Greedy Heuristic for Berth Allocation in Tidal Bulk Ports

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Abstract. *In berth allocation problem, a berth is defined as a specific location alongside a quay where a ship loader is available for loading or unloading vessels, accommodating only one vessel at a time. In tidal ports, draft conditions are hardly affected by the tide conditions, as depth at low tide or tide flow. Some port terminals are associated with important transnational enterprises which maintain strong control over the stock level of their goods. Since the stock level sometimes depends on a continuous process of consumption or production of minerals, the basic criterion for decision making is to give priority to the vessels related to the most critical mineral stock level. A second basic criterion is related to performance measures that may consider overall quay utilisation, demurrage, makespan or total service time within a given planning horizon. This paper presents a greedy heuristic to make berth decision trying minimizing total service time, not considering yet stock level conditions. Some problem instances are solved by the proposed heuristic and comparisons are made to evaluate its performance.*

1. Introduction

In Brazil, ports that handle dry bulk cargo, called bulk ports, are responsible for the outgoing of great part of agricultural exports, including coffee and soy, minerals such as iron ore, and imports of petrol derivatives. In port planning task, the operational teams are used to work with concepts related to time issues: Expected Time of Arrival (ETA), Expected Time of Berthing (ETB), Expected Time of Completion (ETC) and Expected Time of Sailing (ETS). ETA is previously known, but the others depend on certain operational conditions, like tidal conditions, berth availability, handling time and the relative importance of the vessel.

In this paper, the problem of allocating berth positions for vessels in tidal bulk port terminals is considered as follow. A berth is a quay location, equipped with one or more ship loaders, usually accommodating one vessel at a time. In tidal ports, even when a berth position is available, vessels may need to wait for mooring. At low tide, available depth in such ports is not adequate for the movement of ships. The transit from waiting areas to the berth position is done in time windows at regular time intervals, previously known, in general, during high tides. Bulk ports essentially operate with bulk cargo, transported unpackaged in large quantities, classified as liquid (e.g., petroleum, gasoline, caustic soda and chemicals) or dry (e.g., coal, grain, iron ore and bauxite ore). Despite relatively ample literature about decision making in container ports, very little space has been devoted to grain or bulk cargo ports [Günther and Kim,2005, Cordeau et al., 2005, Imai et al.,2006, Bierwirth and Meisel,2009].

This paper is devoted to the proposition of a specific greedy criterion employed in a heuristic algorithm to minimize the overall service time. By minor decisions, made step-by-step, the proposed algorithm tries allocating vessels to berths following the ETA priority, regarding the berth throughput.

The remainder of this paper is organized as follows. The greedy heuristic is proposed in Section 2. In Section 3, the computational results are examined and discussed and the conclusions are summarized, at last, in Section 4.

2. Greedy heuristic proposal

The Berth Allocation Problem in Tidal Bulk ports with Stock constraints (BAPTBS) has been modelled in a discrete form as an assignment of N ships to L berths, over a planning horizon of M TTW (Time Tabling Windows) [Barros et al., 2009]. For convenience, TTWs happen in a regular and known time frequency TF ($TF \cong 12$ hours, if contemplating only hide tides). The time scale, including all time-dependent data, as vessel's arrival times, days on hand, etc, is discretized and expressed as multiple of TTW duration. The data for BAPTBS, in the heterogeneous case, without considering stock level issues, are given by [Barros et al., 2009]:

- N: set of ships, $n = |N|$;
- M: set of TTWs, $m = |M|$;
- L: set of berth positions, $l = |L|$;
- K: set of $|K|$ raw material;
- a_i: arrival TTW of ship i;
- v_l: throughput of load/unload for beth l;
- q_{ik}: the cargo load of ship i with respect to bulk cargo k.

