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# Supply chain design and optimization: Challenges and opportunities

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ABSTRACT

Optimal supply chain design is vital to the success of industrial concerns now more than ever before. This paper reviews some principal research opportunities and challenges in the field of supply chain design. The growing area of enterprise-wide optimization and the increasing importance of energy and sustainability issues provide plentiful opportunities for supply chain design research. However, modeling, algorithmic, and computational challenges arise from these research opportunities. There are three major technical challenge areas where knowledge gaps can be addressed in supply chain design, namely multi-scale challenges, multi-objective and sustainability challenges, and multi-player challenges. This paper provides an overview of opportunity areas, a description of relevant technical challenges, and a perspective on how these challenges might be addressed in supply chain design. Illustrative examples are presented to illuminate avenues for future research.



## 1. Introduction

Supply chains may be defined as an integrated network of facilities and transportation options for the supply, manufacture, storage, and distribution of materials and products. They vary considerably in size, complexity, and scale from industry to industry (Simchi-Levi, 2005; Shapiro, 2006; Chopra and Meindl, 2012). Standard elements of supply chains might involve suppliers, manufacturers, and distributors. In the physical dimension, these elements translate to processing facilities, factories, trucks, trains, sea-faring vessels, and warehouses (Fig. 1). An optimally designed supply chain should, through one or a variety of metrics, reflect the "best" configuration and operation of all of these elements. Therefore, it is in industry's best interest to optimize their supply chains in some manner (Wassick, 2009). However, optimizing a supply chain can be a technically challenging task, especially for large ones. Consider a global supply chain similar to that of Fig. 1. This supply chain is a large-scale, complex system that includes a variety of supply, production, and distribution facilities (Ottino, 2011). There will also be an assortment of transportation options with different lead times and methods (truck, barge, air, etc.) to link these entities together, creating an integrated network. Furthermore, the supply chain would be subject to a variety of uncertainties, such as supply disruption, global price changes of commodity goods, etc. Thus, there is great economic potential and practical need to optimally design and coordinate all activities of all supply chain entities to achieve seamless operation for large-scale and complex supply chains under uncertainty. Consequently, optimization models and methods for supply chain design and operations have been of great interest to industry and academia over the past decades (Papageorgiou, 2009; Grossmann, 2012; Barbosa-Póvoa, 2012; Chopra and Meindl, 2012).

Supply chain design has been an active research area in Process Systems Engineering (PSE). An increasing number of research articles on this topic published in high-profile journals reflects its importance. Fig. 2 shows the number of journal articles addressing the topic of supply chain(s) published in the last two decades in *AIChE Journal*, *Chemical Engineering Research and Design*, *Chemical Engineering Science*, *Computers & Chemical Engineering*, and *Industrial and Engineering Chemistry Research*, as well as their citations. These journals do not cover all of the publications by PSE researchers in the supply chain area, but these data illuminate general trends. Clearly, the topic of supply chains is of growing importance in the PSE research community.

There are a number of excellent review papers on process supply chain optimization (Shah, 2005; Papageorgiou, 2009; Barbosa-Póvoa, 2012; Barbosa-Povoa, 2014). Instead of reviewing the broad area of supply chain modeling and optimization, the scope of this paper is restricted to supply chain design and its integration with supply chain operations. As supply chains themselves can be quite large and complex, methods to optimally design them can lead to cumbersome modeling and computational challenges. Much effort has been expended on this front from a variety of different sources and angles, and part of this article is to communicate this work in

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**Fig. 1.** Supply chains can be global in scope and can be composed of suppliers, manufacturers and distributors connected by a variety of transportation and delivery methods.

the context of supply chain design. Furthermore, this work seeks to identify opportunities and challenges in supply chain design research. Enterprise-wide optimization (EWO) involves optimizing the operations of R&D, material supply, manufacturing, and distribution of a company to reduce costs and inventories (Grossmann, 2005), and can provide a key tool for the advancement of supply chain design. Additionally, the recent trends toward sustainability, especially in energy, presents clear opportunities for future supply chain design research. These two key opportunities will be more clearly described in the following sections, followed by a description of technical challenges to be overcome, including multi-scale challenges, multi-objective and sustainability challenges, and multi-player challenges.

The following section will describe these opportunities in detail. Section 3 will discuss the aforementioned three key technical challenges that we have identified in supply chain design research. A variety of different approaches to these challenges will be discussed, and modeling and computational challenges that have arisen within each area will be highlighted. We also present illustrative examples from the literature that uniquely address these challenges and provide platforms for future research.

