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A Robust Metaheuristic for the Rail Shuttle Routing Problem with Uncertainty: A Real Case Study in the Le Havre Port

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ABSTRACT

This study addresses the Rail Shuttle Routing Problem (RSRP) in the Le Havre port, where rail shuttles carry out the transfer of containers between maritime terminals and the multimodal terminal. The transfer times of shuttles and the empty travel times of locomotives both depend on several factors and are supposedly uncertain. The aim of this work is to improve the performance of the container transfer system in the Le Havre port, by minimising the total empty travel time of locomotives and protecting against delays. The deterministic problem is first modelled as a Vehicle Routing Problem with Time Windows (VRPTW); then, uncertainties are introduced into this model and Robust Ant Colony Optimisation (RACO) is proposed to solve the problem under uncertainties.

1. Introduction

Maritime transport plays an important role in the international movement of containers. Indeed, today over 90% of goods are transported by sea. This is made possible through the standardisation of containers and the increasing size of the world fleet of container ships, which has increased from 3000 units in 2004 to around 5100 units in 2014 for a total capacity that exceeds 17.7 million TUEs (UNCTAD, 2014). Even though this evolution has been accompanied by an acceleration in the transfer of goods and a reduction in the transportation costs, it has also caused a significant challenge for terminal managers who have seen their storage areas become increasingly congested. To meet this challenge, the Le Havre port built a multimodal terminal, which acts as a hub, not far from its maritime terminals, with the objective of reducing congestion in its storage areas. This new multimodal platform promotes consolidated transport and reduces CO_2 emissions by using alternative modes to road transport. In this new logistics system (Fig. 1), the transfer of containers between the multimodal terminal and the maritime terminals is carried out by rail shuttles, where the delivery of containers to their final destinations is made by freight trains, barges or trucks.

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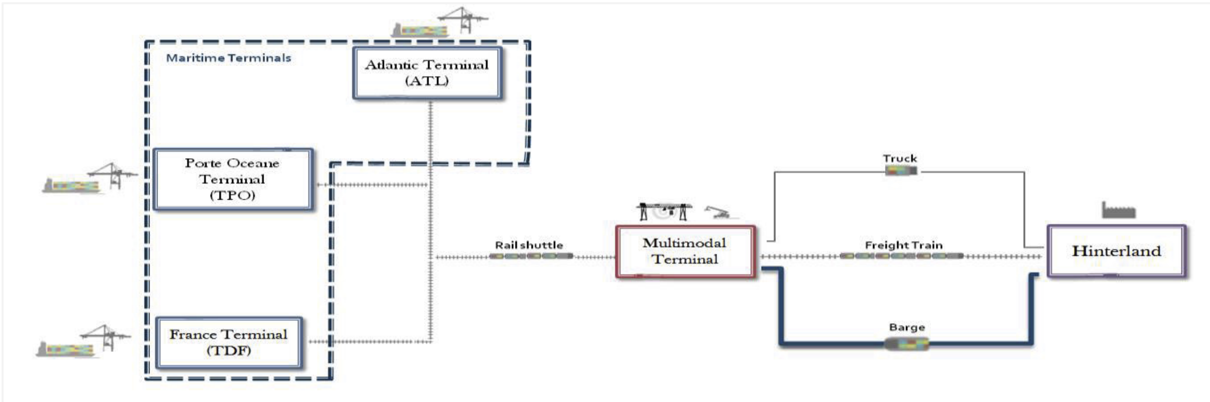

Fig. 1. Logistics system for the Le Havre port

In this work, we study the transfer of containers by rail shuttles in the Le Havre port, which we denote as the Rail Shuttle Routing Problem (RSRP). The aim is to propose an optimisation approach that defines new rules for container transfer between the multimodal terminal and the maritime terminals. Thus, we propose a mixed integer linear programming model to build routes that minimise the rate of unproductive locomotive movements, while applying time windows to the availability of shuttles to allow only the transfer of the totally handled shuttles and to meet delivery deadlines. Furthermore, we aim to offer robust solutions against uncertainties that may affect data, since it is common in the Le Havre port that travel times between container terminals increase due to poor weather, failures or the unstable loading of containers onto the shuttles.

