Preface

Scope

This book deals with stochastic combinatorial optimization problems in supply chain disruption management, with a particular focus on management of disrupted flows in customer-driven supply chains. The problems are modeled using a scenario-based stochastic mixed integer programming to address risk-neutral, risk-averse, and mean-risk decision-making in the presence of supply chain disruption risks. One of the main objectives of this book is to present a computationally efficient portfolio approach to integrated decision-making in global supply chains under disruption risks, where the portfolio is defined as the allocation of demand for parts and finished products, respectively, among suppliers and production facilities. The allocation of demand for parts among suppliers is defined as a supply portfolio, whereas the allocation of demand for products among production facilities (e.g., assembly plants) is defined as a demand or capacity portfolio. Unlike most of reported research on the supply chain risk management which mainly focuses on the risk mitigation decisions taken prior to a disruption, the proposed portfolio approach combines decisions made before, during, and after the disruption. When a disruption occurs, the primary portfolios determined prior to a disruption are replaced by recovery portfolios. The selection of portfolios will be combined with management of disrupted material flows, i.e., supply, production, and distribution scheduling under disruption risks. This book demonstrates that the developed portfolio approach leads to a well-structured decision-making and computationally efficient mathematical formulations, in particular, to stochastic mixed integer programs with a strong LP relaxation. Moreover,

- integrated versus hierarchical decision-making is compared depending on the available information on disruptive events;
- a multi-objective decision-making is analyzed to trade off between: cost versus service level objective functions, fairness versus non-equitability of objective functions, average versus worst-case performance of a supply chain, etc.;

- a multi-period decision-making is modeled to capture dynamics of disruption and recovery processes, i.e., static versus dynamic portfolios, scheduling of supply, production, and distribution operations to control disrupted flows under time-varying conditions such as demands and capacities;
- a multi-level disruption scenarios are modeled to capture partially disrupted flows, partially fulfilled orders, partially recovered facilities, and partially available capacity.

This book also addresses the issue of fundamental understanding of average-case and worst-case performance of a global supply chain in the presence of flow disruption risks as well as understanding of the recovery mechanisms.

A straightforward computational approach used in this book is to solve the deterministic equivalent mixed integer program of a two-stage stochastic mixed integer program with recourse, which allows for a direct application of commercially available software for mixed integer programming. In the computational experiments reported throughout this book, an advanced algebraic modeling language AMPL (see, Fourer et al. 2003) and the CPLEX, Gurobi, and XPRESS solvers have been applied.

Content

This book is divided into an introductory Chap. 1, where an overview of supply chain disruption modeling and management is provided, and the five main parts. Part I addresses selection of a supply portfolio, Part II, integrated selection of supply portfolio and scheduling, Part III, integrated, equitably efficient selection of supply portfolio and scheduling, Part IV, integrated selection of primary and recovery supply (and demand) portfolios and scheduling, and finally, Part V addresses disruption management of information flows in supply chains.

Part I (Chaps. 2–4) introduces the portfolio approach for supplier selection and order quantity allocation in the presence of supply chain disruption risks, i.e., for determining a supply portfolio. The proposed portfolio approach allows the two popular in financial engineering percentile measures of risk, Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR), to be applied for managing the risk of supply disruptions. For a finite number of scenarios, CVaR allows the evaluation of worst-case costs (or worst-case service level) and shaping of the resulting cost (service level) distribution through optimal supplier selection and order quantity allocation decisions, i.e., the selection of optimal supply portfolio. Part I is comprised of these chapters:

- Chapter 2, Selection of Static Supply Portfolio. This chapter deals with selection of a static supply portfolio under disruption risks, i.e., for determining a single-period allocation of demand for parts among selected suppliers to minimize expected or expected worst-case cost or maximize expected or expected worst-case service level.

- Chapter 3, Selection of Dynamic Supply Portfolio. In this chapter, the static portfolio approach and the stochastic mixed integer programming formulations presented in Chap. 2 are enhanced for a multi-period supplier selection and order quantity allocation in the presence of both the low-probability and high-impact supply chain disruption risks and the high-probability and low-impact supply chain delay risks. The suppliers are subject to local delivery delay risks, and both local and regional delivery disruption risks. In the delivery scenario analysis, both types of the supply chain risks are simultaneously considered.
- Chapter 4, Selection of Resilient Supply Portfolio. In this chapter, the portfolio approach and SMIP (Stochastic Mixed Integer Programming) models presented in Chap. 2 are enhanced for the combined selection and protection of part suppliers and order quantity allocation in a supply chain with disruption risks. The protection decisions include the selection of suppliers to be protected against disruptions and the allocation of emergency inventory of parts to be prepositioned at the protected suppliers so as to maintain uninterrupted supplies in case of natural or man-made disruptive events.

