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Berth allocation in an ore terminal with demurrage, despatch and maintenance

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ABSTRACT

This paper presents a Berth Allocation Problem (BAP) encountered in an ore terminal located in a Brazilian port. The BAP consists of assigning ships to berthing positions along a quay in a port. In the Brazilian port considered here, maintenance activities have to be performed at the berths and extra fees (demurrage) or rewards (despatch) for the port administrator are incurred. We propose a mixed integer linear programming model for the problem and a set of instances based on real data in order to validate the model. An adaptive large neighborhood search (ALNS) heuristic is applied to solve the instances and computational experiments are performed. The results indicate that the ALNS heuristic yields good solutions on all instances.

1. Introduction

Transportation demand has significantly increased the development of new technologies for the construction of large ships due to worldwide globalization. Thus, ports must constantly adapt to satisfy the new demand and must keep looking for new ways to increase their operational efficiency. Among the costs involved in port operations are those related to allocating ships to berths. This process is known as the Berth Allocation Problem (BAP).

In the BAP one must determine when and where the ships should moor along a quay. The typical objective is to minimize the total time spent by the ships at the port. Here, we must take into account both the economical use of available resources in the port and the fast service requirements imposed by the shipowners. In some cases, different objectives can be combined, such as priorities for some kinds of ship, for example. There are two versions of the BAP: in the discrete case, the ships must berth in specific locations along the quay whereas in the continuous case they can berth anywhere along the quay. Several mathematical models have been proposed to model the BAP. They have become a fundamental tool for the optimization of ship scheduling.

Motivated by the shipment of solid bulk cargoes, which is the main cargo type handled in Brazilian Private Terminals (ANTAQ, 2014), see Fig. 1, this paper proposes a mixed integer linear programming model to represent the berth allocation process at an ore terminal administered by a private company located in Vitória, Espírito Santo State, Brazil.

We have studied the main physical and operational characteristics of the ore terminal to generate our mathematical model. In order to evaluate it, we have created a set of instances based on the availability of ships over a period of more than two months at the ore terminal. CPLEX was used to perform computational experiments with the model. Given the limitations of this approach, we have then developed an adaptive large neighborhood search (ALNS) heuristic to solve the problem. The ALNS was chosen due to its excellent performance on several other combinatorial problems. To the best of our knowledge it was not used before to solve a BAP. Computational results confirm that the proposed heuristic can be applied to practical situations.

The remainder of this paper is organized as follows. Section 2 describes the Brazilian BAP, while a brief literature review is presented in Section 3. The proposed model is detailed in Section 4 and the ALNS heuristic is described in Section 5. Computational results are presented in Section 6, followed by conclusions in Section 7.

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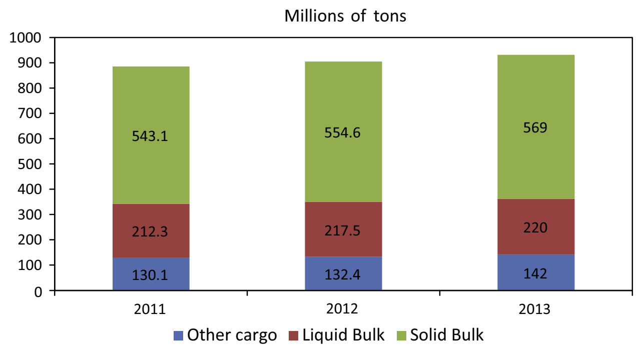

Fig. 1. Cargo handling evolution in Brazilian ports (ANTAQ, 2014).

2. Brazilian BAP

The Ore Terminal (OT) is a "terminal for a private use" (TPU) administered by a private Brazilian company. It is located in the city of Vitória in the Espírito Santo State, Brazil. The OT is made up of three distinct terminals: Iron Ore, Bulk Liquids and Diverse Products. The OT is a major terminal in Brazil. It handles the largest amount of cargo among all TPUs (110.5 milions of tons in 2013). The ore handling represented 92.6% of the OT operations. Fig. 2 shows the amount of cargo handled by the Brazilian TPUs in 2013.

The OT is accessible by rail and road and has two piers capable of handling three ships simultaneously (it has three berths). The first pier is able to handle two ships at the same time: ships with up to 170,000 tons of iron ore at the south side (berth 1), and ships with up to 200,000 tons of iron ore at the north side (berth 2). The third pier (berth 3) can handle ships with up to 365,000 tons of iron ore. Table 1 presents some operational data of the OT.

