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Optimal planning for container prestaging, discharging, and loading processes at seaport rail terminals with uncertainty

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ABSTRACT

This paper considers the optimal planning problem for container prestaging and dynamic discharging/loading at seaport rail terminals subject to uncertainties. We formulate the problem into a stochastic dynamic programming model to minimise the total logistics cost. Four simplified strategies are proposed. Experiments based on a real case study are performed to compare the optimal strategy with four simplified strategies in terms of cost, computing time and practicality. Results show that the seaport can use prestaging to reduce the cost involved and that an appropriate discharging/loading plan can be created in response to different prestaging situations and uncertain scenarios.

1. Introduction

Global Container port traffic has increased from nearly 85 million TEUs (twenty-foot equivalent unit) in 1990 to 700 million TEUs in 2016. Meanwhile, the size of containerships has increased dramatically, from 5000 TEU in 1990 to 21400 TEU in 2017 (UNCTAD, 2017). The growing traffic volume puts a huge pressure on container ports, which act as critical interface points between seaborne transport and hinterland transport. The deployment of mega-vessels tends to concentrate container loading/unloading activities at hub and gateway ports, adding further pressure to container ports to cope with the surge effect of container flows.

In addition, traffic congestion and emissions (e.g. mainly caused by truck movements) in the areas surrounding seaports have raised serious environmental concerns. Rail transport is regarded as one of the most effective ways to tackle the above challenges due to its high capacity and low emissions. However, the limited handling capacity in seaport rail terminals is not able to match the growing demand; thus there is a compelling need to improve the efficiency of rail terminal operations at seaports in order to achieve sustainability and reduce pollution and congestion in container transport chains.

In a broad context, numerous studies have been conducted on the optimisation of container terminal operations. Readers can refer to the survey papers such as Steenken et al. (2004); Gunther and Kim (2006); Stahlbock and Voß (2008); Bierwirth and Meisel (2010); Carlo et al. (2014); and Kim and Lee (2015). However, it is noted that most of the optimisation models focused on quayside and yardside operations with a relatively limited number of studies on landside operations interfacing with hinterland transport activities. In particular, the operations management issues associated with seaport rail terminals have been under-studied (Caballini et al., 2016; Heggen et al., 2016).

Trains arrive at a seaport rail terminal, carrying export containers which are discharged and transported to storage yards close to ship berth terminals. Then, import containers are loaded onto trains either directly from storage yards or from the rail terminal

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buffer, where import containers have been prestaged (stored in advance). Both the discharge process and the load process have to be carried out within pre-specified working time windows; in particular each train has a strict departure time due to railway network scheduling. There is often a considerable distance (up to several miles) between rail terminals and storage yards, yard cranes serve multiple tasks, and other factors exist such as weather conditions, equipment breakdown, etc; therefore, a high level of uncertainty is involved in the transportation of containers between the storage yards and the train. In a similar manner to how yard template planning is used to determine the assignment of spaces in a container port prior to a vessel's arrival (Zhen, 2014), a container prestaging mechanism is introduced in this research. Prestaging refers to moving containers from storage yards to the rail terminal buffer in advance, in order to shorten the distance they need to be moved at time critical points so as to mitigate risks imposed by various uncertainties and to better meet the departure deadline. However, prestaging has to be appropriately planned as prestaging activity is costlier and rail terminal buffer space is limited. The discharging and loading processes are performed within planned time windows. A time window may be divided into multiple periods (e.g. hourly periods). Flow rates are defined as container movements between the rail terminal and the storage yards at each period, which may change dynamically over the discharging and loading time windows. In this paper, we propose an integrated model to optimise the decisions of container prestaging and of container flow rates in the presence of uncertainties.

To the best of our knowledge, we are the first to investigate container prestaging issue at rail terminal. The main contributions of this research include: (i) this study investigates the issues of simultaneously optimising container prestaging and container flow rates at seaport rail terminals subject to time windows. (ii) we obtain the optimal strategy using the stochastic dynamic programming method. To overcome the challenge of the computational complexity, we propose four simplified strategies, which are more computationally efficient and readily applicable in practice. In particular, the Bang-bang strategy can achieve a performance very close to the optimal strategy. (iii) The current industrial practice relating to planning prestaging, discharging and loading is manual and time consuming; therefore, this work offers the opportunity for terminal operators to improve the efficiency of rail terminal operations.

The rest of the paper is organised as follows. Section 2 reviews the relevant literature together with an empirical example to motivate the study. In Section 3, an integrated stochastic dynamic programming model is formulated, which is able to optimise the decisions of container prestaging and the decisions of container discharging and loading rates in the presence of uncertainties. Section 4 presents solution strategies including the optimal strategy and four simplified strategies. In Section 5, the model is extended to tackle multiple train situations. In Section 6, numerical examples based on a real case study are provided to compare these strategies and illustrate their effectiveness in a range of scenarios. Finally, we draw conclusions and indicate further research in Section 7.

2. Literature review and an empirical example

This section contains two subsections Section 2.1 Literature review, and Section 2.2 Operations at rail terminal. Section 2.1 provides a summary and critical evaluation on the work in relation to the research topic. A critique of review is also demonstrated to

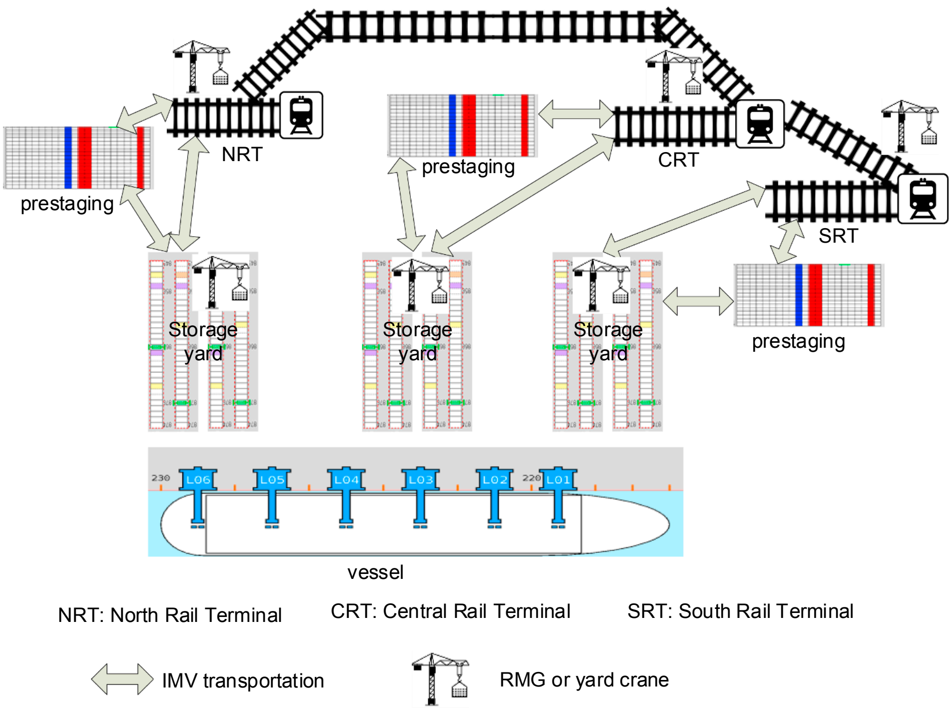

Fig. 1. An illustrative map of rail terminal operations at seaport.