Stochastic network design with rerouting

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Service network design under uncertainty is fundamentally crucial for all freight transportation companies. The main challenge is to strike a balance between two conflicting objectives: low network setup costs and low expected operational costs. Together these have a significant impact on the quality of freight services. Increasing redundancy at crucial network links is a common way to improve network flexibility. However, in a highly uncertain environment, a single predefined network is unlikely to suit all possible future scenarios, unless it is prohibitively costly. Hence, rescheduling is often an effective alternative.

The main contribution of this paper is two-fold: primarily, we propose a stochastic programming model for stochastic service network design with options of both vehicle rerouting and service outsourcing to address demand stochasticity more efficiently. Secondly, some interesting observations and insights drawn from our experimental studies could have important implications for stochastic service network design practices. Application of the proposed model could potentially substantially reduce network setup costs and expensive outsourcing, but maintain a similar level of flexibility to those that can be offered by other related models in the literature.

We set the model in the framework of stochastic programming. The main result is a model that provides a design with operational flexibility that can handle varying demand scenarios. This operational flexibility can be useful also if the stochastics is mis-specified, i.e. is different from what we assume. However, in this paper the focus is not on ambiguity (interesting as that is), but rather on understanding the role of rerouting and its effect on operational flexibility. It is also worth noting that for many applications that fit into this modelling scheme, particularly trucking, but also air airfreight transportation, data is normally available in large amounts, and estimating distributions is not unreasonable.

As for earlier papers, we have formulated our model in a two-stage setting. This is not primarily for simplicity, but because we see this as the most appropriate framework. The problem we are discussing in this paper is what has been called an ``inherently two-stage problem'', see Chapter 1 of King and Wallace (2012). These are problems where the first stage is structurally different from all the others. In our case, the first stage is to set up the service network, the rest amount to using/operating the network from Stage 1 in an uncertain environment. Typically, the first stage decisions are either expensive or irreversible (or both). For such models, the focus is on Stage 1, all the other stages are there only for creating a correct understanding of how the network will be operated, so as to get the network set up correctly. The clue of such models is the flow of information from the operational phase to the design phase. It is important to realize that the later stages are not interesting in their own rights; it is quite clear that once the service network is established, a much more detailed model will be developed for operational decisions. So the quality of how we model the operational phase should be based on its ability to feed back to the Stage 1 decisions, and not on its ''accuracy''. In this regard we are also following earlier work, such as Lium et al. (2009). So although the use of the service network in principle is an infinite horizon problem (or maybe just one with a very large but finite number of stages) representing the life of the design, we represent it with weekly snap-shots (scenarios) of demand patterns. For each scenario we model the transportation, including rerouting (and route recovery) of vessels and outsourcing of goods. This is of course an approximation (like all models are), but describes well the setting in which the service network must operate. So for this kind of models, it is actually a goal to avoid the multi-stage aspect of the real problem. That contains many details which are not needed for setting up the network. Only when we reach the operational phase itself do we need to care about the small details related to the fact that the operations take place in a dynamic environment.

Alan King and Stein W. Wallace, *Modeling with stochastic programming*, Springer, NY, 2012.

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