Enterprise-wide optimization under uncertainties: developing a framework for integrated, resilient, and sustainable supply chain modelling and optimization

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The fast-changing pace of globalization and the unprecedented flow of information have transformed chemical industries and their supply chains into complex, interconnected networks. This transformation introduces challenges such as the bullwhip effect, amplified distortions in supply and demand, difficulties in recovering from disruptions, and challenges in meeting sustainability goals. Consequently, innovative frameworks are needed to manage and mitigate these complexities and risks. This thesis addresses these challenges through a structured approach divided into three parts: (i) developing a framework for data-driven integrated supply chain optimization, leveraging advanced analytics to enhance decision-making and operational efficiency; (ii) designing resilient supply chains that ensure flexibility and robustness for adaptation and recovery from uncertainties and disruptions; and (iii) creating a framework for sustainable supply chain design, applied to plastic waste transformation to optimize performance and sustainability.

The benefits of an integrated supply chain model include cost reduction, lean management, and reduced redundancy. However, implementing such models presents challenges, particularly managing complexity across multiple scales, often leading to the curse of dimensionality. These challenges result in a compromise between computational efficiency and decision quality. Recognizing the importance of integrated models, the first part of this thesis addresses these challenges through a data-driven integration framework. Some constraints are replaced with a surrogate model developed from enterprise data and machine learning. This framework was applied to integrate tactical planning with operational planning and scheduling. A dataset from a high-fidelity scheduling model was used to build this surrogate, capturing the feasibility region. Validation showed the surrogate model provided non-inferior solutions with computational advantages, motivating higher-level integration. This approach reduces computational time without compromising solution quality.

The second part of this thesis addresses the issues of uncertainty and disruption within the supply chain, challenges worsened by increased competition and market volatility. Flexibility in planning is

crucial, making modular manufacturing a promising strategy. We developed a framework for a modular supply chain, offering economies of scale, reduced time to market, and better management of demand and supply variability. To tackle disruptions, we integrated proactive and reactive measures, including strategic planning, risk assessment, real-time adjustments, and contingency planning. Additionally, we proposed a stochastic modeling approach to handle uncertainties more effectively, considering various probabilistic scenarios for dynamic adaptation. This model outperforms its deterministic counterpart, enhancing supply chain objectives like cost efficiency, reliability, and responsiveness, proving especially effective where traditional models fall short.

The third part of this thesis focuses on designing a sustainable supply chain model. Increasing awareness of the impact of economic activity on environmental health makes sustainability a growing challenge as activity scales. To address these issues, we developed an enterprise method to ensure sustainable supply chain operations. This method integrates sustainable practices into every stage of the supply chain, from sourcing raw materials to delivering the final product, with decisions evaluated in a multi-objective fashion. Applied to a plastic waste supply chain problem, this methodology resulted in a sustainable network design and operations. By incorporating environmental considerations, the model demonstrates that it is possible to create a supply chain that supports economic growth while minimizing environmental impact and maximizing profit.

In summary, this thesis presents a structured approach to addressing modern supply chain challenges through data-driven integration, resilient design, and sustainable practices, advancing both theoretical understanding and practical applications.