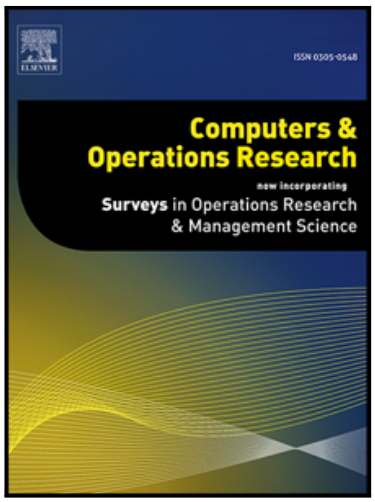

ADVANCES IN STOCHASTIC PROGRAMMING AND ROBUST OPTIMIZATION FOR SUPPLY CHAIN PLANNING

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ADVANCES IN STOCHASTIC PROGRAMMING AND ROBUST OPTIMIZATION FOR SUPPLY CHAIN PLANNING

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Abstract:

This special issue addresses the advances in stochastic programming and robust optimization for supply chain planning by examining novel methods, practices, and opportunities. The articles present and analyze opportunities to improve supply chain planning through exploring various uncertainty situations and problems, sustainability assessment, vendor selection, risk mitigation, retail supply chain planning, and supply chain coordination. This editorial note summarizes the discussions on the stochastic models, algorithms, and methodologies developed for the evaluation and effective implementation of supply chain planning under various concerns. A dominant finding is that supply chain planning through the advancement of stochastic programming and robust optimization should be explored in a variety of ways and within different fields of applications.

Keywords: Supply chain planning, stochastic programming, robust optimization, uncertainties

1. Introduction:

In most manufacturing and service organizations, supply chain planning (SCP) can be considered as the forefront of business functions from procurement of raw materials to fulfillment of customer demands. SCP can be categorized into strategic, tactical, and operational decisions according to the time horizon that is taken into account. Today's complex business environment is characterized with high uncertainty, frequent disruption, and great variability, so maintaining an efficient and viable supply chain becomes a major challenge for many companies. A supply chain operating in such a hostile environment has to cope with planning parameters such as cost, demand, and supply that have inherent uncertainty. In addition, a supply chain can be affected by major natural or man-made disruptions such as earthquakes, floods, terrorist attacks, and economic crises.

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Therefore, SCP is often made in the presence of uncertainty, for which robust optimization and stochastic programming are viable tools to assist in reaching SCP decisions.

Hence, this Special Issue (SI) is open to researchers throughout the world who are interested in applying advanced techniques of robust optimization and stochastic programming to address significant issues of SCP under uncertainty. Contributions in terms of theoretical advances, methodological development, or innovative applications of robust optimization and stochastic programming for SCP are all welcome. We aim to publish high-quality research papers that employ a variety of rigorous and pertinent research methodologies supported with strong empirical evidence based on extensive numerical results. In this context, this special issue (SI) for *Computers and Operations Research* (*COR*) is open to a wide range of topics analyzing supply chain planning under uncertainty:

- Exact or novel heuristic algorithms for solving resource-based stochastic programs. Simple metaheuristic approaches are not sufficient to address the objective of *COR*
- Exact algorithms for risk-based stochastic models and minmax problems
- Exact algorithms for multi-objective stochastic optimization
- Novel scenario generation and reduction methods for dealing with uncertainty in scenario-based stochastic programs
- Computational aspects for solving robust optimization models with interval uncertainty
- Decision making in a competitive environment under uncertainty
- Bi-level programming for decision making under uncertainty
- Simulation-based optimization approaches
- Models and techniques for risk averse decision making
- Optimal control of dynamic systems under uncertainty
- Stochastic dynamic programming models

From the number of submissions received, the Editors selected 9 papers for publication in this Special Issue based on their quality, novelty, and the new insights towards supply chain planning they provided. In general, this SI contributes to knowledge improvement in terms of both theoretical insights and empirical practices. From the theoretical perspective, the SI aims to develop fresh insights in supply chain planning. From a practice perspective, it addresses some relevant challenges: gaining comprehensive advantages, improving planning strategies, understanding supply disruptions, supply chain network redesign techniques, and scheduling lead times. However, the editorial note is organized as below. Following this introduction, the second section offers a

literature review on supply chain planning and related strategies. In the third section, a brief summary of the various articles selected for inclusion in this Special Issue is included. This section classifies the accepted articles into three subsections: namely, uncertainties in supply chain planning, sustainability in supply chain planning, vendor selection, retail planning and coordination through supply chain planning along with implications. The final section draws some learning points from this SI.

