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Integrated production and intermodal transportation planning in large scale production–distribution-networks

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ABSTRACT

We present a model and solution approach for combining production and intermodal transportation planning in a supply network. A close and detailed integration of both decision fields is missing in the literature so far. The model includes relevant decisions regarding production setups and output volumes of plants, cargo consolidation at intermodal terminals, and capacity bookings for road and rail transports. A Branch-and-Cut method and heuristics are designed for solving the problem. A comprehensive case study for a chemical company identified a 6%-cost saving from the integrated planning. At the same time, companies are successfully supported in establishing eco-friendly distribution processes.

1. Introduction

Intermodal rail/road transportation integrates short haul road transports with long haul rail transports to combine the advantages of both modes (European Commissions, 2002). It provides potentials for relieving congested road infrastructure, for reducing green house gas emissions, and for achieving economies of scale from jointly shipping large volumes of cargo. However, establishing intermodal transports comes along with severe challenges like (i) the organizational effort required to coordinate the activities of the involved parties, (ii) the threat of long door-to-door delivery times, and (iii) additional cost of drayage transports and transshipment operations that may outweigh the economies of scale, see e.g. Behrends and Flodén (2012). The latter necessitates that a large volume of cargo has to be bundled in a single rail trip such that substantial economies are achievable (Kreutzberger, 2008). Also, the shipper's door must be at far distance from the customer's door such that the cost saving in rail transportation can exceed the additional cost of drayage and transshipments (Kim and Van Wee, 2011).

Coping with these challenges and achieving economic advantages from switching to intermodal transportation is most likely possible for internationally acting companies that produce large volumes of cargo. Such companies are e.g. found in the process industry, especially in steel industry and chemical industry, see De Jong and Ben-Akiva (2007). These companies run networks of production sites, where each plant is capable to produce a mix of products out of a portfolio (Papageorgiou, 2009). The output volumes of the plants are planned network-wide on a medium-term horizon of weeks or months. Typically, large lot sizes are advantageous to limit lengthy and costly setups of complex production aggregates (Kallrath, 2002). Furthermore, customer order lead times are often several weeks which allows to conduct a make-to-order production on a

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multi-period time horizon. Also the use of rail transportation is accepted even if it takes a few days longer than road transportation. Since large volumes of cargo have to be moved, the companies can act as shipper organizations and book transport capacities at rail operators and truckage companies by themselves instead of calling in freight forwarding agencies. However, the structure of distributed production necessitates to decide where and when to make, store, and consolidate goods for a joint shipment by rail.

A simplified version of this problem is studied in Bierwirth et al. (2012), called the intermodal transportation problem (ITP). Given the production output of plants and the customers' period demand for a single product type, the problem is to optimize the consolidation and flow of cargo in an intermodal rail/road network with regard to minimum transportation cost. In particular, decisions on the usage of door-to-door (D2D) road transports or intermodal rail/road transports are made. Intermodal transportation takes place either by chartering a block train completely (so called full-train-load (FTL) service) or by booking transport capacity for single transport units (so called less-than-train-load (LTL) service). Of course, the latter incurs a higher per unit transportation cost. Bierwirth et al. (2012) have solved a real ITP instance faced by a chemical company in Europe. It was found that a considerable amount of transport volume can be shifted from road to rail without increasing (in some situations even at decreasing) transportation cost.

An open question is, however, whether intermodal transportation can take further benefit from combining a company's production and distribution planning. Integrating both fields is expected to improve the *spatial consolidation* of cargo in a distributed production network (i.e. where to produce and to collect products for joint shipments in the rail mode) and the *temporal consolidation* (i.e. over which time periods to collect cargo for joint shipments). To investigate these issues and to reach a deeper understanding of the drivers of intermodal transportation, this paper extents the ITP towards the following directions:

- The planning comprises *multiple products*, i.e. different types of products can be consolidated in fully loaded trains.
- The *master production scheduling* is integrated with the *transportation planning*, enabling e.g. that products ordered by far distant customers are made at plants that have close access to the rail network.
- The planning covers *multiple periods* such that *inventory holding* at plants and intermodal terminals allows saving setup cost and a better consolidation of rail transports.
- *Multi-stage rail transports* are enabled to collect freight from multiple plants before shipping it to the destination area.

Since intermodal transportation offers opportunities for saving cost and performing environmentally friendly transports, we can pursue two objectives: (1) Minimizing the total cost of production and transportation and (2) minimizing the percentage of D2D-deliveries by truck. The two objectives are conflicting whenever D2D-service cost is less than intermodal transport cost. Therefore, Pareto-optimal solutions are determined where total cost and the percentage of road transportation are traded off to different extent. These solutions reveal the cost a company has to accept for achieving a certain share of intermodal transportation. This issue is of growing importance as public authorities and customers are increasingly requesting an environmentally friendly distribution of goods. We exemplify the approach by a real world case study from the chemical industry.

The paper is organized as follows. In Section 2 we review the relevant literature and relate it to our study. The integrated production–distribution planning problem is described and modeled in Section 3. In Section 4, we show how to combine an environmental objective and a cost objective in a bi-criteria optimization. Section 5 presents solution methods and Section 6 provides a comprehensive case study. Section 7 concludes the paper.

2. Literature review

The conditions under which intermodal rail/road transportation is a viable option for industrial distribution have been investigated numerously. Caris et al. (2008) provide a literature survey on diverse problems that are faced by the actors involved in the organization and execution of intermodal transports. The routing of single shipments through an intermodal transportation network is considered among others in Boardman et al. (1997), and Ziliaskopoulos and Wardell (2000). Recent papers extend the routing decisions to a set of shipments or to volumes of cargo that must be brought from given origins to given demand points. Freight consolidation comes into play, especially if various modes of transport are considered with vehicles differing in their load capacity. Table 1 lists the literature that is related closest to our study. The papers are classified by (1) production-related decisions that are combined with the transportation planning, (2) whether or not inventory holding is incorporated, (3) the modes of transport distinguished in the planning, (4) the maximum number of transport stages in a transport chain, (5) whether or not direct deliveries from origins to destinations are allowed next to intermodal transports, (6) whether or not consolidation decisions (like booking of vehicles or transport capacity) are included for achieving economies of scale, (7) whether a single commodity or multiple commodities are considered, (8) the way time is treated in the planning approach, (9) whether the optimization strives for minimizing cost (respectively for maximizing profit), time related service measures (like door-to-door delivery times), or environmental implications (like overall transportation effort or the amount of green house gases emitted), and (10) the method proposed for solving the problem.

The first group of papers in Table 1 combine transportation planning for different modes of transport with location decisions for intermodal terminals and transshipment hubs. Production decisions are not within the scope of these studies. Most