A mixed integer nonlinear programming bi-objective model for intermodal network design

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Abstract

Intermodal transport is promoted by Europe as an environmentally friendly alternative to road. The location of intermodal terminals, where the transfer of goods between modes occurs, is a key issue for achieving economic and environmental competitiveness. We present a bi-objective model for the intermodal terminal location-allocation problem. Operational costs and CO_2 emissions are minimized using three modes: road, intermodal rail and intermodal inland waterways transport. Economies of scale are modeled by nonlinear cost and emission functions. Intermodal global performances are assessed on the Belgian case study.

Keywords: intermodal network design, CO_2 emissions, bi-objective model, economies of scale

Intermodal transport is promoted by the European Commission (2011) as an opportunity for reducing the environmental and societal negative impacts of transport. Intermodal transport is defined as the transport of goods using two or more modes, in the same loading unit, without handling of the goods themselves (United Nations, 2001). The main benefits of intermodal transport, in terms of costs or externalities, are achieved on the long-haul travel, by the use of a more environmentally friendly mode, such as rail or inland waterways. The location of intermodal terminals is of strategic importance in terms of competitiveness with door-to-door road transport. Indeed, optimal location ensures that the advantages obtained on the long-haul travel can compensate the higher costs and externalities generated on the pre- and post-haulage travels by truck. Good locations of intermodal terminals also improve the flow consolidation process. Large quantities of goods are thus transported, which leads to economies of scale on the long-haul travel performed by rail or inland waterways.

This research presents an innovative bi-objective location-allocation model which focuses on the optimization of operational costs and CO_2 emissions of transport. The model represents the perspective of transportation companies, which have to support operational costs and try to minimize their total CO_2 emissions. Their first objective, cost minimization, is quite straightforward from the economic perspective. The second objective, emission minimization, is induced by marketing reasons or willingness to match CO_2 emissions policies instigated by public authorities.

The bi-objective model is solved using the ϵ -constraint method proposed by Chankong and Haimes (1983), which consists in transforming a multi-objective problem into single-objective optimization. The cost function is kept as the objective and the emission function is introduced as a constraint. The maximum allowed amount of emissions is iteratively varied in order to generate the Pareto front, which includes all the non-dominated points, i.e. all the solutions for which one of the objective function cannot be improved without worsening the value of the other. The method used for identifying the different ϵ values is detailed in the current presentation.

The particularity of this study is to model intermodal economies of scale using nonlinear functions of the weight transported, instead of classically considering a discount factor on the long-haul travel. Economies of scale are taken into account from the transportation point of view, but also from the transshipment perspective at the intermodal terminal. Two methods have been identified for solving the nonlinear problem. The first one consists in using a nonlinear commercial solver (KNITRO). The second one deals with the piecewise linearization of the nonlinear functions, in order to solve the model with a linear commercial solver (CPLEX). The objective is to identify how the terminal locations and flow repartitions are sensitive to the expression of economies of scale, using specifically dedicated nonlinear functions.

We apply the model to the Belgian case-study. Flow exchanges inside Belgium, as well as flow interactions between Belgium and its neighboring countries are taken into account. The use of intermodal transport is often recommended on medium and long distances. Nevertheless we find it interesting to analyze how the modal split between road-only and intermodal transport behaves on short distances. Belgium, thanks to its reduced geographical area, is therefore a good case-study on which the developed model can be applied. In addition, the important exchange of flows between Belgium and its neighboring countries also allows the analysis on longer distances.

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