2. Literature on Supply Chain Planning

To provide the overview of this SI, initially a broad search was conducted to document the number of papers published in the area of 'Supply chain planning'. In this section, the Scopus databases were accessed. The search term includes the research areas: namely, supply chain planning, uncertainty in supply chain, stochastic optimization on supply chain, and so on; the search period used was from 1999 to 2nd April 2018. An overview of the number of articles is presented in Figure 1. After looking into the journal's specific search, Figure 2 clearly demonstrates that the *European Journal of Operations Research* was the leading journal in terms of numbers of papers from Scopus.

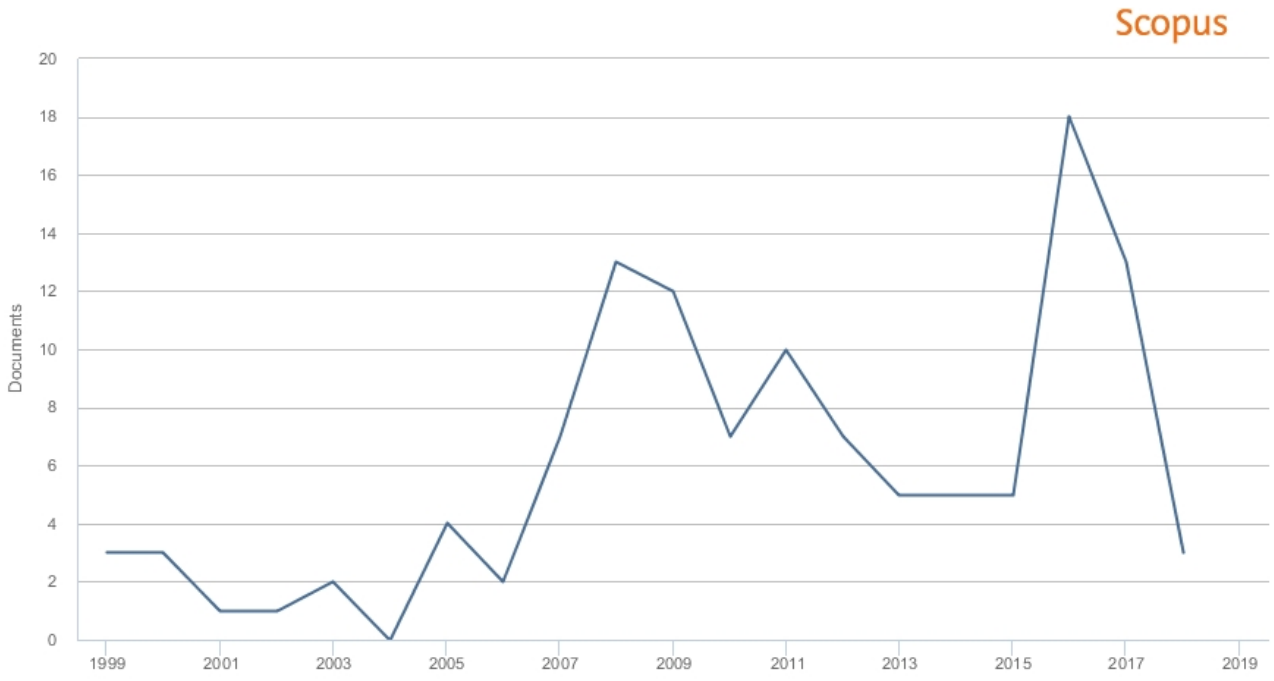

Figure 1: Number of supply chain planning papers published in various time periods (1999 - 2nd April 2018) as revealed in (Scopus)

