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Model and heuristic for berth allocation in tidal bulk ports with stock level constraints

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ABSTRACT

We consider the problem of allocating berth positions for vessels in tidal bulk port terminals. 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 depend on high tide conditions, since available depth at low tide is not adequate for the movement of ships. 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 decision to load or unload vessels must consider the amount of the bulk cargo stored in the port yards. Therefore, a 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 to decide what sequence of vessels reduces the overall demurrage within a given planning horizon. This paper presents an integer linear programming model based on the transportation problem to represent the Berth Allocation Problem in Tidal Bulk ports with Stock level conditions (BAPTBS). Problem instances are solved by a commercial solver and by a Simulated Annealing-based algorithm (SA). The SA employs a problem-specific heuristic, becoming a valid alternative for finding out good solutions for difficult instances.

1. Introduction

The importance of the port grows with increasing progress in the technology of construction of big ships and improved trade between nations resulting from globalization. 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. Bulk ports play an important role in the Brazilian economy and its greater efficiency is being sought through administrative and operational efforts.

In port planning task, the operational teams work with four concepts: 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. Vessel priority is strongly associated with logistic issues in trading management and industrial plant workflow.

In this paper, the problem of allocating berth positions for vessels in tidal bulk port terminals is considered. A berth is a quay location, equipped with one or more ship loaders. It is usual to say that a berth may accommodate 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 during high tide which happens at 12-h intervals, approximately.

Bulk ports essentially operate with bulk cargo. Bulk cargo is 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). Vessels are loaded using either excavators and conveyor belts or pipelines. Silos or stockpiles for the bulk cargo are often alongside the berth.

This research is motivated by a problem at the maritime industrial port complex of São Luís, formed by Itaqui port and the private terminals of Ponta da Madeira (Vale Mining Company) and Aluminum Consortium of Maranhão (Alumar Aluminum refinery). The private terminals of Vale and Alumar, large transnational enterprises, maintain a strong control over the raw material stock level. The three port terminals are together responsible for the second largest grain cargo handling in Brazil (Vale, 2008).

The mining company moves cargo along 9820 km of its railroad network to its 6 port terminals. About 81.7 million tonnes of cargo

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are loaded through the Ponta da Madeira Complex (based on 2006 reports), most of which are minerals as iron ore and pellets (Vale, 2008). Furthermore, Vale also loads more than 60 different types of products, such as steel, coal, limestone, granite, containers, pig iron, agricultural products, wood, pulp, vehicles and various cargoes. For bulk operations, stock level must be sufficient for loading onto the ships.

The aluminum refinery, in turn, controls the stock level by avoiding production collapse caused by lack of some raw material, such as coke, caustic soda, petroleum pitch and bauxite ore. A raw material with stock below a certain critical level gains high priority for unloading. The stock level is measured in terms of days-on-hand (DOH).

The relative importance of the vessels is also influenced by contractual costs. Trips are associated with transport contracts that define a set of rules and responsibilities for both the contractor and the owner or shipper. Through such contracts, vessels must arrive in pre-established lay-day windows, defined by the logistic enterprise team, considering mineral consumption or production. The lay-day definition is a sufficiently hard problem, solved at a strategic level before an operational one.

The contractual cost is commonly incurred due to delayed ship operation caused by events under contractor responsibility, like unavailability of shiploaders or even management decisions. When vessels at a port are not loaded on time a charge, called demurrage, is levied against the ship-contractor. If a vessel is loaded ahead of schedule the ship-contractor receives a credit called dispatch. Demurrage or dispatch at the discharge (or charge) port can be estimated during allocation planning.

The problem of allocating berth positions for vessels in tidal bulk terminals considers some conditions as hard constraints and others as penalty costs to be minimized. The problem is to determine the berths so as to minimize the total demurrage incurred given the tidal conditions and the stock level constraints. Berth constraints may not be considered, i.e, berth positions are similarly equipped (homogeneous berth positions) and they may load or unload any bulk cargo. The term bulk cargo is employed in this work to represent any kind of ingoing or outgoing good. Fig. 1 illustrates the operational scenario in a tidal bulk port with homogeneous berth position.

