable, the time required for the ship operation for vessel i, $i \in S$;

wqi: Wait for homework time of vessel i, $i \in S$;

$c_1$:the penalty cost per unit time ;

$c_2$:the additional travel cost per unit distance for delivering the container;

$c_3$:the cost of wait time;

M: A large constant.

#### 2) Objective Function

It is the main goal of pier operation to increase benefits of a ship enterprise by both ensuring ship working efficiency and develop a pier rapidly and healthily in a sound pier operation environment[9]. A sound pier operation environment indicates the lowering of production cost on the premise of ensuring safety. It is not recommended to shorten ship in-factory time by improving operational efficiency via consuming higher production cost or via lowering safety level [10].

Dynamic continuous-berth-mode scheduling is to arrange berths for ships successively according to coastline length. Berths are not restrained by physical space. The mode is generally applied in production and scheduling management in piers with berths of similar water depths. It is noteworthy that, ships berthing at various shifts of a berth must be of the same model in the berth mode of two-dimensional berth groups.

According to the features of scheduling mode, there are three optimization objectives:

(1) When a ship arrives, shipyard scheduling personnel generally allocate a berth and relevant equipment according to the volume and working period of the ship. In the world of experience, uneven allocation of equipment and berth resources does happen. This may result in in-factory repair periods of certain ships exceeding contract periods. Therefore, shipyard adjustment managers integrate impacts of all factors to avoid in-factory repair period of ship products exceeding planned periods. In this scenario, the objective function to analyze and optimize this purpose is as follows:

$$f_1 = \min \sum_{i=1}^{s} (t_{ei} - t_{ai}) \tag{7}$$

(2) There is an optimal working berth for each ship before it arrives. A ship needs a series of pre-operation berth shifting to arrive at its optimal working berth when there are more ships arriving. Therefore, operation start time of a ship is not necessarily the same as its arrival time. A ship can directly berth at its optimal working berth for operation when there are fewer ships at a pier. It is better to keep the actual berth of a ship closer to its optimal working berth when it cannot berth there. This will save costs and avoid safety

risks. According to this optimization objective, the objective function is as below:

$$f_2 = min \sum_{i=1}^{s} |b_i - p_i| \tag{8}$$

(3) Generally, ship waiting cost will drop necessarily if pier efficiency is improved and ship waiting time (period from arrival to optimal working berth) is shortened. The improvement of pier efficiency, however, necessarily increases system load. Service cost will increase accordingly. Therefore, one of the objectives of optimal berth allocation is to minimize the sum of waiting cost and service cost, i.e. minimum total system cost. The objective function is as follows.

$$f_3 = \min(c_1 \sum_{i=1}^{s} |b_i - p_i| + c_2 \sum_{i=1}^{s} |t_{ci} - t_{bi}| + c_3 \sum_{i=1}^{s} w_{qi}) \tag{9}$$

Berth scheduling in shipyard is a multi-objective optimization issue. Optimal status of a pier scheduling system is a balance between production activities and a normal production order.

subject to

$$t_{ai} \le t_{bi} \quad \forall i \in S \tag{10}$$

$$t_{ai} \le t_{ci} \quad \forall i \in S \tag{11}$$

$$s \le N \tag{12}$$

$$b_i + l_i \le L \quad \forall i \in S \tag{13}$$

$$b_i + l_i \le b_j + M(1 - z_{ij}) \quad \forall i,j \in S \quad i \ne j \tag{14}$$

$$t_{ci} \le t_{aj} + M(1 - \theta_{ij}) \quad \forall i,j \in S \quad i \ne j \tag{15}$$

$$m_c^{min} \le m_i \le m_c^{max} \tag{16}$$

$$z_{ij} + z_{ji} + \theta_{ij} + \theta_{ji} \quad \forall i,j \in S \quad i \ne j \tag{17}$$

Functions (10) and (11) respectively represent the operation start time of ship *i*. The time is not always the same as the arrival time. In addition, the arrival period is shorter than the departure period. Function (12) indicates that the

number of arriving ships is lower than the total system capacity in the function. Function (13) shows that any ship

must berth within the coastline of a pier. Functions (14) and (15) respectively define the relations between location and time of two ships. Function (16) defines the bearing limits of equipment used by a ship. Function (17) defines that it is prohibited to overlap the berth locations or in-factory time of any two ships.