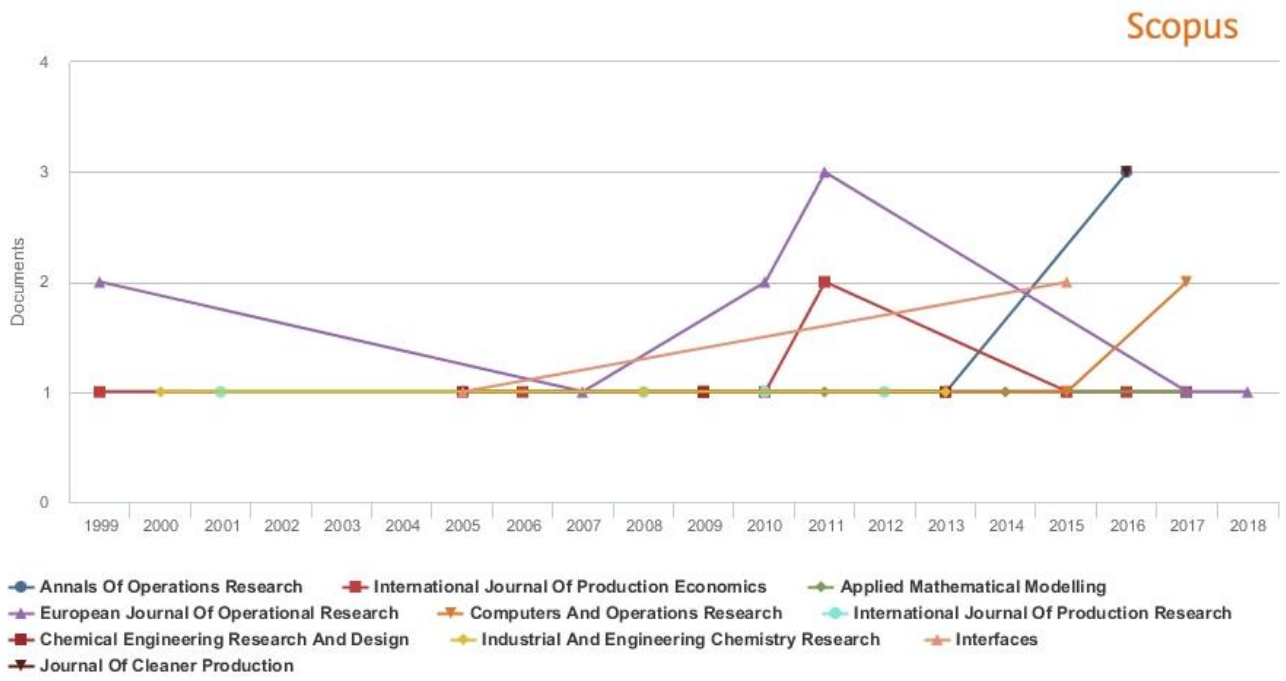

Figure 2: Share of top international journals with highest contributions in publishing supply chain planning topics as revealed in (Scopus)

In order to refine the search to identify the document type, the Scopus databases were investigated further. In this search, conference papers, notebook chapters, books, and short surveys were excluded. After excluding these items, a total of 121 were considered. The document types considered in this section included articles, articles in press, and reviews. The overview of document types is shown in Figure 3.

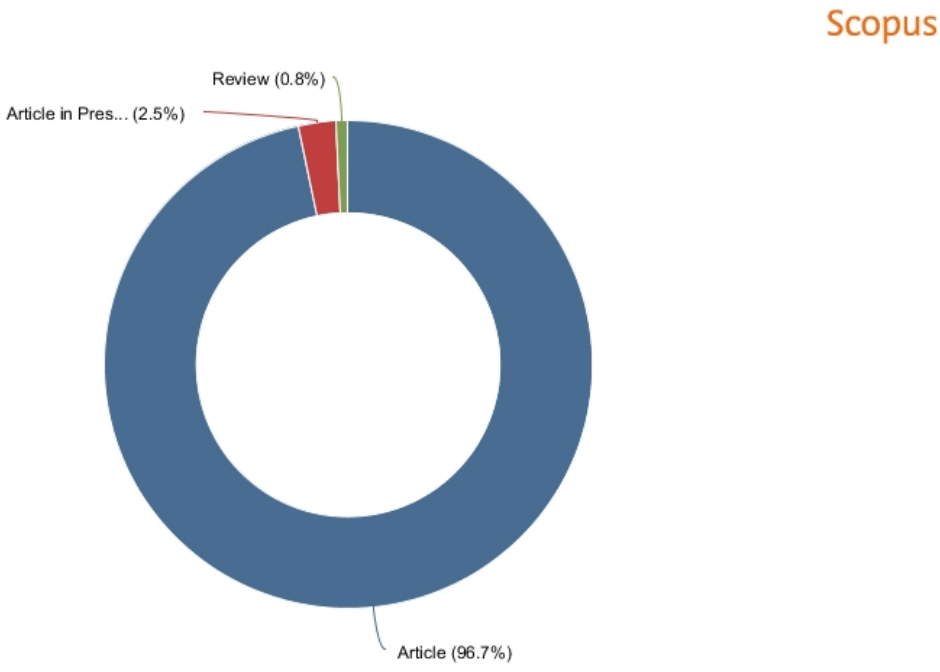

Figure 3: Percentage Share of different document types of journal articles as revealed in (Scopus)