Part II of this book concerns with integrated selection of supply portfolio and scheduling. The medium- to short-term decisions of the supplier selection and order quantity allocation, driven by the time-varying customer demand, are made along with scheduling of customer orders execution and distribution. The advantage of such a joint decision-making is especially evident in the presence of supply chain disruption risks. Part II has two chapters:

- Chapter 5, Integrated Selection of Supply Portfolio and Scheduling of Production. This chapter proposes a SMIP approach to integrated supplier selection and customer order scheduling in the presence of supply chain disruption risks, for a single, dual, or multiple sourcing strategy. The suppliers are assumed to be located in two or more disjoint geographic regions: in the producer's region (domestic suppliers) and outside the producer's region (foreign suppliers). The supplies are subject to independent random local disruptions that are uniquely associated with a particular supplier and to random regional disruptions that may result in disruption of all suppliers in the same geographic region simultaneously.
- Chapter 6, Integrated Selection of Supply Portfolio and Scheduling of Production and Distribution. The purpose of this chapter is to study the integrated decision-making to simultaneously select suppliers of parts, allocate order quantity, and schedule production and delivery of finished products to customers in a supply chain under disruption risks. In addition to supplier selection, order quantity allocation, and scheduling of customer orders, distribution of finished products to customers is simultaneously considered with different shipping methods to optimize the trade-off between cost and service level. The three different shipping methods will be modeled and compared for the distribution of products: batch shipping with a single shipment of different

customer orders, batch shipping with multiple shipments of different customer orders, and individual shipping of each customer order immediately after its completion.

Part III addresses equitably efficient selection of supply portfolio and scheduling. A fair optimization of an average performance of a supply chain with respect to equally important conflicting objective functions and a fair mean-risk optimization of average-case and worst-case performance are considered in the presence of supply chain disruption risks. The conflicting and equally important objective functions are expected values of cost and customer service level and the corresponding expected and expected worst-case values, respectively. The fairness and the mean-risk fairness reflect the decision maker's common requirement to maintain an equally good performance of a supply chain with respect to equally important objectives and under varying operating conditions. Part III has two chapters:

- Chapter 7, A Fair Decision-Making under Disruption Risks. In this chapter, the two risk-neutral conflicting criteria—expected cost and expected service level—are fairly optimized to achieve an equitably efficient supply portfolio and production schedule in the presence of supply chain disruption risks. In order to obtain an equitably efficient solution, the ordered weighted averaging (OWA) aggregation of the two conflicting objective functions is applied. The equitably efficient solutions obtained for the ordered weighted averaging aggregation of the two conflicting objective functions will be compared with non-dominated solutions obtained using the weighted-sum aggregation approach.
- Chapter 8, A Robust Decision-Making under Disruption Risks. In this chapter, we look for an equitably efficient solution with respect to both average-case and worst-case performance measures of a supply chain. Such an equitably efficient average-case and worst-case solution or equivalently equitably efficient risk-neutral and risk-averse solution will be called a fair mean-risk solution. The solution will equitably focus on the two objective functions: the expected value (average-case performance measure) and the expected worst-case value (worst-case performance measure), i.e., Conditional Value-at-Risk of the selected optimality criterion, cost, or service level. The fair mean-risk decision-making aims at equalizing the distance to optimality both under business-as-usual and under worst-case conditions, which reflects a common requirement to maintain an equally good performance of a supply chain under varying operating conditions. Therefore, the mean-risk fairness, i.e., the equitably efficient performance of a supply chain in the average case as well as in the worst case, in this chapter will be called robustness.