### C. *Algorithm Procedures*

First of all, assume that there are *n* number of arriving ships. It is imperative that the number of arriving ships cannot exceed the maximum system capacity N, which is generally determined by pier size. Bring in all ship sets to be allocated to generate the initial population of a certain size according to scheduling rules. Calculate target value functions and identify if they meet the termination conditions. If yes, end the process. Otherwise, enter a new hierarchical optimization process. In each hierarchical optimization process, allocate fitness to each individual, i.e. scalarize a single fitness degree value for the objective function value in the vector format of each individual according to a certain algorithm. Then select a certain number of individuals according to the fitness degree value and conduct operations such as crossover and mutation on them in a certain probability. Check the feasibility of new solutions after crossover and mutation and then re-allocate berths. Finally, select a certain number of individuals as a new generation population from the communal group of new solutions and previous solutions. The largest difference between multi-objective optimization algorithm and single-objective optimization algorithm is the fitness allocation before selection.

## III. EXAMPLE

### A. *Comparison with Conventional Genetic Algorithms*

According to matlab simulated calculation, select a random value if the production period is within 14 days. Ship arrival time and working time comply with generalized probability distribution. At a random arrival time within the 14 days, the number of ships is 15. Select and compare 20 schemes from multi-objective co-operation algorithms and conventional genetic algorithms (show in Table 1). Set the population size to 200, crossover probability to 0.85, mutation probability to 0.5, and maximum iterations to 500. Search scope shrinks gradually as iterations increase.

TABLE I THE RESULTS CONTRAST OF TWO KINDS OF ALGORITHM

| **Berthing plan** | **multi-objective co-operation algorithms** | | **conventional genetic algorithms** | |
|---|---|---|---|---|
| | **Time (hours)** | **The number of iterations** | **Time (hours)** | **The number of iterations** |
| 1 | 2170 | 300 | 1958 | 300 |
| 2 | 2145 | 450 | 2093 | 300 |
| 3 | 1967 | 300 | 2403 | 200 |
| 4 | 2042 | 400 | 2568 | 450 |
| 5 | 2423 | 250 | 2081 | 400 |
| 6 | 2315 | 450 | 1716 | 300 |
| 7 | 2008 | 300 | 2218 | 250 |
| 8 | 2296 | 350 | 3024 | 300 |
| 9 | 2138 | 400 | 2654 | 350 |
| 10 | 2325 | 250 | 1924 | 200 |
| 11 | 2497 | 300 | 2622 | 300 |
| 12 | 2056 | 250 | 2342 | 350 |
| 13 | 2265 | 300 | 2738 | 400 |
| 14 | 2113 | 300 | 2227 | 450 |

| | | | | |
|---|---|---|---|---|
| 15 | 2255 | 200 | 2107 | 250 |
| 16 | 1869 | 450 | 2992 | 350 |
| 17 | 2064 | 450 | 2796 | 300 |
| 18 | 2198 | 400 | 2673 | 350 |
| 19 | 2090 | 400 | 2463 | 400 |
| 20 | 2470 | 400 | 2680 | 300 |