2. Literature Review

2.1. *Prior Research on the Multimodal Terminal*

The multimodal terminal in the Le Havre port (Fig. 2) is composed of five areas: a river yard, an inter-transport area, a rail yard, a receipt beam and a multi-terminal transport area. To fluidise the transport of containers in the Le Havre port and to improve this port's competitiveness against its northern-European competitors, the operators of the Le Havre port must cope with several management problems in each area of the multimodal terminal. Some of these problems are classic issues described in the literature of container terminal management, and many works have been devoted to studying these problems.

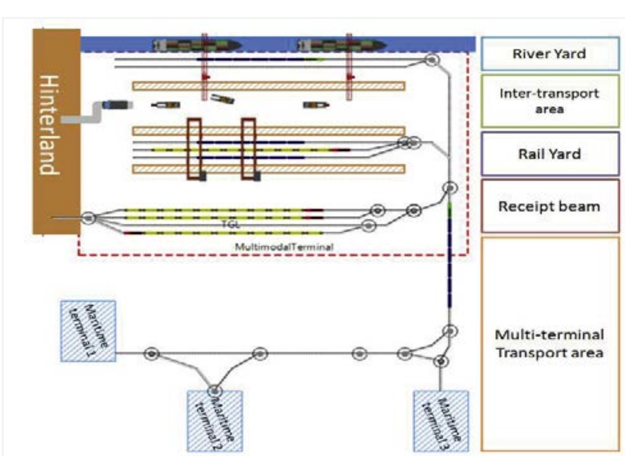

Fig. 2. Multimodal terminal design showing each of its areas

Among these problems, we mention the stowage problem (Imai et al., 2006; Monaco et al., 2014; Ding and Chou, 2015) which aims to find a preset assignment of containers to locations in a ship while accounting for the container weights and the destination ports, to ensure the stability of vessels and to minimise unproductive movements during unloading operations. The quay crane scheduling problem introduced by Daganzo (1989), subsequently treated in (Lee et al., 2008; Kaveshgar et al., 2012) and more recently in (Chen et al., 2014; Al-Dhaheri and Diabet, 2015), aims to determine the order of containers loading and unloading by quay cranes to minimise the total time spent by the vessel in the port.

Generally, at the multimodal terminal, containers are transhipped directly from barges or freight trains to rail shuttles and vice versa. However, to accelerate the handling process or to reduce congestion in the storage areas of maritime terminals, containers are sometimes first stored in the multimodal terminal buffers and are then distributed to the other areas of the multimodal terminal by reach stackers. These operations give rise to two problems: the internal transport operations problem and the container stacking problem (Steenken et al., 1993; Ng et al., 2007).

The organisation of the multimodal terminal also raises some new problems, such as scheduling the service slots for freight trains and rail shuttles. The objective is to determine the assignment order of freight trains and rail shuttles to the rail yard, to meet the departure times of freight trains and to minimise their waiting times in the receipt beam. The rail yard track allocation problem, which aims to determine the track and the track position that each rail shuttle or freight train should be assigned (Oudani et al., 2015), minimises translational movements (horizontal movements) and directional movements (vertical movements) of yard cranes. Then, a plan for handling the containers should be developed to minimise the total handling time (Leriche et al., 2015, Abourraja et al., 2017).

Finally, at the multi-terminal transport area, the major problem that arises is the optimisation of container transfer between the multimodal terminal and the maritime terminals (Rouky et al., 2016). Currently, rail shuttles perform the transfer of containers between the multimodal terminal and the maritime terminals. According to the waterwheel principle of movement (Leriche et al., 2015), the transfer of containers between each maritime terminal and the multimodal terminal is managed independently. In other words, the movements of locomotives between the maritime terminals are not allowed. At each time, a locomotive that transfers a shuttle from the multimodal terminal to a maritime terminal faces three choices upon arrival at a maritime terminal: it recuperates a shuttle destined to the multimodal terminal, it waits at the maritime terminal until a shuttle becomes available or it returns to the multimodal terminal. Fig.3 summarises the principal operational research problems for