Part IV focuses on selection of primary and recovery portfolios and scheduling. The selection of primary suppliers and order quantity allocation to mitigate the impact of disruption risks is combined with selection of recovery suppliers and assembly plants to optimize the recovery processes. The two decision-making approaches will be considered and compared: an integrated approach with some information about the future potential disruption scenarios available ahead of time and a hierarchical approach with no such information available. In the integrated approach, which may account for all potential disruption scenarios, the primary portfolios that will hedge against all potential disruptive events will be determined along with the recovery portfolios for each scenario. In the hierarchical approach, first the primary portfolios are determined, and then, when the primary portfolios are impacted by a disruptive event, the recovery portfolios are selected to optimize the process of recovery from the disruption. Both the integrated and the hierarchical decision-making account for time and cost of mitigation and recovery processes and aim at optimizing cost and service level as the two equally important, conflicting objective functions. Part IV has two chapters:

- Chapter 9, Selection of Primary and Recovery Supply Portfolios and Scheduling. In this chapter, the portfolio approach presented in the previous chapters for the selection of primary suppliers and order quantity allocation to mitigate the impact of disruption risks is enhanced also for the recovery process, i.e., for the selection of both primary and recovery suppliers and order quantity allocation to mitigate the impact of disruption risks and optimize the recovery process. Unlike most of reported research on the supply chain risk management which focuses on the risk mitigation decisions taken prior to a disruption, this chapter combines decisions made before, during, and after the disruption.
- Chapter 10, Selection of Primary and Recovery Supply and Demand Portfolios and Scheduling. In this chapter, the portfolio approach proposed in Chap. 9 for the selection of primary and recovery suppliers and order quantity allocation to mitigate the impact of disruption risks is enhanced also for the recovery process of the firm's assembly plants for finished products. Unlike most of reported research on supply chain disruption management, a disruptive event is assumed to impact both a primary supplier of parts and the buyer's firm primary assembly plant. Then, the firm may choose alternate (recovery) suppliers and move production to alternate (recovery) plants along with transshipment of parts from the impacted primary plant to the recovery plants. The resulting allocation of unfulfilled demand for parts among recovery suppliers and unfulfilled demand for products among recovery assembly plants determines recovery supply portfolio and recovery demand portfolio, respectively.

Part V deals with disruption management of information flows in supply chains caused by cybersecurity incidents. The supply portfolio approach applied to mitigate the impact of supply disruptions has been modified to select countermeasure portfolio to mitigate the impact of information flow disruptions. Part V has one chapter:

- Chapter 11, Selection of Cybersecurity Safeguards Portfolio. This chapter deals with the selection of countermeasure portfolio in cybersecurity planning to prevent or mitigate the impact of information flow disruptions on a supply chain. A scenario-based bi-objective SMIP approach with CVaR as a risk measure is proposed for the decision-making. Given a set of potential threats and a set of available countermeasures, the decision maker needs to decide which countermeasure to implement under limited budget to minimize potential losses from successful cyberattacks. The selection of countermeasures is based on their effectiveness of blocking different threats, implementation costs, and probability of potential attack scenarios. The bi-objective trade-off model provides the decision maker with a simple tool for balancing expected and worst-case losses and for shaping of the resulting cost distribution through the selection of optimal subset of countermeasures for implementation, i.e., the selection of optimal countermeasure portfolio.

Parts I–IV and the chapters within each part are arranged in the order recommended for reading, while Part V with Chap. 11 can be read independently of the other chapters. Each chapter ends with the end-of-chapter problems to help the reader a self-check of material comprehension and to encourage for a further self-study.

This book can be considered a companion as well as a follower of my previous book on scheduling in supply chains using mixed integer programming (Sawik 2011a), where deterministic MIP approaches were developed for integrated scheduling in customer-driven supply chains, in particular, in the electronics supply chains. The reader interested in knowing more about stochastic programming is referred to the monographs by Birge and Louveaux (2011) or Kall and Mayer (2011). For a general introduction to mixed integer programming models and techniques, the reader is referred to the application-oriented book by Chen et al. (2010) or to the seminal work in the field by Nemhauser and Wolsey (1999). The fundamentals of supply chain theory are well presented by Snyder and Shen (2011), and for an engineering-oriented general reference work on supply chains, the reader is referred to the book by Dolgui and Proth (2010). Finally, some books cover supply chain risk management in general, e.g., Kouvelis et al. (2011), and some of these emphasize supply chain disruption management, e.g., Gurnani et al. (2012).

Audience

This book is addressed to practitioners and researchers on supply chain risk management and disruption management, and to students in management, industrial engineering, operations research, applied mathematics, computer science and the like at masters and Ph.D. levels. It is not necessary to have a detailed knowledge of stochastic programming and integer programming in order to go through this book. The knowledge required corresponds to the level of an introductory course in operations research and supply chain management for engineering, management, and economics students.

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