EXTENDED GREAT DELUGE APPROACH FOR THE INTEGRATED DYNAMIC BERTH ALLOCATION AND CRANE ASSIGNMENT PROBLEM

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ABSTRACT
Globalization has quickly increased the volume of commodity flows using all modes of transport. Specifically, since the 1970s, containerization has increasingly facilitated the transport of goods throughout the world, and every major port is expected to double, and possibly triple, its container traffic by 2020. In order to accommodate the growth in international container transport, terminals must make significant changes to keep pace with increasing demand. One important manner in which existing terminal capacity could be increased would be through an increase in their efficiency. In this paper, we consider terminal efficiency from the perspective of simultaneously improving both berth and quay crane scheduling. The approach is applied to a modeling scheme found in the literature, and this study contributes to knowledge by improving the results found using a new metaheuristic and a crane transfer refinement procedure.

Keywords: Berth allocation, Quay crane assignment, Extended Great deluge metaheuristics, Optimization.

1. INTRODUCTION

Container terminals are the areas where containers are transported from one point to another using different pieces of handling equipment. Such terminals are continually growing in importance as maritime transport faces the challenge of using new technologies to build larger and larger ships. Moreover, transport frequency is only rising as commercial exchanges are developed to meet economic growth. To be able to compete within this environment, container terminals must be managed efficiently. To that end, managers must concentrate on the Berth, which is the most critical resource for determining container terminal capacity. An alternative approach to increasing Berth capacity involves improving its productivity through its efficient use (Park and Kim, 2003). One of the components of such efficient utilization is a focus on quay cranes, which are the main equipment used to move containers at terminals.

2. BERTH ALLOCATION AND CRANE ASSIGNMENT PROBLEM (BACAP)

More and more studies are being dedicated to the examination of container terminals and efficient operations that improve their productivity. Among them, studies dealing with berths and cranes are increasingly of interest to more and more researchers.

Recently, other studies have examined the two problems simultaneously, because they are actually encountered and interact in a port. In fact, the goal of a CAP (Crane Assignment Problem) is to determine the total time of docking at the quay (including the time of service: loading/unloading and waiting time), which represents an input of the Berth allocation problem (BAP). Modeling both problems simultaneously thus approximates the reality of the harbor; consequently, resolving the joint problem would be allow immediate application by a harbour manager.

The combination of both the BAP and the CAP leads to an interesting problem called the BACAP (Berth Allocation and Crane Assignment Problem); this combination has seldom been examined in the literature, but is beginning to attract the interest of the researchers in the field.

The concept was pioneered by Park and Kim (2003), who modeled the problem in its static-continuous variant in Integer Programming, and adopted a two-phase resolution. Meisel and Bierwirth (2006) were interested in the continuous-dynamic variant, and classified the problem as a Resource Constrained Project Scheduling Problem (RCPSP). A discrete dynamic variant was studied by Liang et al. (2008, 2009a), Liang et al. (2009b) and Liang et al. (2009c), who modeled the problem based on a mono-objective and multi-objective approach, and in both cases, adopted the genetic algorithm for the resolution. Imai et al. (2008) focus on the version discrete-dynamic. Their modeling objective was the minimization of the total time of service, including the constraints of the CAP. The resolution was based on the genetic algorithm, which is chosen for its ability to solve such problems using commercial mathematical programming tools. Miseil and Bierwirth (2009) used the model suggested by the pioneers Park and Kim (2003), and proposed a one-phase resolution based on the construction of a feasible solution, which was then further improved by metaheuristics.

In a recent publication, Bierwirth and Meisel (2010) were interested in the review of the literature on the integration of BAP and CAP problems. They listed the models formulated for the BACAP (Berth allowance and Crane Assignment Problem) and those used in resolutions been proposed over the last five years. They concluded that there is growing interest in such problems relating to in harbor management, and thus encourage future researchers to find new models more realistic and new effective resolution methods.

3. BACAP PROBLEM FORMULATIONS

3.1. Liang's Problem (2009)

The authors approached the problem to determine the exact position and the berthing time of each ship arriving at the quay of a port, as well as the exact number of Quay Cranes assigned to each of them in order to minimize the total time of accosting to the quay (including the time of loading/unloading, waiting and the time associated with the difference between the end of the service and the time of departure of the container ship estimated and programmed by the managers). Their model was implemented on a real harbour terminal in china.