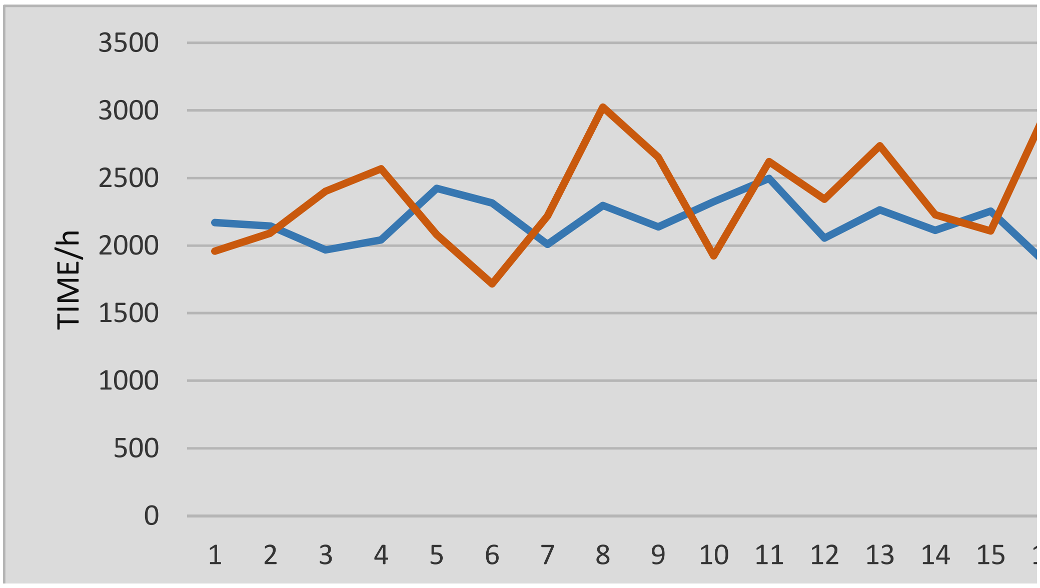


Figure 1. The results contrast of two kinds of algorithm

According to Fig.(1), conventional genetic algorithms are of diversity, a large search scope, a large solution fluctuation, and a high probability of poor solutions because the initial population is generated randomly. Comparatively, multi-objective berth co-operation algorithms may bring individual schemes worse than conventional genetic algorithms. These schemes are, however, comparatively stable. Solutions are of high quality. The probability of poor solutions is low as well. In terms of iterations, the two see a minor difference. Convergence happens within 500 times. This verifies the validity of the algorithm.

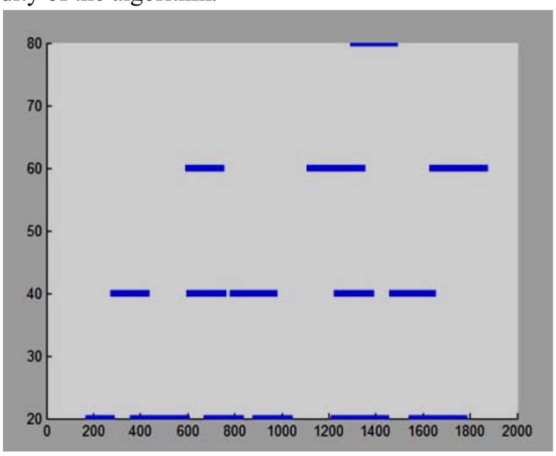


Figure 2. Berth layout

From the perspective of system, the results of the model are more instructive to actual production activities as ship quantity increases. It is not optimal but acceptable for an individual ship.

## B. *Algorithm Convergence*

Berth layout is solved by programming with matlab2011b based on the multi-objective co-operation method with scheduling rules show in Fig. (2). Fig. (3) illustrates fitness convergence. There is sound fitness convergence. This means that the solutions are efficient.

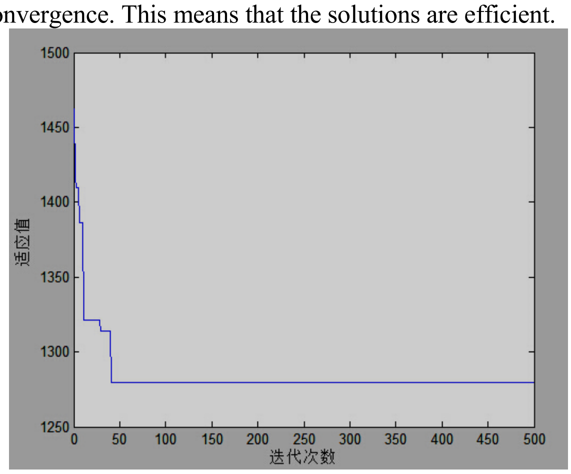


Figure 3. Fitness convergence

## IV. CONCLUSION

This paper studies the multi-objective co-operation optimization method for pier berth allocation. The method aims at minimum total in-factory time and shortest distance to the optimal working berth. Then the paper introduces the optimization model in dynamic continuous berth mode according to actual pier operation. With mutual correlation and mutual suppression between three objective functions, the optimization model ensures that each ship can finish working tasks in a planned period. From the perspective of solutions, this paper solves berth of various size ships according to the multi-objective co-operation method with scheduling rules. As the results reveal, the method brings higher quality solutions than conventional genetic algorithms.

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