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Closed-loop coordination of inland vessels operations in large seaports using hybrid logic-based benders decomposition

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This paper addresses two coordination problems that exist in the waterborne transport in large seaports, the long time of stay of inland vessels and insufficient terminal and quay crane planning with respect to their sailing schedules. A novel coordination model is proposed and tackled using logic-based Benders decomposition and Large Neighborhood Search. In addition, a closed-loop perspective is taken, in which possible disturbances that may occur are considered. Simulation results show that our approach can scale to real-world sizes and provide better schedules for inland vessels within the port. The potential of using inland vessels for inter-terminal transport is also extensively investigated.

1. Introduction

Seaports are crucial nodes in international trade and transport (Song and Panayides, 2012b). Some of the cargoes arriving at seaports are transshipped to other ports, while others are transported to inland destinations (Song and Panayides, 2012a). Large seaports usually consist of multiple terminals serving container vessels, railways, and other forms of hinterland transportation. In the port of Rotterdam in 2015, 7,386,528 containers were handled (Port of Rotterdam Authority, 2015a), and 30% of them used inland waterway transport (Song and Panayides, 2012a). In addition, 10,613 sea-going vessels and 77,000 freight inland vessels have moored in the port in 2015 for transporting cargo (Port of Rotterdam Authority, 2015b). Fig. 1 shows the average number of vessels that arrive at and departure from the port of Rotterdam during a typical day; 23.65% of them are cargo vessels. To improve handling of current and future container flows, the Port of Rotterdam aims to raise the use of waterborne transport to have the largest modal share over the next 20 years (Port of Rotterdam Authority, 2011).

Over the last decades, the inter-port competition has moved to the competition between transport chains. Therefore, port authorities need to be more proactive in improving their hinterland strategies (Notteboom and Rodrigue, 2005; Song and Panayides, 2012a; Horst and Langen, 2015). Efficient handling of inland container vessels in the port improves the performance of the hinterland service of the port, and makes it more attractive to port customers and encourages them to make more use of waterborne transport by inland vessels (Horst and Langen, 2015; Konings et al., 2013; Douma, 2008; Nextlogic, 2012). To achieve that, intense cooperation and coordination between inland vessels and seaports are required.

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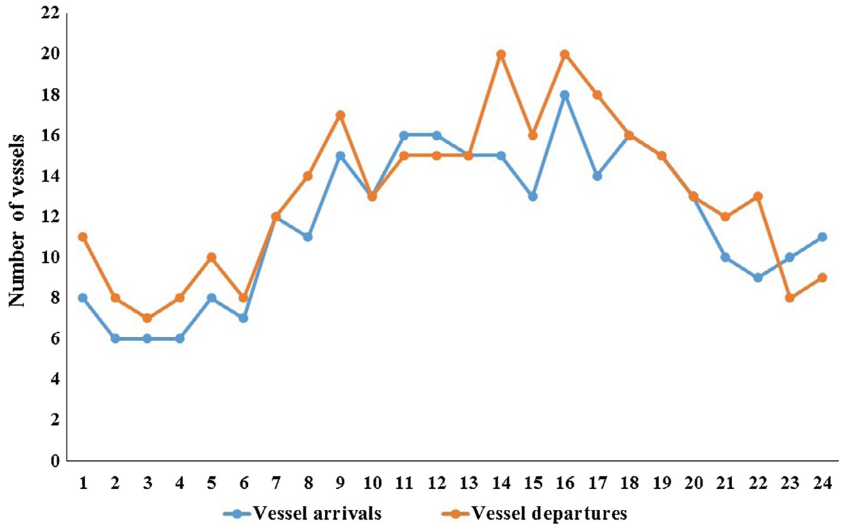

Fig. 1. The average arrivals and departures of vessels in the port of Rotterdam during a day (MarineTraffic, 2016).

1.1. Problem description

Two coordination problems exist in the waterborne transport in large seaports: firstly, the long stay in the port and secondly, the insufficient terminal and quay planning with respect to the sailing schedules of sea-going vessels and inland vessels (Horst and Langen, 2015).

Every time an inland container vessel enters the port, it calls at many different terminals spread over the port area, a map of container terminals and depots in the port of Rotterdam in given in Fig. 2. Since many inland container vessels call at the same terminal, congestion and waiting times are inevitable (Konings et al., 2013). In practice, the inland vessel operator makes calls to the terminal operator and makes appointments on the agreed time window in which the vessel can be handled to load and unload containers (Douma, 2008; Konings et al., 2013; Horst and Langen, 2015; Nextlogic, 2012). The process of phone calls back and forth takes up an unnecessarily large amount of the planners time (Douma, 2008; Nextlogic, 2012; Horst and Langen, 2015). In addition, when a delay at a terminal happens, the vessel's agreed time window at the next terminal will be missed. Vessel operators have to make allowance for such events by inserting large margins when planning their visits to terminals, otherwise the reliability of the transport service might be undermined (Konings et al., 2013).

For example, in the port of Rotterdam, it is reported that in 59% of the barge visits the actual start of handling deviates more than 2 h from the agreed time windows, and the average time a vessel spends in the port varies from 21 h for small vessels (ship length <85 m) up to 36 h for large vessels (ship length >110 m) (Nextlogic, 2012). Moreover, the average waiting time of an inland container vessel for visiting a terminal is about 1 h, but waiting times of up to a whole day are also possible (Pielage et al., 2007).

On the other hand, as terminal operators have contractual relationships with the deep sea carriers, sea-going vessels currently typically have absolute priority over inland vessels at terminals, and inland vessels are scheduled after sea-going vessels have been handled (Douma, 2008; Nextlogic, 2012; Horst and Langen, 2015; Konings et al., 2013). This can further increase the waiting time of inland vessels at terminals. Long waiting time implies loss of time and money, and could undermine the competitive position of ports' hinterland services. Insufficient planning at quays and terminals makes transport of inland vessels unreliable and unpredictable in the ports.

Therefore, efficient handling of inland container vessels in the seaports is crucial to significantly reduce waiting time and turnaround times and enable a higher capacity utilization of inland vessels, as well as improving the reliability and the efficiency of inland waterway transport from seaports to hinterland and vice versa. Moreover, this could also contribute to the inter-terminal transport (ITT) in large seaports. ITT represents the movement of containers that are transferred between terminals within the port when they are transshipped between the same or different modes of transportation (Duinkerken et al., 2007; Tierney et al., 2014; Schroer et al., 2014), and these containers are referred to as ITT containers. By making use of the available space on inland vessels when they are transporting between terminals, the inland vessels can also be used to transport ITT containers, which could be a potential solution for alleviating the congestion of ITT on roads.

The publications that focus on the planning of inland container vessels in the seaports are scarce. Several papers focus on perspective of enhancing coordination between terminals and inland vessels, such as Martijn et al. (2004), Moonen et al. (2005), Douma et al. (2009, 2011, 2012) and Li et al. (2014, 2015b). Meanwhile, several papers focus on perspective of enhancing coordination between inland vessels themselves (Li et al., 2015a, 2016), using a partially distributed planning method which involves coordination rules, mixed integer programming and constraint programming. In the above-