The ships scheduling is usually made considering a fortnightly or a monthly planning horizon. Some ships may already be in the port at the beginning of the berth allocation planning phase and estimated arriving times are used for the remaining ships.

A cargo time indicates the time at which the cargo of a given ship will be available to be handled. In some cases, the ship can be at the port but the cargo to be loaded is not yet available. In such cases, the ship can only moor if its cargo is available to be handled.

2.1. Demurrage and despatch

An agreement between the port administrator and the shipowners defines a period normally allowed to load or unload cargo, called *laytime*. The laytime is an interval during which the ship will be available to be handled. If the laytime is exceeded, a *demurrage* situation occurs. In this case, the port administrator

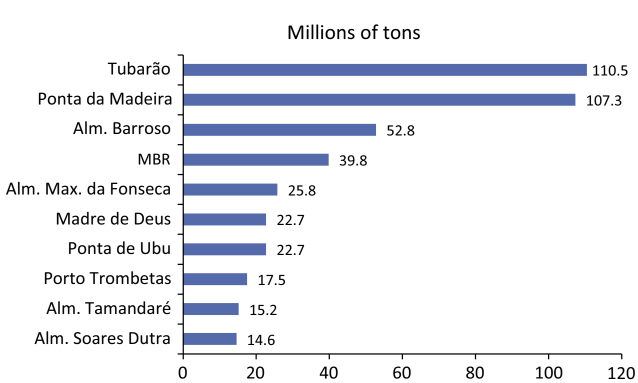

Fig. 2. Cargo handled in Brazilian TPUs in 2013 (ANTAQ, 2014).

Table 1
Operational data from ore terminal.

Berth	1	2	3
Max. weight (10^3 tons)	170	200	365
Max. length (m)	285	301	350
Nominal handling rate (10^3 tons/h)	16	16	16
Average handling rate (10^3 tons/h)	12	12	12

must pay an extra fee to the shipowner. However, if a ship is handled before the laytime, we have a *despatch* situation and the shipowner provides a reward for the port administrator. The demurrage and despatch fees are defined by contract and can be different for each ship.

2.2. Berth maintenance

Another common situation in the OT is related to scheduled maintenance activities to be performed at the berths. Maintenance is essential to repair and preserve the equipment used to handle the ships. It is important to consider maintenance together with the ships handling during the berth allocation. A maintenance activity can be modeled as a dummy ship which must be handled at a precise time by a specific berth, which means that this berth cannot receive ships during that time. To facilitate reading, in the remainder of this paper we will use the word "ship" to designate an actual ship or a "maintenance activity".

3. Review of the berth allocation problem

Several models and algorithms have been proposed for the BAP over the last two decades. Here we can highlight some of the most important ones.

Thurman (1989) was one of the earliest authors to study the BAP. He constructed an optimization model for berth planning at the Norfolk Naval Station in the United States. However, research on the BAP really took off at the beginning of the 21st century.

Imai, Nishimura, and Papadimitriou (2001) proposed a dynamic approach for the BAP. The authors considered the dynamic arrival of ships in the port. They presented a model and a Lagrangian relaxation algorithm to solve the problem. Two years later, Imai, Nishimura, and Papadimitriou (2003) upgraded their approach by considering different service priorities between the ships and proposed a genetic algorithm to solve the problem. The same authors (Imai, Sun, Nishimura, & Papadimitriou, 2005) later treated a different approach based on the solution of a cutting stock problem. Physical restrictions at the port, represented by the diversity of the ships (length) were considered by Imai, Nishimura, and Papadimitriou (2008).

Cordeau, Laporte, Legato, and Moccia (2005) noted that the discrete BAP can be viewed as a parallel machine scheduling problem (Pinedo, 1995) where berths correspond to machines and ships correspond to jobs. These authors developed two tabu search heuristics to solve the discrete and continuous versions of the BAP using data from the port of Gioia Tauro in Italy. They compared them with a truncated branch-and-bound algorithm applied to an exact formulation and showed that their two heuristics were able to handle various features of real-life problems, including time windows, as well preferred and acceptable berthing areas. The authors proposed some sets of instances which have been used as benchmarks in some recent papers.

Monaco and Sammarra (2007) proposed a strong mixed integer programming model based on the machine scheduling representation, which they solved by Lagrangean relaxation.