The assumptions below were advanced for the formulation of the problem:

- Each container ship has a maximum number of cranes to be assigned.
- The time service of a container ship is directly dependent on the number of cranes assigned
- It is assumed that the time of arrival of the ship container to the port is known in advance, but the ship cannot berth before the expected arrival time
  → Which leads to the dynamic aspect of the problem.
- Loading/unloading operations must be carried out without interruption.
- Each zone of accosting must be able accommodate a maximum of one container ship.
  → Which leads to the discrete aspect of the problem.
- The crane transfer time is ignored.

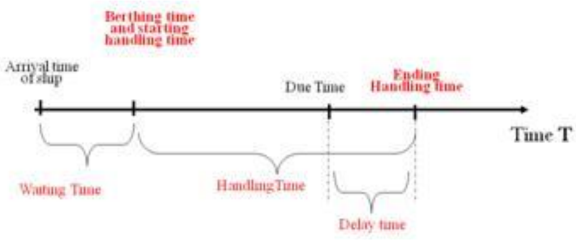

Figure 1: Ship's Timeline

$$Min\ \mathbf{Z} = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{n}\frac{c_i}{\nu.h_j}x_{ijk} + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{n}(s_i - a_i)x_{ijk+}\sum_{j=1}^{n}\sum_{k=1}^{m}\left(s_i + \frac{c_i}{\nu.h_j} - d_i\right)x_{ijk} \quad \textbf{(1)}$$

Subject to:

$$\sum_{j=1}^{m}\sum_{k=1}^{n}x_{ijk} = 1 \qquad \forall i \in (1,2....n) \quad \textbf{(2)}$$

$$\sum_{i=1}^{n}x_{ijk} = 1 \qquad \forall j \in (1,2....m)\,, \forall \mathbf{k} \in \mathbf{(1,2,.....n)} \quad \textbf{(3)}$$

$$\left(s_i + \frac{c_i}{\nu.h_j}\right)x_{ij,k-1} \le s_l x_{ljk} \quad , \quad \forall \mathbf{i,k,l} \in \mathbf{(1,2,...n),} \quad \forall j \in (1,2....m) \quad \textbf{(4)}$$

$$\sum_{j=1}^{m}h_j = H \quad \textbf{(5)}$$

$$x_{ijk} = 1 \quad or \quad 0 \qquad \forall i,k,j \in (1,2....n) \quad \textbf{(6)}$$

$$s_i \ge a_i \qquad \forall i \quad \textbf{(7)}$$

$$h_j : \text{int}\,eger \qquad \forall j \quad \textbf{(8)}$$

Where:

Indices

i (= 1, 2…n) ϵ V set of ships
j (= 1, 2…m) ϵ B set of berths
k (= 1, 2…n) ϵ O set of service orders

Parameters

.n : number of ships
.m : number of berths
.Wi : subset of V such that ship p with sp > ai
.ν : working speed of the cranes
H : the total number of cranes available in the port
.a_i : arrival time (estimated) of ship i
.c_i : number of containers required for loading/unloading for the ship i
.d_i : due departure time of ship i

Decision Variables

.s_i : starting time for i loading/unloading of ship i

.h_i : number of cranes assigned to ship i

.x_{ijk} : 1 , if the ship i is served as the k^{th} ship at the berth j; 0 , otherwise

The modeling above very simply and comprehensively represents the BACAP in its discrete-dynamic variant. The total time minimization objective makes the model very generalizable, and capable of being applied to most harbour situations.

The authors proposed a hybrid evolutionary algorithm based on a genetic algorithm to find an approximate optimal solution for the problem.

4. METHODOLOGY FOR THE PROPOSED APPROACH

The proposed model represents hard constraints that make the resolution by metaheuristics meeting much of non-feasible solutions that the algorithm must circumvent. For this reason, a population method such as the genetic algorithm is not fully appropriate for such problems.

In this paper, and to mitigate the obstacle above, we propose to solve Liang's BACAP with a new metaheuristic method based on neighbourhood search.

The Extended Great Deluge metaheuristic is then applied. Prior to that, a heuristic is constructed to find the first feasible solution, which is gradually improved with the exploration of the neighbourhood by the metaheuristic algorithm.

This is what differentiates the approach suggested in this research from the resolution suggested by the authors, which sets on a random initial solution.