Several berth allocation models have been proposed in the literature. They differ in terms of the assumptions being made, such as whether the vessel waiting is allowed (Guan, Xiao, Cheung, & Li, 2002; Imai, Nishimura, & Papadimitriou, 2001; Kim & Moon, 2003), whether multiple mooring vessels at a berth is possible, whether vessel arrival times are considered, whether the processing times are proportional to vessel size (Lim, 1998), whether the berth positions are continuous or discrete (Cordeau, Laporte, Legato, & Moccia, 2005), and so on. Vessels do not need to wait when berth space is abundant, when parallel mooring is possible, or there are not any tidal conditions to be considered.

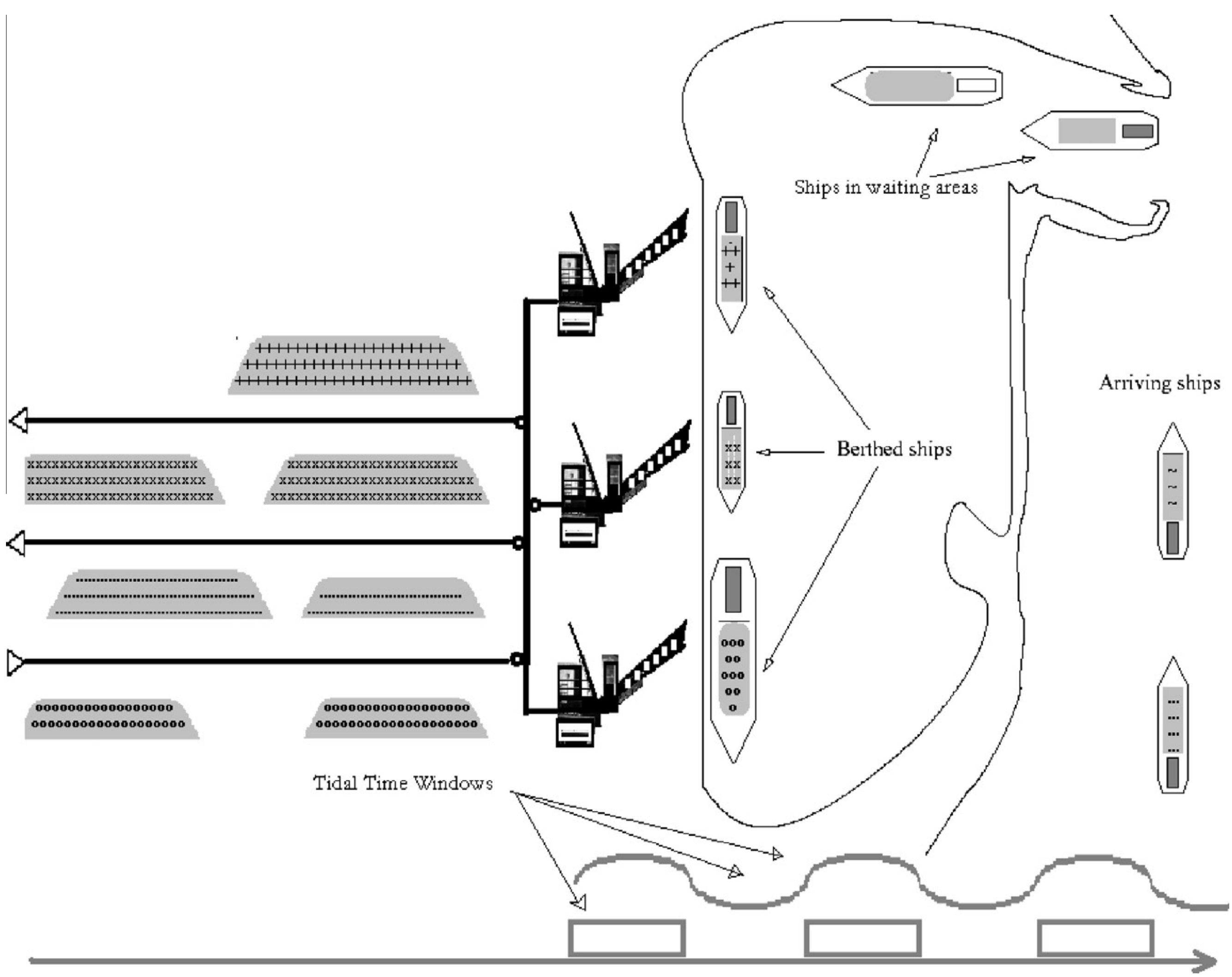

Fig. 1. Operational scenario in a tidal bulk port with homogeneous berth position.