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Bilevel optimization in the context of intermodal pricing: state of art

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Abstract

With the rising interest to stimulate intermodal transport, determining pricing strategies can be intrinsically challenging. We provide a review on the current state of research in intermodal pricing, through which we identify a peculiar gap in optimization approaches. A suggestion to exploit the bilevel optimization technique is presented, as well as an account of its widely successful application to price setting problems. The different approaches to express the network users' behavior, regarded as the lower level problem, are highlighted together with the particular modeling aspects of intermodal networks.

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Keywords: intermodal transport; pricing problems; bilevel optimization; Stackelberg games; network equilibrium

1. Introduction

The European conference of ministers of transport (1997) defined *intermodal transport* as the movement of goods, in one and the same loading unit (or vehicle), by successive modes of transport without handling the goods themselves when changing modes. Generally, rail or inland waterways are used for most of the traveled route, known as the *main haulage*, and road for the shortest possible initial and final parts of the transport chain, known as the *pre- and post-haulage* or *drayage operations*.

External effects of intermodal transport are significantly lower than those of the all-road transport, which hence makes the former a more sustainable and ecologically preferred choice in most cases. This conclusion is solid enough even in the presence of uncertainty factors and scientific debates on the subject (Kreutzberger et al., 2003). Triggered by the growing world-wide interest to confine the harmful effects of transport on the environment, intermodal transport has gained a special interest among researchers and policy-makers, e.g. the roadmap set by the

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European Commission's White Paper (2011) aims to shift 30% of road freight over 300 km to other more environment-friendly modes by the year 2030, and more than 50% by 2050.

However, despite the above motivation and the considerable opportunities to generate economies of scale through freight consolidation and higher load factors (Kreutzberger, 2003), intermodal transport is facing a stiff competition from all-road transport in Europe. Indeed, 44.9% of the freight transport takes place via road (European Commission, 2013).

In addition to a number of qualitative and level-of-service related factors, intermodal transport competitiveness, and modal choice for that matter, is greatly sensitive to the determination of the right services tariff, known as the *pricing strategy* (Bontekoning et al., 2004). Generally speaking, pricing strategies are distinguishable in the way they handle the interplay between profitability and competitiveness. A service price has to be high enough to cover its costs, and hence generate a profit, and low enough to remain attractive to the target customers.

In the intermodal transport context, service prices are to be considered as tactical decisions. Bontekoning et al. (2004) identify two levels, at which the pricing strategy operates. First, at the level of the individual actor in the intermodal chain, where in order to devise his own strategy, each actor must be aware of his own market postion and the cost structure of the other actors. Previous studies belonging to this class are mainly concerned with calculating opportunity costs and providing educated pricing guidelines in this light, mostly from the prespective of the network (mainhaul) and the drayage operators. Second, a pricing strategy can be considered at the whole door-to-door level, where pricing decisions are taken for the intermodal service from the perspective of the service providers (carriers), while accounting for the potential competition and the target customers' (shippers') choices.

In addition to acknowledging the previous view, we suggest a further classification of the latter category: simulation versus optimization approaches. While several examples of decision support systems simulating service prices and pricing-related policies can be noted, the literature is almost silent on optimization methods for intermodal pricing except for a few attempts, either directed to limited case studies or relying basically on market research and customers segmentation methods to capture the network users' reactions to their pricing decisions. Driven by the limitations imposed by these approaches in what concerns the service and customer classes, and the demanding need for handling more generalized and realistic cases, we aim through this paper at justifying a motivation to exploit a modeling concept that was found successful in the domain of pricing problems in general, and the spinned-off network-based variants in specific: namely bilevel optimization. The paper will be organized as follows: we start by reviewing intermodal pricing-related approaches following the suggested classification in section 2. Section 3 covers the main categories of bilevel optimization problems both in the general transportation as well as the pricing context, including the previous bilevel attempts applied to intermodal networks. In section 4, we consider the design possibilites in applying bilevel optimization to intermodal pricing, mainly for the lower-level problem, as well as the modeling of multi-modal networks. Our discussion is finally concluded in serction 5.

2. Intermodal pricing review

The first developed multi-modal network models that were able to handle intermodal flows appeared in the early 1990s (Caris et al., 2013). The most notable decision problems are terminals location-allocation, internalizing external costs, bundling strategies and pricing strategies. The last include the models that consider pricing decisions as simulated parameters, as well as those that consider them as explicit decision variables. We are interested by the studies that directly deal with service pricing questions, as well as by those that tackle decision factors influencing the intermodal market position and its promotion such as: introducing taxes/subsidies and changing the fuel prices.

2.1. Simulation models

The Geographic Information Systems (GIS) technology has introduced new opportunities to model large and complex intermodal networks. One example is the GIS-based location analysis model entitled "LAMBIT" (Macharis and Pekin, 2009). The authors aim to make ex-ante and ex-post analysis of policy measures in Belgium to stimulate the intermodal transport market. In addition to assessing the efficiency of adding new terminals, the model simulates policy options of price scenarios. The model consists of multiple layers depicting each mode of transport, and nodes depicting the location of the intermodal terminals and the port of Antwerp. The transport prices of each mode are estimated according to the real market price structures. The Dijkstra algorithm is then applied to find the shortest path and the intermodal transport costs from the port of Antwerp to each Belgian municipality. The total