The construction of the initial feasible solution aims to increase the rate of acceptance of the metaheuristic within the resolution, which also results in increasing the efficiency and speed of the resolution.

Besides the application of another type of algorithm to solve the problem, we integrate the priority aspect for the resolution. In fact, unlike Liang's approach, we add constraint relatively to the priority service in case of arbitrage between two arrivals. The approach suggested in this paper is to first adopt the FCFS rule, and then the Most charged First rule OR Less Charged First rule in the case of arbitrage. Such a context could arise in order to satisfy some customers. The harbor manager could then have different scheduling scenarios and XXX

To refine the optimal solution found by the metaheuristic, we apply a procedure that allows the transfer of cranes between berths under certain circumstances (conditions). Such transfers can minimize handling time for some ships, and consequently, total service time.

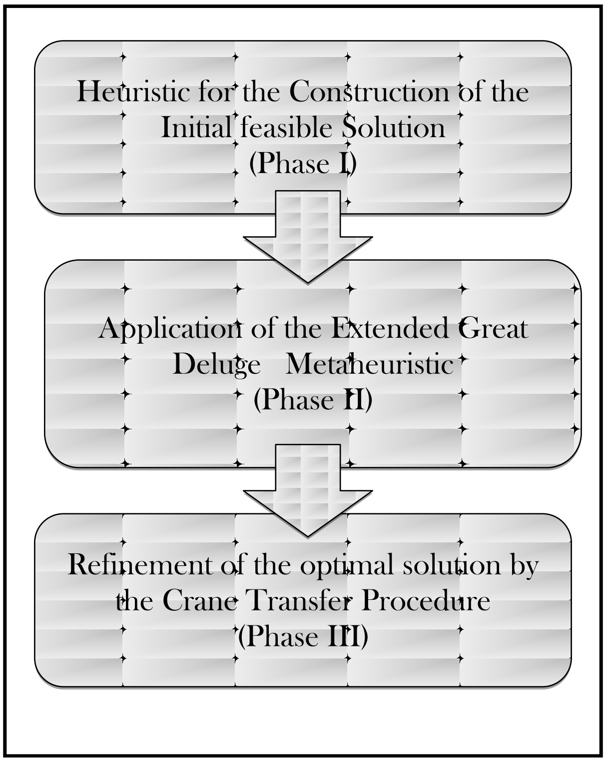

Figure 2: BACAP Resolution Approach

4.1. Heuristic for the initial solution

Before the application of the metaheuristic, a heuristic is constructed to find the first feasible solution, which is gradually improved with the exploration of the neighbourhood by the metaheuristic algorithm.

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Figure 3 illustrates the proposed heuristic used to find the first feasible solution to the problem.

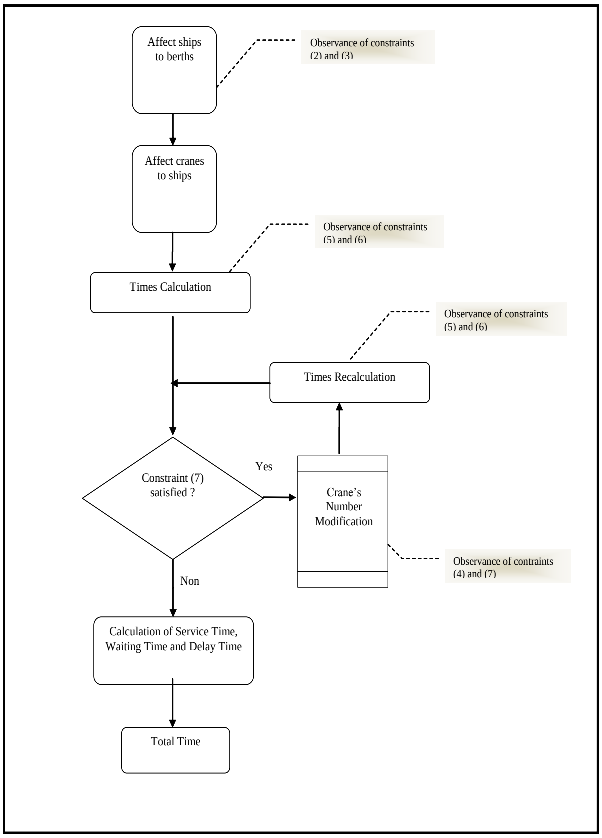


Figure 3: Proposed heuristic to construct the initial solution

4.2. Extended Great Deluge metaheuristic

As explained above, the choice of the metaheuristic that will improve the initial solution was related to a local search or neighbourhood metaheuristics. To that end, we explored the relatively new Extended Great Deluge (EGD) (Burke et al., 2004).