The handling time, h_{il}, depends on the cargo load q_{ik} of ship and the berth throughput v_l (Eq. 1). The objetive function, employed in this work, minimizes the total service time over the planning horizon (Eq. 2) taking in account the decision variable y (Eq. 3).

$$h_{il} = \left\lceil \frac{\sum_{k=1}^{|K|} q_{ik}}{v_l} \right\rceil \tag{1}$$

$$\min \sum_{i=1}^{N} \sum_{j=a_i}^{M} \sum_{l=1}^{L} \left\lceil \frac{j - a_i + 1}{h_{il}} \right\rceil \times y_{ijl} \tag{2}$$

where y_{ijl} represents the decision variable that assigns ship i to berth l at TTW j:

$$y_{ijl} = \begin{cases} 1 & \text{if ship } i \text{ is allocated to berth } l \text{ at TTW } j \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

The greedy strategy, now proposed, for the (BAPTBS) considers the operational cost, expressed by a time equation, of a given decision y_{ijl} that affects all the subsequent decisions in the planning horizon. Initially, vessels are sorted, considering their ETA, stablishing a *first-in-first-out* priority queue (FIFO). After that, iteratively, the vessels are removed from FIFO and assigned to a berth with minor operational cost in its first available TTW. Eventual draws in FIFO are arbitrarily decided. The pseudocode 1 summarizes the greedy algorithm.

Algorithm 1 Greedy Algorithm

```
begin
for n ∈ N do
    i ← getShip(FIFO)
    for l ∈ L do
        cost ← calculateCost (i, l, &b_i, &h_il)
        if cost < MinCost then
            MinCost ← cost
            MinBerth ← b_i
            MinOperation ← h_il
        end
    end
end
UpdateOcupationMatrix (MinBerth, MinOperation)
end

float calculateCost (i, l, &b_i, &h_il)
{
for j ← a_i to M do
    if y_ijl = 0 then
        b_i ← m
        h_il ← ⌈ (Σ_{k=1}^{|K|} q_ik) / v_l ⌉
    end
end
return(b_i + h_il)
}
```

3. Computational experiments

A set of heterogeneous case instances is presented in Table 1. One can see 14 instances of 10, 15, 20 and 30 ships, varying the number of berths. The optimal values and TTW were obtained by CPLEX, a high performance Linear Programming (LP) and Mixed Integer Programming (MIP) solver [Ilog,2012]. The CPLEX has spent a running time from 1 upto 28,000 seconds, or even not to solve a given instance, depending on its hardness. [Instances that have unknown optimal solutions were represented by a cross ('-') at 'Optimal' column in Table 1.] As one can see, the Greedy Heuristic running time is about 0.01 second. However, due to its approximative nature, the proposed heuristic just finds a local optimal solution, except to the instance "15-30-4". The Table 1 shows the computational results obtained.

Considering that, in general, first ships are served by fastest berths, slow berths cannot be used throughout the planning horizon, this happen with instance "10-15-4", where the berth number 3 is always idle, [because this berth is the slowest one. This is done by the nature of objetive function (makespan), that considers to minimize individual makespans' ships. Minimizing individual makespans' ships means to cause its ETC minimum by to allocate ships to fastest berths, avoiding slow ones. In this case, slow berths tend to stay idle for this purpose. Some BAPTBS solutions generated by exact optimization methods presented idle berths in planning horizon, like aproximative ones. If idle berth harm the final solution, then a method to avoid this problem should be used, like to force ships using idle berths].

Table 1. Computational results obtained by the greedy algorithm for problem instances

Instance	Ship	Berth	TTW	Time (s)	Optimal	Obtained
10-15-4	10	4	15	0.00	29	31
10-20-3	10	3	20	0.00	44	45
10-25-2	10	2	25	0.01	43	46
15-30-4	15	4	30	0.01	77	77
15-35-3	15	3	35	0.01	86	101
15-40-2	15	2	40	0.01	121	144
20-40-3	20	3	40	0.01	107	128
20-40-4	20	4	40	0.01	108	123
20-45-4	20	4	45	0.03	105	123
20-50-3	20	3	50	0.03	-	128
20-55-2	20	2	55	0.01	297	318
30-70-4	30	4	70	0.03	-	230
30-75-3	30	3	75	0.03	190	229
30-80-2	30	2	80	0.03	-	679

4. Conclusion

The Berth Allocation Problem in Tidal Bulk ports with Stock constraints (BAPTBS) consists of determining the assignment of ships to berths in a given planning horizon, depending on tidal conditions, berth availability, handling time and the relative importance of the vessel.

This paper presents a greedy algorithm to minimize the total service time, regarding the service time of each assignment. The proposed heuristic aims to be faster than other approaches since it is a polinomial time algorithm. The computational results point to improvement needs and subsequent developments as to extend the greedy strategy to a constructive phase of a further Greedy Randomized Adaptive Search Procedure (GRASP), in which the improvement phase can adjust the port lineup to avoid stock level crashes.

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