The number of supply chain papers contributed according to country of origin was also analyzed; the top ten countries are shown in Figure 4. United States led the list with 34 documents, followed by Spain with 14 documents, Germany with 12 documents, Iran with 11 documents, and Denmark, India, and the UK with nine each.

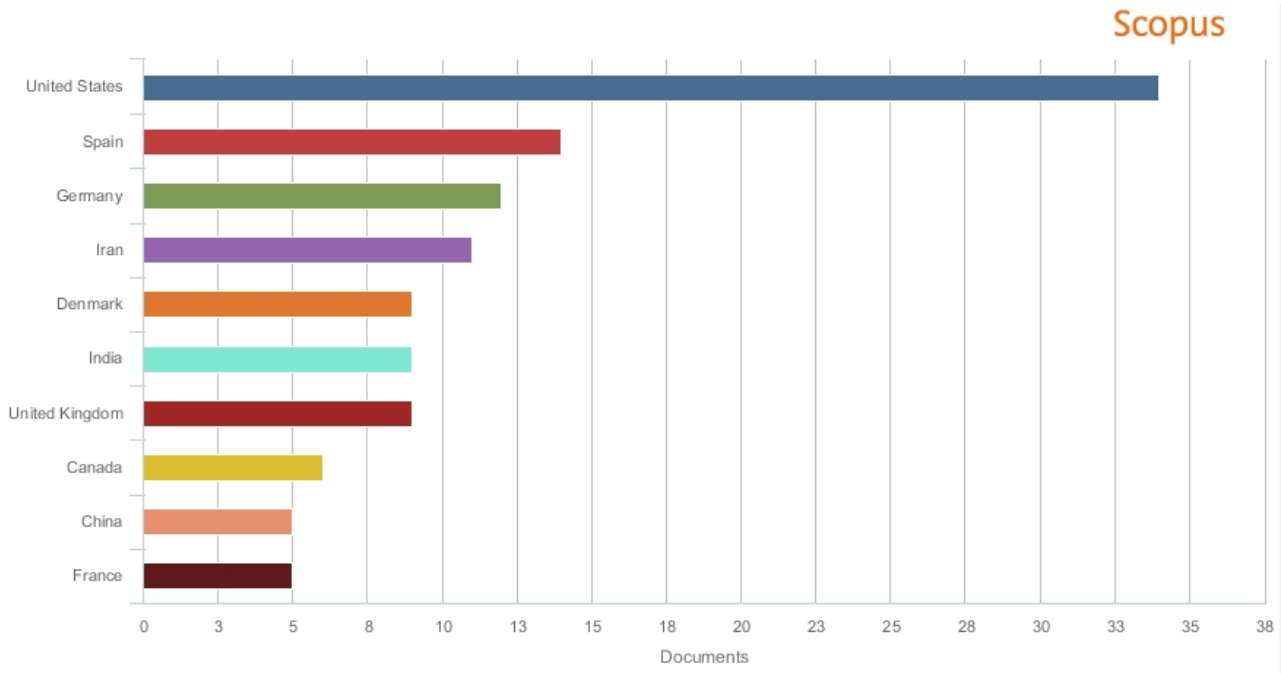

Figure 4: Share of country origin publishing supply chain planning topics as revealed in (Scopus)

The contributions of the authors with the numbers of supply chain planning papers are shown in Figure 5. Further, Figure 6 shows the subject distribution of the supply chain planning papers in which it is evident that most of the papers were published under the "Decision Science" classification.