For the application of this algorithm to our problem, we needed:

1. The initial solution S found by the heuristic.
2. The definition of the neighbourhood N(S) of this solution.

Table 1: Extended Great Deluge method

Extended Great Deluge Method
 	
Set the initial solution ***S***
Calculate initial cost function ***f(s)***
Initial ceiling ***B=f(s)***
Specify input parameter Δ***B=?***
While not stopping condition do
    Define neighbourhood ***N(s)***
    Randomly select the candidate solution S^* Є ***N(s)***
    If $(f(s^*) \le f(s))$ or $(f(s^*) \le B)$
    Then Accept S^*
    Lower the ceiling $B = B - \Delta B$
End while.

The neighbourhood was created while making minor modifications to the initial solution S, such as to the permutation between two container ships taken randomly. The permutation was done for both the berth and the cranes assignment. Following the modifications, the algorithm applied tests on the neighbourhood solution to check if all the constraints were satisfied.

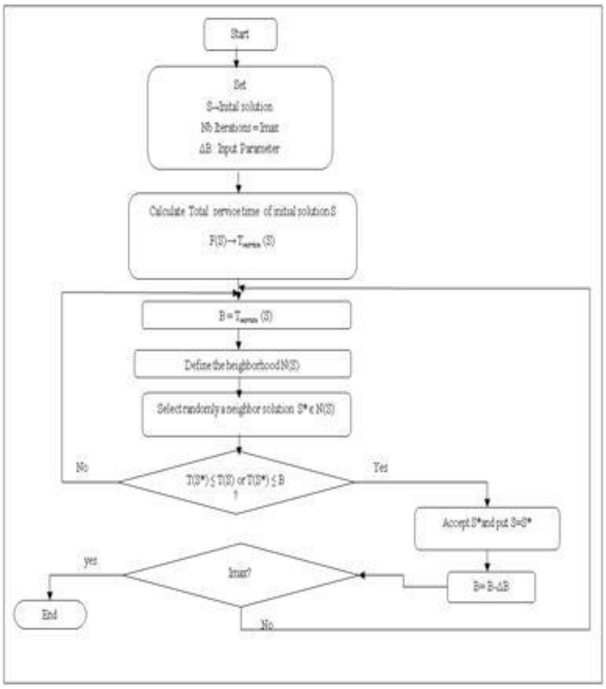


Figure 4: Proposed heuristic to construct the initial solution

5. PRIORITY RULES INCLUDED IN THE MODEL

In this paper, unlike with Liang et al.'s approach (2009a), we include priority rules.

1. Like Liang's approach: Give FCFS rule for the initial solution and then randomly generate neighbourhood solutions.
2. FCFS rule that is governing even the neighbourhood solutions.
3. FCFS rule like (b) and when 2 ships assigned to the same berth have the same time arrival, we prioritize the Most charged one.
4. FCFS rule like (b) and when 2 ships assigned to the same berth have the same time arrival, we prioritize the less charged one.

5.1. Constraints added to the model

For each of the configurations above, a constraint that guarantees the priority rule is added.

a) FCFS-Rule:

b) FCFS-Rule followed by the most charged ship rule in case of arbitrage:

(9*i*)

c) FCFS-Rule followed by the less charged ship rule in case of arbitrage:

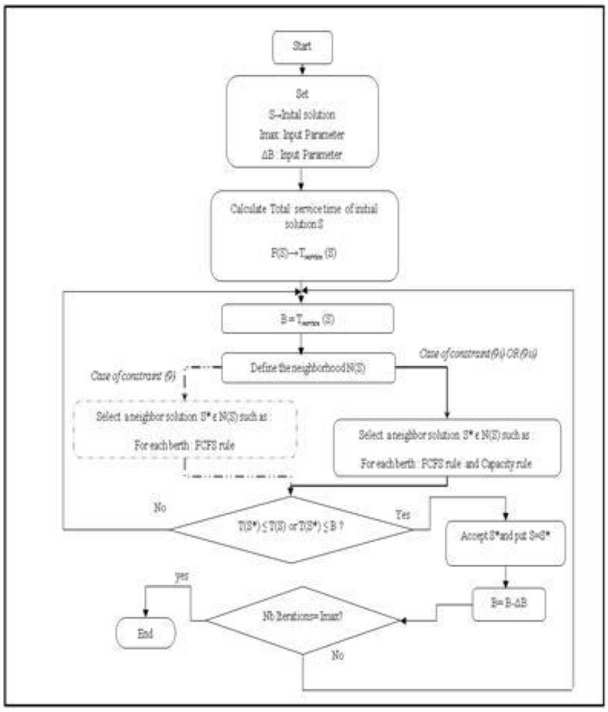


Figure 5: Extended Great Deluge algorithm

6. THE REFINEMENT PROCEDURE BY CRANE TRANSFER

After obtaining the optimal solution by the EGD metaheuristic, we try to improve the result by transferring some cranes, when permitted, in order to minimize some ships' service time. The assumptions below are considered:

1. The adjustment of cranes during service time (charging or discharging of ships) is allowed.
2. Cranes are transferred from one berth to another when handling is completed for ship *A*, and at the same time, another ship *B* on the other berth is still under service. The transfer thus minimizes the remaining time of service for ship *B*.
3. Crane transfer is permitted between two consecutive berths or between berths via others if the latter are not engaged in ship loading or unloading.
4. After servicing the k^{th} ship in a berth, the cranes used can be transferred totally or partially to the $k+1^{th}$ ship in the same berth, when permitted.
5. Time of transfer is ignored for the moment, but can be calculated considering the number of cranes or the distance of transfer.

7. EXPERIMENTS AND RESULTS

The authors applied their methods to solve a real case, at a Shanghai container terminal company in China. In that case, there were 4 berths and 7 quay cranes. The working speed of the quay crane was common to all the cranes and was set at 40TEU/h. The data concerning the arrival time, the time due and the capacities of the ships are shown in the Table2.

In our case, we will use the EGD, preceded by the initial solution construction heuristic to first compare the optimal solution found by Liang et al. (2009a) to the EGD solution. We then present the scheduling in both the Most Charged First and Less Charged First cases. Finally, we present the refined solution found by application of the transfer crane procedure. The parameter settings for the metaheuristic were: Nb iterations = 200,000 and delatB =0.005.

The approach is coded in Matlab R2009b, on a Pentium 4 processor (2-GHz clock) computer.

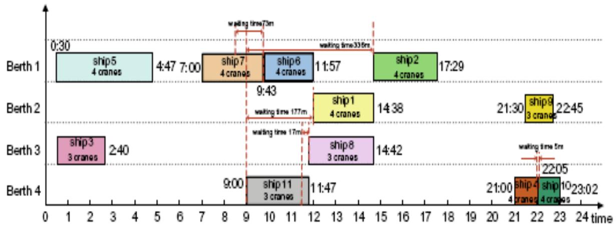
Table 2: Ship Information

	Ship name	Arrival Time	Time Due	Total number of container loading/unloading (TEU)
1	MSG	09:00	20:00	428
2	NTD	09:00	21:00	455
3	CG	00:30	13:00	259
4	NT	21:00	23:50	172
5	LZ	00:30	23:50	684
6	XY	08:30	21:00	356
7	LZI	07:00	20:30	435
8	GC	11:30	23:50	350
9	LP	21:30	23:50	150
10	LYQ	22:00	23:50	150
11	CCG	09:00	23:50	333

7.1. Optimal solution for Liang's problem

The authors solved the problem and found an approximate optimal solution, 2165 min, that minimizes the total service time. Figure 6 illustrates the Gantt chart for that solution.

Figure 6: Gantt chart for Liang's solution (2009a)



7.2. Optimal solutions for the EGD approach

In this paper, and when we apply the FCFS rule for the initial solution and randomly generate the neighbourhood solutions during the metaheuristic resolution, we improved the optimal solution to 1857.4 min. as total service time. That represents 307.6 min or about more than 5 hours less than the authors' optimal solution. The distribution of times in minutes is: 1103.7 min for the handling, 749.7 for the waiting, and 4 min as delay time. The Gantt chart for the solution is shown in Figure 7.

The EGD metaheuristic is then a practical and powerful method resolving the problem. In our Gantt, the number of the quay cranes transfers is lower than in Liang's solution.

We also obtain the solutions below for the FCFS rule, and for the FCFS with the two handling priority rule cases.

