Decision Support Systems 79 (2015) 33–45

Contents lists available at ScienceDirect

Decision Support Systems

journal homepage: www.elsevier.com/locate/dss

A decision support system tool for the transportation by barge of import containers: A case study

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ARTICLE INFO

Article history:
Received 4 November 2014
Received in revised form 27 July 2015
Accepted 2 August 2015
Available online 6 August 2015

Keywords:
Inland transport
Routing
Mode selection
Container
Decision support system

ABSTRACT

In this paper, we present a DSS that generates schedules for the transportation of containers by barge in the hinterland, in particular from sea terminals to an inland terminal. As a case study, we propose the transportation from the ports of Rotterdam and Antwerp to a terminal in the south of the Netherlands, where the problem is typical. This problem is modeled as a heterogeneous fleet vehicle routing problem. The main decision is based on the trade-off of either consolidating containers to generate economies of scale with barges or alternatively dispatch, expensively and quickly, single containers by truck. The DSS is flexible as it can be applied to different settings by properly tuning the several parameters in the model. With numerical experiments, based on real world data, we evaluate the effectiveness of this system and its applicability.

1. Introduction

In recent years, traffic of containers has increased considerably. Global trade favors the use of containers, as standardized handling units are necessary for the different logistic systems worldwide, and lead to a lower cost of transportation [2]. One of the main advantages of this standardization is the encouragement of multimodal transport, that favors economies of scale in transport, and can reduce congestion and emissions [12].

Recently, the transportation of containers in the hinterlands is drawing considerable attention for several reasons. This transportation leg has been acknowledged to be the most costly in many container supply chains; 40% to 70% of the total transportation cost is in the hinterland [26]. Moreover, an excessive use of trucks between sea ports and hinterland causes issues of congestion and pollution [38]. Promoting the use of alternative modes of transport is one of the primary measures to decrease the drawbacks of inland transportation and generate economies of scale [12,15].

In Europe, especially in the Northwestern area where the flow of containers is the highest, the problem is relevant [22]. The hinterland is mostly affected by import container flows; the imbalance with the outbound traffic has been estimated to be in the ratio of 2:1 [32]. Therefore, inbound road traffic around the sea ports is becoming unsustainable and several expedients are being considered. Trains and barges are favored for the fact that they can generate economies of scale and can push large bundles far in the hinterland. Also port authorities and governments are supporting their use. For instance, the Port of Rotterdam defined a target for the 2035 modal split. The goal is to transport at least 45% of the volumes by barge, at least 20% by train, and at most 35% by truck. The modal shift will not be achieved easily and will require increasing performance from barge and train services [22].

In the Netherlands, many inland terminals provide transport services to and from the Port of Rotterdam and Antwerp. In the Brabant region (Southern Netherlands), tributaries of the river Meuse can connect the hinterland with the sea ports and also provide connections with other waterways. These geographical conditions are considerably favorable to the use of barges, such that inland terminals are providing their customers regular barge services in addition to trucks. For instance, this is the case for a terminal located in Veghel, which is the case study of this research. Additionally, many receivers prefer barge transport not only for its lower costs, but also for facilitation at customs and more flexibility in terms of dwelling time at the terminal premises [13]. Finally, the barge service is becoming more and more reliable due to new bundling policies within the ports that can limit complex routes among quays [27].

As the competitiveness of barge transport is increasing in this region, its demand has grown substantially. By the Port of Rotterdam, it is estimated that from 1985 to 1995 barge traffic grew from 200,000 TEU to about 1 million TEU; in 2005 the volume was about 2 million TEU, approximately a market share of 31% [21]; in 2014, a share of 36% against 53% of truck and only 11% of rail [30]. While trains are usually utilized for long distances and their services are mostly pre-scheduled,

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http://dx.doi.org/10.1016/j.dss.2015.08.001
0167-9236/

for barges planners have to deal with large and complex scheduling problems. The challenge is to consolidate containers with different necessities related to time. In fact, time constraints, such as due dates and different release dates, make the consolidation complex. Besides, other factors, as multiple quays, where to pick up containers and minimum utilization level, increase the complexity for the scheduler. All these components can somehow limit the use of barges and favor the use of trucks.

The aim of this paper is to develop a DSS for the optimal allocation of import containers to a heterogeneous fleet composed by barges and trucks; besides the paper aims to explore different aspects in this decision making process and to give managerial insights. The validity of the model is supported by a case study conducted at an inland terminal in the Netherlands. The DSS eases the creation of the schedules. It takes data concerning the availability, due dates and locations from the internal data base. Then, it feeds the algorithm which computes the schedule. Besides, different parameters can be adjusted by the planner to generate schedules with different features. Finally, the output is translated and made readable to the planner. The research questions we want to address are: How to model and solve the transportation of import containers in the hinterland? What is the incidence of due dates in the planning process? To what extent the level of barge utilization affects the allocation and the total cost? To what extent is it possible to reduce multiple visits of port quays in each tour? How the availability of information in the time horizon can affect the planning process?

