A Choice-Driven Service Network Design and Pricing model considering Shippers' Behavior

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Service Network Design (SND) problems are critical for intermodal transport planning. Indeed, they cover most tactical decisions of a carrier, e.g., the itineraries to be served or the offered frequencies. In the existing SND literature, only a handful of works cover pricing decisions and preferences of shippers. With this work, we integrate these two aspects within a Choice-Driven Service Network Design and Pricing (CD-SNDP) problem.

It is formulated as a bi-level optimization. The upper level represents an inland barge operator, whose objective is to maximize their profits under fleet size and capacity constraints. The lower level describes the utility maximization of shippers, that have four transport alternatives: the barge operator, a competing inland waterway carrier, train, and truck. The first one is related to the upper level, whereas the last three are competing options exogenous to the model. We estimated the utility functions for these alternatives in a previous work, where a mixture formulation was introduced to represent the heterogenous cost sensitivities of shippers. This bi-level SNDP problem can be reformulated into a single level linear problem using the strong duality theorem, the big M technique and expressing frequencies as binary variables.

With the mixture formulation of utility functions, we are able to introduce a stochastic version of the SNDP problem. In particular, the cost coefficient for intermodal alternatives (barge and train) is assumed to be randomly distributed among the population of shippers. The problem is then solved using Sample Average Approximation (SAA).

We compare several models: a benchmark where shippers are purely cost minimizers, a deterministic version of the CD-SNDP incorporating a Multinomial Logit (MNL) model, a stochastic version including a MNL with random error terms, and finally the aforementioned stochastic version with mixture model. The obtained solutions are assessed through an out-of-sample simulation, which imitates the behavior of a "real population of shippers".

The results reveal that the deterministic version of the CD-SNDP provides profits that are considerably higher than those with the benchmark. This is due to a better evaluation of the mode shares in the optimization model, leading to more accurate pricing. The two stochastic versions allow to further improve the resulting profits, although by a shallower margin, thanks to their improved demand representation.

The proposed CD-SNDP problem allows to design services and set prices that account for the behavior of shippers. The transport operator is thus able to respond more accurately to the shippers' needs and, therefore, can gain a significant advantage against their competitors.