For the FCFS rule: Gantt chart in Figure 8.

Total service =1803.1 min., Handling = 1350.6 min, Waiting = 452 min. and Delay = 0 min

For the FCFS with the Most charged ship priority, we obtain an optimal solution as: (Figure 9)

S={berth1, berth2, berth3, berth4}
= {Ship 8;
Ship 3, Ship9;
Ship5;
Ship7, Ship6, Ship2, Ship1, Ship11, Ship4, Ship10}

with total times in min. as:1915.6 for the total service, 1403.8 for Handling, 511.7 for waiting and no Delay.

For the FCFS with the Less charged ship priority, we obtain an optimal solution as: (Figure 10)

S={berth1, berth2, berth3, berth4}
= {Ship7, Ship6, Ship10;
Ship8;
Ship3, Ship5, Ship9;
Ship11, Ship1, Ship2, Ship4}

with total times in min. as:1914.1 for the total service, 1337 for Handling, 577 for waiting and no Delay.

To apply our Crane transfer procedure, we choose the optimal solution found by the EGD in the random context (see Figure 7). The transfer steps considered are as follows:

1. For berth 2, and after using 7 cranes for the first and the second ships served, which are ships 7 and 6, we can add 2 cranes to serve the ship 11, which only has 5 cranes.
2. After serving ship 9 in berth 3, we can transfer the cranes used (totally or partially) to berth 1 to serve ship 4, such that the handling is

minimized and ship 10 arrives at 9 PM and waits before service can begin.

3. For berth 4, and after using 7 cranes for the first ship served, which is ship 3, we can add 3 cranes to serve ship 5, which has only 4 cranes.

After transferring the cranes from ship to ship and berth to berth, we obtain a more optimal solution. The cranes or resources are then best dispatched between the ships. The Total service time is then 1559.9 min against 1857 before the transfer. The times distributions are: 879.2 min. 680.7 min. and no Delay. (Figure 11)

8. CONCLUSION

In this paper, we solve a BACAP in its discrete-dynamic variant. The approach used is based on an Extended Great Deluge metaheuristic preceded by a heuristic to construct the initial feasible solution. A transfer crane procedure is added to enhance the quality of the solution.

The proposed approach provides very satisfactory results, particularly when we compare it with the hGA approach proposed by Liang et al. (2009a). The EGD metaheuristic gave interesting results for the multiobjective case as well. In fact, tests were applied to solve the Liang and Al. (2009b), and the results were very satisfactory.

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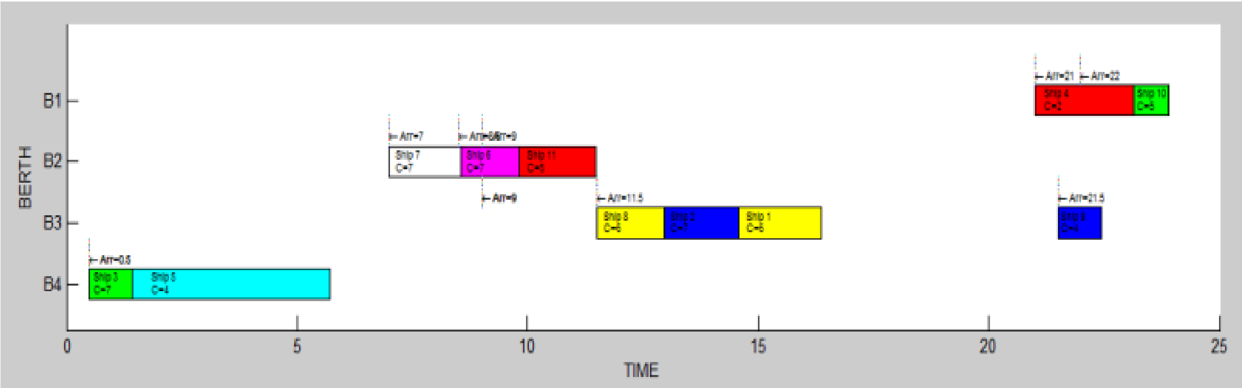

