Robust Supply Chain Design for Highly-Customized Manufacturing

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Abstract

Customers in today's evolving markets are seeking options that best suit their specific needs; consequently, the demand for highly-customized and personalized products has been growing steadily. In order to facilitate customized manufacturing, the structure of the underlying supply chain (SC) needs to be enhanced in terms of flexibility and resilience. In this study, we consider an SC comprising a main manufacturer that produces custom-designed modular-structured products, featured with different design complexity levels. The products have a bill-of-material (BOM) that can be altered in terms of the design of a subset of sub-assemblies and components. It is further assumed that the company collaborates with a group of manufacturers and part suppliers (upstream SC entities), differentiated in terms of capacity, technological capabilities, and cost, along with a group of logistics carriers (downstream entities) distinguished in the sense of their cost and lead time. In other words, in addition to involving customers in the product design, the company also provides different modes of product delivery (e.g., fast, regular, and slow) offered by different logistics carriers. We also incorporate the uncertainty involved in the manufacturing of subassemblies and parts featured with complex designs. More specifically, to reflect the amount of effort required to manufacture complex designs, the production and procurement costs of (highly or moderately complex) items are considered as piece-wise linear functions of their order quantity. Furthermore, the manufacturing capability of upstream entities for producing complex items are assumed uncertain, and modeled as scenarios. More precisely, under some scenarios, the producers/suppliers will not be capable of fulfilling the order of highly/moderately complex items within the promised production lead time due to technological limitations.

To obtain the optimal configuration of the above-mentioned SC, we first develop a deterministic mixed-integer programming (MIP) model that seeks the optimal choice of sub-assembly producers, part suppliers, and logistics carriers in addition to the optimal quantity of procurement, production, and transportation at different echelons. The objective is to minimize the total manufacturing, transportation, and lost-sale cost. Afterward, in order to incorporate the uncertain technological capabilities of producers/suppliers, the above MIP model is reformulated as a two-stage stochastic program (2-SP). In this model, three types of corrective (recourse) actions are considered in order to compensate for the incapability of producers/suppliers in the manufacturing of complex products. These actions correspond to resorting to backup suppliers/producers; purchasing sub-assemblies and components from the open market; and lost-sale, in case none of the first two actions are feasible. Obviously, the cost of all recourse actions mentioned above is substantially higher than the cost of the initial assignment of producers/suppliers that must be set prior to receive full insight in terms of suppliers' capabilities. We explore a sample average approximation (SAA) scheme to solve the 2-stage stochastic MIP model under different scenario sets. In-depth computational experiments are conducted to validate the proposed models and solution algorithm while showcasing the value of incorporating uncertainty into the SC design problem.

Keywords
Supply chain design, Customized manufacturing, Stochastic programming, and Sample Average Approximation.

Biographies

Masoumeh Kazemi Zanjani Dr. Masoumeh Kazemi Zanjani is an Associate Professor in the Department of Mechanical, Industrial, and Aerospace Engineering at Concordia University. She is a regular member of the Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT). She holds a B.Sc., M.Sc., and PhD. degree in Industrial Engineering. Her research expertise revolves around the development of robust and data-driven decision support tools, relying on stochastic and robust optimization approaches, for supply chain management, production planning, maintenance logistics, and healthcare operations management. Dr. Kazemi Zanjani has published over 30 scientific articles on these topics in top Industrial Engineering journals. She has been the principal investigator of several competitive federal and provincial research grants in Canada. She has been supervising 9 PhD and 14 MSc students and one postdoctoral fellow.

Hoora Katoozian is a PhD candidate in Industrial Engineering at Concordia University and a student member of Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT). Her PhD thesis is centered on the design of robust and configurable supply chains that facilitate the manufacturing of highly-customized products in the context of Industry 4.0. Her research interests include operations research, supply chain management, decision-making under uncertainty, and data-driven optimization. She also collaborates with Flextronics Global Services (US) as a part-time data scientist. She has so far received several scholarships and research awards during her PhD program.