Contributed session

Heuristic Algorithms for a Bilevel Service Network Design and Pricing Model

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Abstract Pricing decisions play a crucial role in positioning a certain product or service. They involve a non-trivial tradeoff between increasing revenues and keeping the service economically appealing, which requires a wise management of the underlying costs and a knowledge of the market situation in terms of the customers' alternative options. In the context of freight transport services, this stream of problems is equally relevant in the rise of reduced policy interventions (e.g., deregulation, privatisation, etc.), and particularly for rail-based transport, where operators are typically required to make months-long slots' reservation requests from the infrastructure managers in light of their expected demands. Other related system examples could include trucking and container shipping lines.

This work is devoted to jointly examining the intertwined tactical problems of designing freight carrying services and determining their associated prices as observed by the shipper firms. We put forward a bilevel model, where the main decision maker (a leader) is portrayed at the upper level, as a freight transport operator seeking to maximize his/her profits by setting the services' tariffs and selecting their subsequent operating frequencies. At the lower level, the shippers (followers), faced with itineraries composed of the leader's services and an always present competition's alternative, react to the leader's decisions in a costs' minimization fashion. As a more precise application context, we consider the leader and the competition as providers of freight-carrying intermodal and trucking services, respectively. Intermodal is used with the interpretation of a multimodal chain of transport services, where the long haul is performed by environment-friendly transport modes with higher payloads, such as rail or inland waterways (IWWs), and road is used for the shortest possible initial and final parts of the journey. The market is thus assumed to consist of small customer shippers seeking to take advantage of freight consolidation, by choosing to send their demands between the proposed intermodal itineraries and the trucking alternative, with the possibility of *splitting* their volumes over several paths.

A linearised mixed-integer programming (MIP) formulation is developed, extending both the path-based multicommodity service network design model in [1] and the bilevel joint design and pricing problem in [2]. Capacitated services and discrete design variables are considered depicting their frequency decisions, as opposed to the classical open-close approach, adding in turn a considerable complexity to the problem. The linearisation steps yield a formulation involving big M constants, which is further enhanced by studying feasible theoretical

bounds. The model is invoked on real-world instances representing large-scale demands at the European continental level, using the classic solver CPLEX. The obtained results suggest a room for improvement, especially in terms of the computation time.

Therefore, we discuss two heuristic approaches to solve the proposed model, addressing its main point of difficulty stemming from the network design part. The first algorithm is based on the idea of starting with an initial, yet costly, services' schedule that is able to accommodate all shipping demands, then, in an iterative manner, decrease the frequencies of those services that do not considerably or positively contribute to the leader's generated gain. The initial solution is obtained from a version of the model with the integral design variables being relaxed: a problem that can converge to optimality in a short amount of time. Afterwards, an iterative procedure is invoked to solve a set of restricted MIP formulations of the model, where a set of the services' frequencies is fixed to the values obtained from the previous iteration. At each step, the choice criteria to decrease the frequency of a certain service are based on its load factor or profit margin's level. Checking techniques are additionally implemented to prevent the algorithm from re-visiting older services' schedules. Finally, the procedure is stopped when objective stagnation is reached and the solution associated with the maximum obtained objective value so far is returned.

Second, a heuristic algorithm is designed based on the Lagrangean relaxation framework. More specifically, we identify the service capacity constraints as the *complicating* ones and append them to the objective to obtain a Lagrangean function. The subgradient optimization algorithm is then applied to find the values of the Lagrange multipliers, where a lower bound on the solution is obtained by an initial constructive heuristic. Due to the particular costs' structure in the objective function, the mutlipliers are initialized with their theoretical lower bounds, instead of an arbitrary value. As in classical Lagrangean heuristics, we seek to restore the feasibility of the obtained solution through a procedure that re-routes the excess volumes on the services whose capacity is violated.

The two developed algorithms are tested on real-world instances with varying sizes and logistics properties. The main points of differences are highlighted, as well as the potential enhancements to achieve solutions with higher qualities.

The underlying research in this work is conducted in accordance with the project BRAIN-TRAINS, concerned with the future of rail freight intermodality in Belgium and Europe, and funded by the Federal Science Policy according to the contract n. BR/132/A4/BRAIN-TRAINS.

Keywords: *network design, network pricing, lagrangean relaxation*

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