Figure 7: Gantt Chart for the randomly context

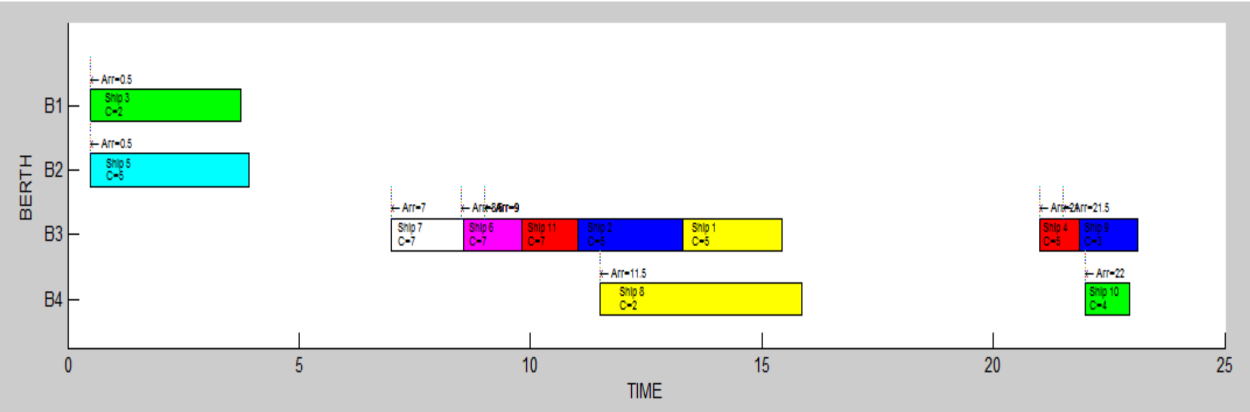

Figure 8: Gantt Chart for the FCFS context

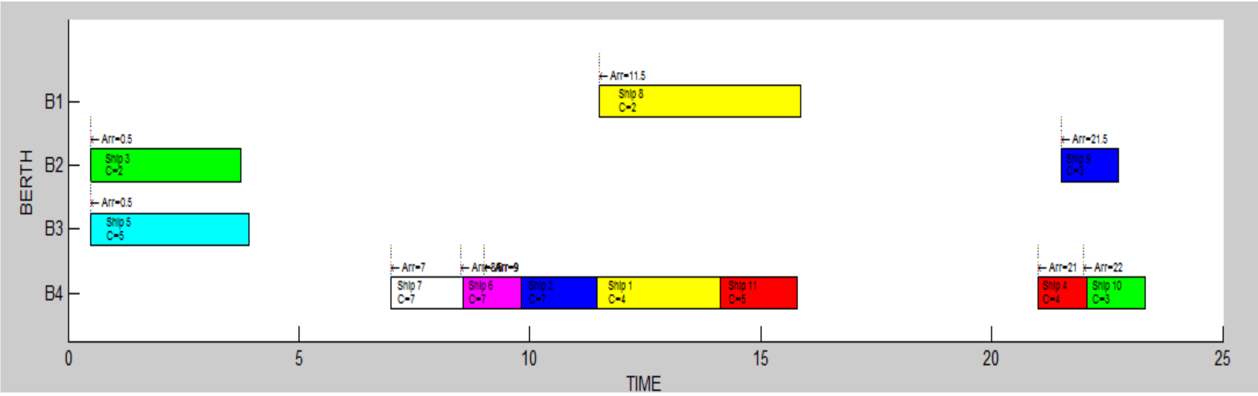

Figure 9: Gantt Chart for the FCFS with Most Charged first