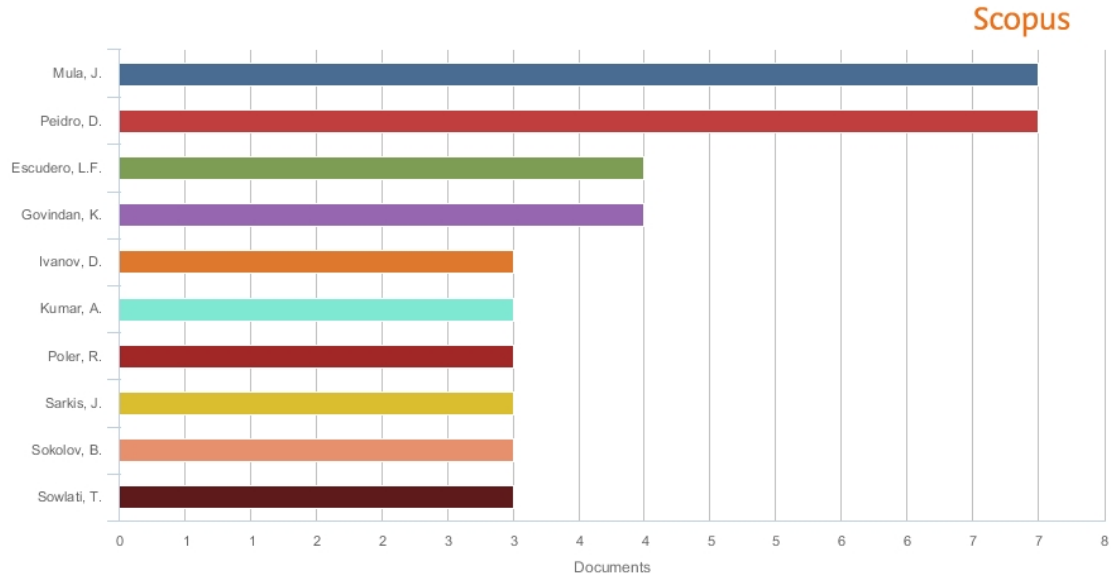

Figure 5: Share of authors publishing supply chain planning topics as revealed in (Scopus)

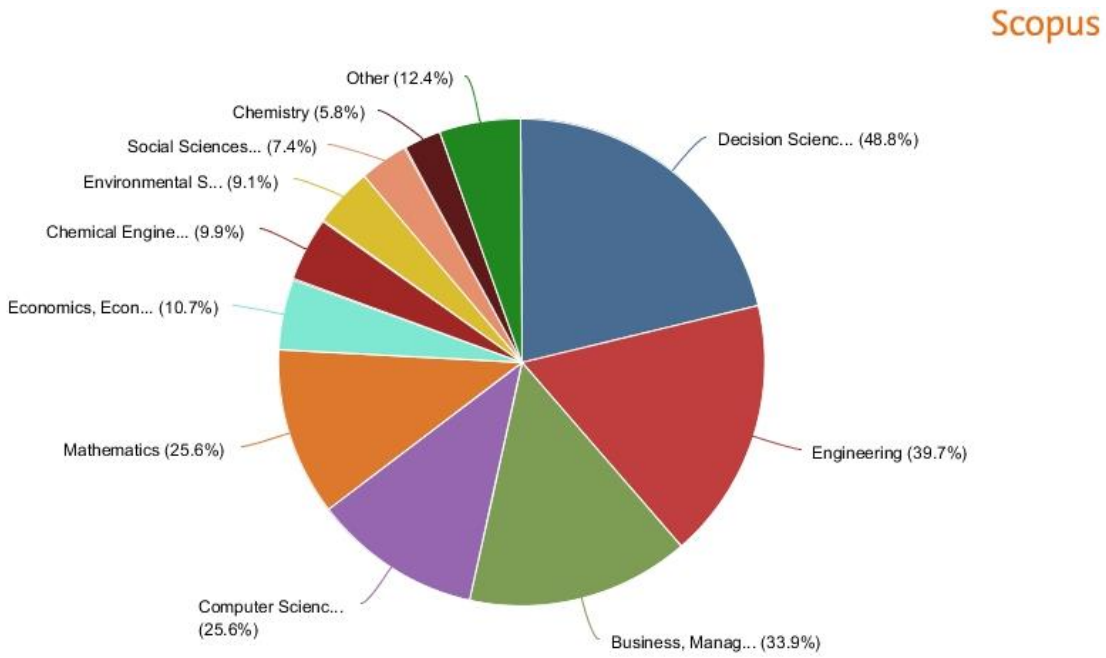

Figure 6: Share of subject publishing supply chain planning topics as revealed in (Scopus)

To conclude this section, a summary of the top twenty most frequently cited articles is provided in Table 1. The increasing interest in this research area provides solid evidence that this SI is timely and is especially relevant for the authors and readers of *Computers and Operations Research* (*C&OR*).