## 2. Research opportunities for supply chain design

There are two key areas of research opportunities for supply chain design: EWO as well as energy and sustainability topics. Certainly energy and sustainability can be studied independently, but the two topics overlap considerably. Studying this overlap between them provides a richer, deeper understanding of the interactions between them. This understanding is key when designing and optimizing entities as large and complex as supply chains. Thus, in the remainder of this work, energy and sustainability opportunities and challenges in supply chain design and optimization are considered hand in hand. There are certainly other important opportunities to consider in future supply chain design research. For example, the realm of so-called Big Data and the analytical strategies that the movement enables could signal a paradigm shift not only in the design and optimization of supply chains, but in a host of other fields (Hazen et al., 2014). The quantity and quality of data that Big Data can provide could affect supply chain design, optimization, and management at all levels of the supply chain (Waller and Fawcett, 2013). Use of Big Data strategies should certainly be considered in supply chain design and optimization moving forward, but this discussion will not be a focus of this paper. Disruptive technologies have the power to fundamentally change the way supply chains are designed. For example, the advent of 3-D printing could galvanize the development of distributed supply chains, as there might not be as large of a need for major centralized manufacturing hubs (Conerly, 2014). Digital manufacturing could drastically hasten product development and supply chain service times, and in February 2014, President Obama announced a commitment to developing this technique with the founding of a state of the art Digital Manufacturing & Design Innovation Institute in Chicago, Illinois (The White House, 2014). Other similar initiatives are developing in Europe and around the globe. Nanotechnology could provide an entirely new scale to supply chain design (Baker and Aston, 2005). However, these opportunities are emerging; EWO and energy/sustainability issues have arrived and are already affecting supply chain design. Thus, while there are a variety of other important research opportunities in supply chain design, we believe that the two areas of EWO and energy/sustainability currently provide major research opportunities. These two opportunities are further described in this section.

### 2.1. Enterprise-wide optimization

Integrated, systems-wide optimization of operations and activities across the entirety of an enterprise is more crucial now than ever to a company's competitiveness. Globalization and modern communications technologies have provided a myriad of opportunities for improving supply chain performance. However, the

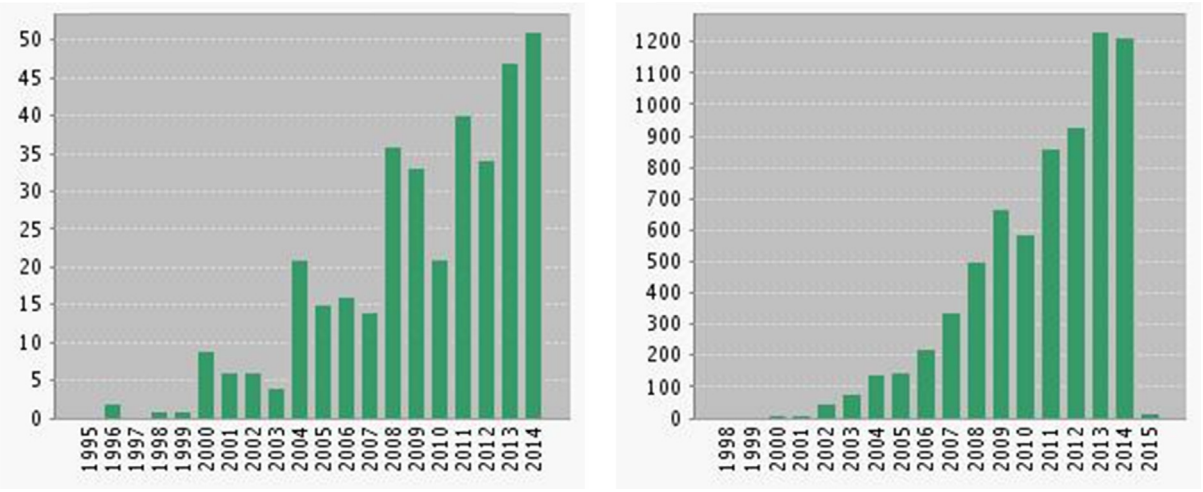


**Fig. 2.** Articles published (left) under a topic of "supply chain(s)" in *AIChE Journal*, *Chemical Engineering Research and Design*, *Chemical Engineering Science*, *Computers and Chemical Engineering*, and *Industrial and Engineering Chemistry Research*, and their citations (right) (Web of Science, 2014).