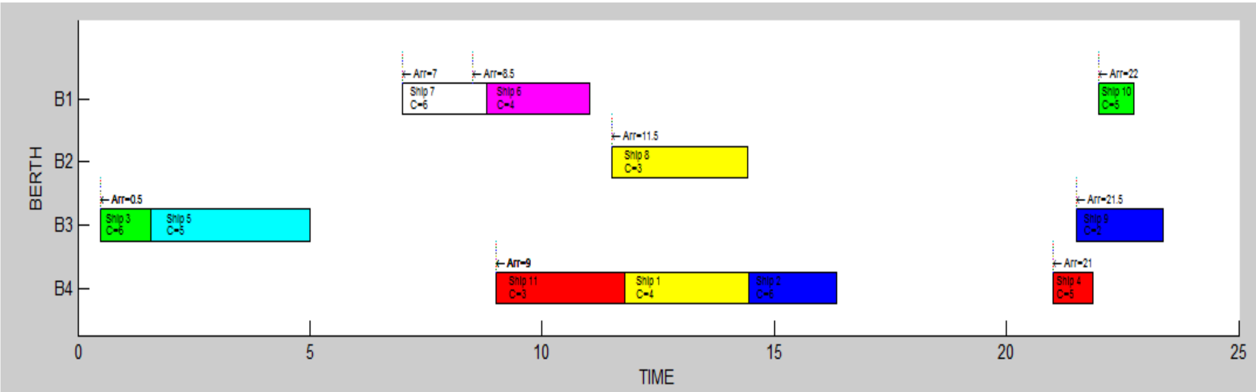

Figure 10: Gantt Chart for the FCFS with Less Charged first

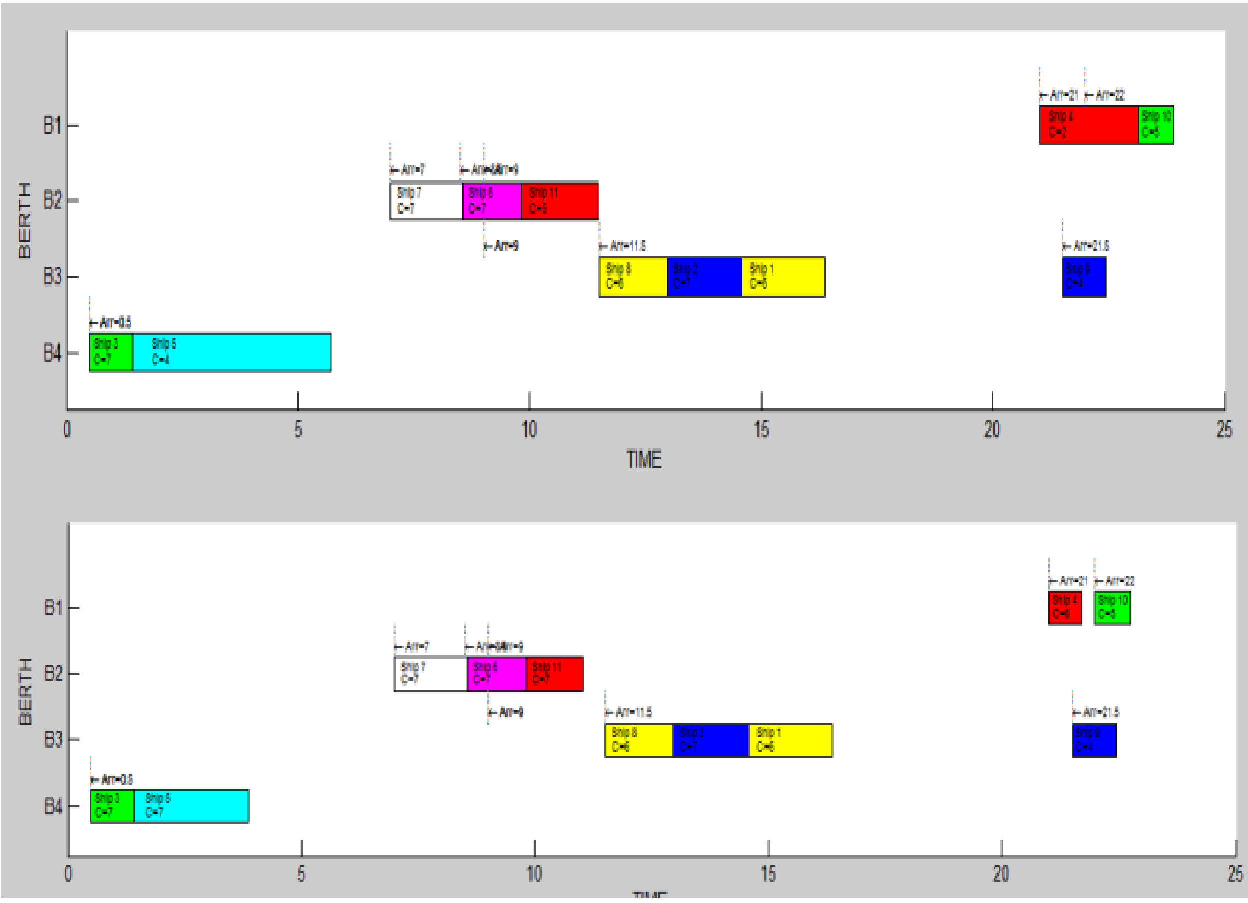

Figure 11: Gantt Charts for the optimal solution before and after crane transfer procedure