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The generalized lock scheduling problem: An exact approach

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ABSTRACT

The present paper introduces an integrated approach to solving the generalized lock scheduling problem. Three interrelated sub problems can be discerned: ship placement, chamber assignment and lockage operation scheduling. In their turn, these are closely related to the 2D bin packing problem, the assignment problem and the (parallel) machine scheduling problem respectively. In previous research, the three sub problems mentioned were considered separately, often using (heuristic) interaction between them to obtain better solutions. A mixed integer linear programming model is presented and applied to instances from both inland locks and locks in a tide independent port. The experiments show that small instances incorporating a wide range of real-life constraints can be solved to optimality.

1. Introduction

Growing maritime traffic leads to an ever increasing pressure on the infrastructure of both ports and waterways. Ports are forced to reduce their handle times and heighten their flexibility to maintain or increase their market share. Inland waterways need to reduce the waiting times at their infrastructure to a minimum if they want to increase the share of waterway transport in multimodal transportation. Locks play a key role in these ports and waterways: a vessel must be processed by at least one lock when entering/leaving a tide independent port; barges may pass several locks while transporting cargo on a waterway. A lock consists of at least one chamber, in which ships can be transferred from one water level to another. When more than one chamber is available, the chambers can be paired (i.e. they are operated together) or they can be operated independently. While some locks consist of several identical chambers, others have chambers of different dimensions and properties. Depending on the size of the chamber, one or more ships can be transferred together in a single lockage operation. Processing a ship in a lock may take up to three decisions, each with a significant impact on the quality of service: selecting the chamber that will transfer the ship, determining a position for the ship in that chamber and setting a starting time for the lockage operation. At present, lock scheduling is performed by human experts, with little or no support from optimization software. Therefore, one could conclude there is a scope for introducing specialized decision support optimization software.

A wide range of port related operations has been researched, such as berth or quay crane related problems (Chang et al., 2010; Chen et al., 2012; Lee et al., 2012) and yard operations (Cao et al., 2010; Lee and Kim, 2010; Petering, 2011), but the lock operations attracted only a limited interest. For an overview, we refer to Stahlbock and Voß (2008). Previous research on the lock scheduling problem has mainly focussed on the Upper Mississippi River (UMR). Here, single chamber locks are used to transport tows that are often larger than the chamber itself. Those have to be split into different groups of barges which

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are transferred one at a time, and rejoined for the next part of the journey. Several techniques for solving congestion for the chain of 600-foot locks on the UMR are presented and validated using a simulation tool in Smith and Nauss (2010) and Smith et al. (2011). Optimal sequencing of the tows after a disruption at a lock on the UMR is presented in Nauss (2008). Coene et al. (2011) study the lockmaster's problem, which focusses exclusively on the scheduling sub problem. They identify it as a batch scheduling problem that can, under certain assumptions, be solved in polynomial time using a dynamic programming algorithm. In Verstichel and Vanden Berghe (2009), inland locks with multiple parallel chambers where several ships can be transferred together are considered. To solve this problem, a problem specific heuristic is combined with a late acceptance hill climber. Instances with a single chamber, identical parallel chambers and multiple heterogeneous chambers can be tackled by this approach. Scheduling lockages for a lock with identical parallel chambers is investigated in Verstichel et al. (2011a). The authors identify the problem as the identical parallel machine scheduling problem with sequence dependent setup times and release dates and present a mathematical model. A heuristic solution method is presented for solving the lock scheduling in this specific setting and its performance is compared with that of a first-come-first-served policy. As only the scheduling part is solved, another solution method is needed to place the ships in the chambers. This ship placement problem is tackled for a single chamber type using exact and heuristic methods in Verstichel et al. (in press).

The present paper discusses an integrated approach to solving the generalized lock scheduling problem. This problem consists of a ship placement problem, a variant of two dimensional bin packing, a chamber assignment problem, and a lockage operation scheduling problem, which is closely related to the parallel machine scheduling problem. When the lock has heterogeneous chambers, a chamber type assignment problem has to be solved as well, leading to a total of three sub problems. In previous research, these sub problems were considered separately, often using heuristic interaction between the parts in order to obtain better solutions. We will present an exact approach that solves all three sub problems together, both for an inland setting and in ports.

In Section 2 the generalized lock scheduling problem and its applicability are discussed. A mathematical model for the problem is presented in Section 3, together with several methods for improving the model's scalability. The experiments are described in Section 4, followed by conclusions in Section 5.

2. The lock scheduling problem

When a ship has to be transferred by a lock, a wide range of constraints has to be taken into account. In this section we will describe these constraints for locks that can transfer one or more ships in a single lockage operation. This type of lock is

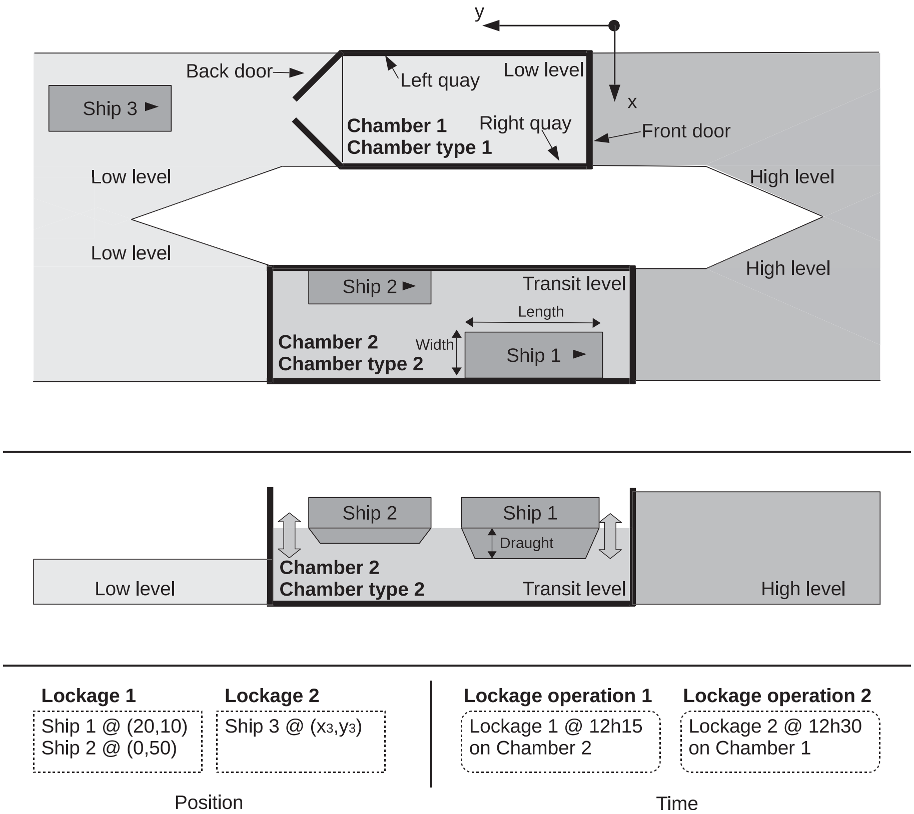

Fig. 1. Visual explanation of the lock scheduling specific terms used throughout the paper.