This paper is organized as follows: Section 2 provides the related literature; Section 3 presents the problem and the case study; Section 4 formulates the mathematical model and a relaxed version; Section 5 describes the heuristic used to generate the schedules; Section 6 presents numerical experiments based on instances drawn from real data; finally Section 7 concludes the paper with our final recommendations.

2. Related literature

Relevant literature with concern to container supply chain systems and the development of DSS's can be grouped into two main areas: operations at container terminals and transportation. As the traffic of containers has grown exponentially in the last two decades worldwide, and the related supply chains have become more and more complex, it is crucial to make effective decisions. Therefore, the topic caught the interest of many researchers to develop decision support tools for different aspects of the supply chain.

With concern to the first area, operations at container terminals, some main problems arise: berth, yard and crane allocation at the quay side and container packing. We refer to [5] for a thorough review of typical problems and related scientific papers. With a DSS point of view, we can find several papers treating the topic. In [36], Ursavas proposed a DSS to optimally allocate berths and cranes considering two conflicting parties: shipping companies and terminal operators. The author provides a multi-objective integer programming model that aims to achieve acceptable service level for the shipping companies and lower operational costs for terminal operators. Murty et al. [24] developed a DSS to analyze a set of inter-related daily operational decisions at a container terminal. The goal is to optimize berthing times of vessels, resources for handling operations, waiting times of trucks and to make the best use of the storage space. Ngai et al. [25] proposed a radio frequency identification (RFID) prototype system that is integrated with mobile commerce in a container depot. The system is implemented to keep track of the locations of stackers and containers, to provide greater visibility of the operations data, and to improve the control over the process. Finally, Chien and Deng [6] proposed a container packing support system. The system incorporates an algorithm, a graphic interface and a simulation program that guides the user step by step in the packing process.

The second area, related to transportation, has mainly tackled the problem of empty container management (ECM). We refer to [33] for a review. In [31], Shen and Khoong developed a DSS to solve empty container repositioning for a shipping company, using a network optimization model. The system considers demand and supply of empty containers over a multiperiod planning horizon and optimizes the flows of containers both on a local and regional level. In [2], Bandeira et al. integrated decisions upon flows of full and empty containers in a single system. They consider a network of suppliers, demand points, harbors and warehouses, and the problem is modeled as a Multiple Depot Vehicle Scheduling Problem; the aim is to minimize global distribution costs. The DSS is composed of a static and dynamic model. The static model optimizes a network flow problem and considers the input given by the dynamic model, which heuristically selects the containers and gives them priority according to transportation times and original dates of order.

Specific literature related to barge transport has recently seen a moderate growth due to the increasing predominance of this modality in some regions, especially Northwestern Europe. In [9], Douma et al. developed a Multi-Agent system to improve the coordination between barge and terminal operators for the Port of Rotterdam. After a sequence of terminals to visit, so-called rotation (which is tackled in our paper), is decided by barge operators, the terminal operator receives the appointments and has to schedule the visit of barges at the quays considering practical constraints. The system is meant to align such activities in an optimal way for both parties. In [13], Frémont and Franc conducted a study on the competitiveness of barge transport for the Port of Le Havre. They claim that in such a setting with lower volumes than Rotterdam and Antwerp, competitiveness can be achieved with additional logistic services to make the barge more appealing: more flexibility with the custom, warehousing and extended detention free periods. Other relevant studies have a simulation perspective and aim to give insights on the network of the ports. In [22], Konings et al. pointed out that a hub-and-spoke network can be beneficial for ports such as Rotterdam as to decrease the number of calls and waiting times. They show with a simulation study that with such a network improvements can be achieved when the cross-docking hub is located at a greater distance, as this can favor economies of scale. Finally, Caris et al. [4] proposed a simulation study that analyzes the impact of different cross-docking facilities on waiting times and capacity utilization for the Port of Antwerp.

To the best of our knowledge literature related to the treated problem is quite scarce, as it mainly focuses on the ECM problem. Somehow, ECM drew more attention to the detriment of the study of the full transportation leg, as this is seen by most as a mere allocation model [2]. As a consequence, we are not able to find any relevant literature that addresses our problem and emphasizes the complexity of the consolidation with a time perspective and also considers the features of barge transport. Somehow, this is surprising. The full container management puts a lot of pressure on planners as the need of respecting deadlines on one hand and the need to consolidate containers to generate economies of scale on the other hand clash with each other. Therefore, this paper aims to fill this gap and the case study is meant to provide an actual motivation for this DSS.

To model this particular hinterland transportation of containers, we need to address the heterogeneous fleet vehicle routing problem (HVRP); while, for a relaxation of the problem, we address the variable size bin packing problem (VS-BPP), see [19] for definitions and [16] for a comparison of different solution methods. With concern to the HVRP, we refer to [1] for a review and to [17] for a survey of its industrial applications. On this problem the literature is indeed quite scarce [11]. Two main variants have been proposed, with a limited and unlimited number of vehicles. As stated by Baldacci et al. [1], for HVRP exact methods have not been developed yet. All the existing studies have focused on developing heuristics. The best performing heuristics appear to be a tabu search algorithm developed in [14], a heuristic column generation method in [34] and a threshold accepting algorithm in [35].