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Models for the discrete berth allocation problem: A computational comparison

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ABSTRACT

In this paper we consider the problem of allocating arriving ships to discrete berth locations at container terminals. This problem is recognized as one of the most important processes for any container terminal. We review and describe three main models of the discrete dynamic berth allocation problem, improve the performance of one model, and, through extensive numerical tests, compare all models from a computational perspective. The results indicate that a generalized set-partitioning model outperforms all other existing models.

1. Introduction

Since the introduction of the container as we know it today in the early 1950s the development in maritime transportation of cargo has been stunning. Since 1990, container trade is estimated to have increased by a factor of five according to UNCTAD Secretariat (2008). The success is, to a large extent, based on the international standard size of a container. Containers are measured in multiples of 20 feet known as Twenty-foot Equivalent Units (TEUs). It is estimated that the global fleet of containers exceeds 23 million TEUs. In 2007, container cargo accounted for 1.24 billion of the 8.02 billion tonnes of all shipping cargo (source: UNCTAD Secretariat (2008)), constituting an increase of 4.8% from the previous year.

The terminals, where containers are loaded and/or unloaded, are an important part of the global transportation of containers. Here containers can change mode from sea to land (road or rail) and vice versa, or they can change from one vessel to another as a hub-and-spoke network is widely adopted. Large vessels can carry up to 15,000 TEUs and operate between huge transshipment terminals (hubs), while smaller vessels (so-called feeders) transport containers between smaller terminals (spokes) and the hubs. Globally it is estimated that the container terminals have a throughput of 485 million TEUs (source: UNCTAD Secretariat (2008)) and that almost half of the container traffic in the world is handled by the 20 largest terminals.

A container terminal usually consists of three areas: the berth (where ships berth), the stowage area (where containers are stored temporarily) and the land-side (where trucks and trains are serviced). The complexity of even medium sized terminals makes it impossible to consider the entire operation and plan it manually. Operations Research, therefore, has contributed to the planning and development within many of the terminal's processes. An overview of the different terminal operations and the impact of Operations Research are described in Steenken et al. (2004).

In this paper we focus on the Berth Allocation Problem (BAP). This problem entails assigning incoming ships to berth positions. Once a vessel is moored, it will remain at the berth until all required container processing has been completed. As

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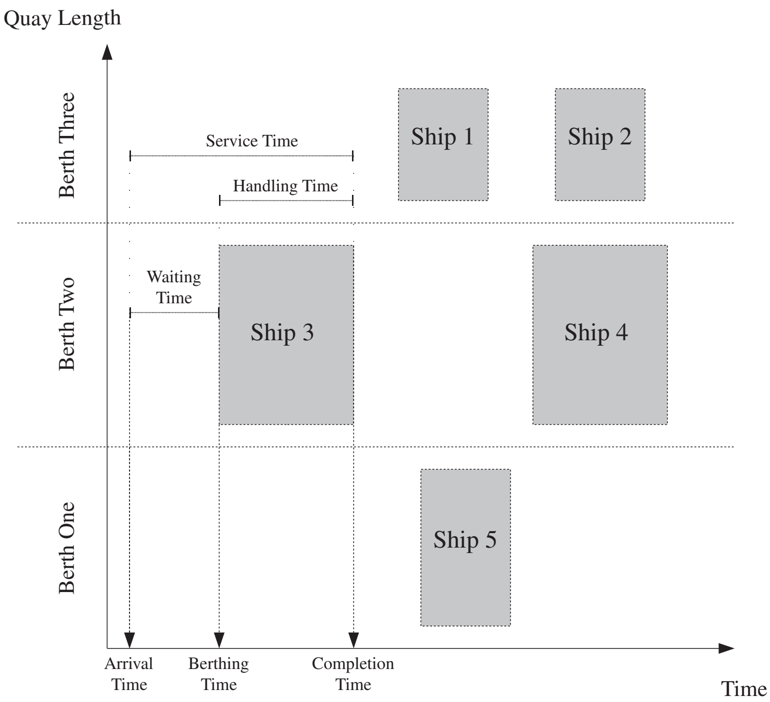

Fig. 1. The representation of the berth-time space.

berth space is very limited at most container terminals, and thousands of containers must be handled daily, an effective berth allocation is critical to the efficient management of the container flow. The BAP is recognized as one of the major container terminal optimization problems in Steenken et al. (2004), and it naturally lends itself towards a description in a two-dimensional space. One dimension is spatial, i.e. the quay length, while the other is a temporal decision horizon, which is often one week. Ships can be represented as rectangles whose dimensions are length and handling time. The handling time is defined to be the time the ship is at the berth, whereas the service time is the total time the ship spends at the port (i.e. the handling time plus any waiting time the ship experiences as a result of not being immediately serviced on arrival). These rectangles must be placed in the decision space without overlapping each other such that the length of the quay and the decision horizon are not violated (see Fig. 1).

The handling time of a ship depends on its position at the quay. This reflects reality in that containers are prepared for particular ships, and the driving distances from the stowage area to the berth must be considered. As mentioned previously, the decision horizon is typically one week; however, this may be updated based on changes to arrival and departure times of ships.

BAP problems can be classified as being either *static* (SBAP) or *dynamic* (DBAP). The static case assumes that all ships are already in the port when the berth assignment is planned, while the latter allows for ships to arrive during container operations at the port. The BAP can be further classified into *discrete* and *continuous* variants. The discrete case allows only one ship at a time at each berthing location, regardless of its size, while the latter permits more.

This paper focuses on the discrete DBAP which is NP-Hard, see e.g. Monaco and Sammarra (2007). We describe the three main models for this variant of the problem, improve the performance of one, and compare all models from a computational perspective. Hence, the contributions of this paper are threefold. Firstly, we show that the multi-depot vehicle routing problem with time windows (MDVRPTW) model proposed in Cordeau et al. (2005), with a few improvements, is competitive with that proposed by Imai et al. (2001). In Cordeau et al. (2005) it was concluded that the latter model is most efficient. Secondly, we show that a set-partitioning model proposed by Christensen and Holst (2008) is able to significantly outperform both aforementioned models. Finally, with the set-partitioning model we provide, for the first time, optimal solutions to all instances proposed in Cordeau et al. (2005). This enables us to assess the quality of previously proposed heuristics.

The structure of this paper is as follows. We begin with a literature review in Section 2, while the different models for the discrete and dynamic variant of the BAP are presented in Section 3. A comparison of the models based on extensive computational experiments is presented in Section 4, and we conclude with a discussion on our findings in Section 5.

2. Literature review

Studies on the BAP have appeared in the literature since the mid 1990s. The focus here is on the discrete DBAP. This is the most researched problem and, in what follows, we review the majority of work in this area. We briefly deal with the other variants, as well as possible extensions, at the end of the review.