Table 1: Overview of first twenty highly cited papers in supply chain planning

S. No	Name of the article	Authors	Article type	Problem addressed	Meth
1	An approach for strategic supply chain planning under uncertainty based on stochastic 0-1 programming	Alonso-Ayuso et al. (2003)	Modelling	Presented a 0-1 model for the deterministic version of the Strategic Supply Chain (SSCh) planning problem, as well as a splitting variable 0-1 mixed deterministic equivalent model for the two-stage stochastic version of the problem.	Bra co algorit
2	A multi-objective robust optimization model for multi-product multi-site aggregate production planning in a supply chain under uncertainty	Al-E-Hashem et al. (2011)	Modelling	Proposal of robust multi-objective mixed integer nonlinear programming model to deal with aggregate production planning robust multi-objective mixed integer nonlinear programming model.	LP-m
3	Fuzzy optimization for supply chain planning under supply, demand and process uncertainties	Peidro et al. (2009)	Modelling	Proposal of fuzzy mathematical programming model for supply chain planning which considers supply, demand, and process uncertainties.	fu pr a
4	Robust planning: A new paradigm for demand chain planning	Van Landeghem and Vanmaele (2002)	Modelling	Presented a framework that clarifies the supply chain planning and demand chain planning with the focus of uncertainty through robust	M S

[2] N= Number of years

				planning for risk assessment.	
5	Risk management for a global supply chain planning under uncertainty: Models and algorithms	You et al. (2009)	Modelling	Proposal of simulation framework based on iteratively solving deterministic and stochastic programming problems with the aim of cost saving assessment with the use of stochastic programming.	S pro and
6	A two-stage modelling and solution framework for multisite midterm planning under demand uncertainty	Gupta and Maranas (2000)	Modelling	Proposal of two stage modelling and solution framework incorporating demand uncertainty in midterm planning problems based on the reference models from McDonald and Karimi.	s pro
7	Mid-term supply chain planning under demand uncertainty: Customer demand satisfaction and inventory management	Gupta et al. (2000)	Modelling	Captured the trade-off involved between inventory depletion, customer demand satisfaction, and production costs in the face of uncertainty in a probabilistic framework through chance-constraints.	Op
8	A multi-structural framework for adaptive supply chain planning and operations control with structure dynamics considerations	Ivanov et al. (2010)	Modelling	Proposal of multi-structural framework of adaptive supply chain planning with structure dynamics considerations.	Ag n
9	Quantitative models for	Peidro et al.	Review	Provided the reader with a	Syster

	supply chain planning under uncertainty	(2009)		starting point for modelling supply chain under uncertainty applying quantitative approaches. Further defined a taxonomy to classify models from 103 bibliographic references dated 1988–2007.	
10	Bioethanol supply chain system planning under supply and demand uncertainties	Chen and Fan (2012)	Modelling	Developed an integrated modelling framework that can be used to support future biofuel system planning under uncertainties.	Two-s pro
11	A probabilistic bi-level linear multi-objective programming problem to supply chain planning	Roghanian et al. (2007)	Modelling	Explored the applications of ‘‘probabilistic bi-level linear multi-objective programming problem” with supply chain problems including market demand, production capacity, and resources availability.	fuzzy t
12	A fuzzy linear programming based approach for tactical supply chain planning in an uncertainty environment	Peidro et al. (2010)	Modelling	Proposal of supply chain planning model where the data associated with all the sources of uncertainty in an supply chain are ill-known and modeled by trapezoidal fuzzy numbers.	fu pro a
13	Managing demand risk in tactical supply chain	Sodhi (2005)	Modelling	Presented a stochastic LP model that works in	S pro

	planning for a global consumer electronics company			conjunction with a deterministic one, the former to determine the shipments promised to customers in for the next 26 weeks, and the latter to request the plants for replenishment over the same horizon.	
14	Effect of (*s*, *S*) ordering policy on the supply chain	Kelle and Milne (1999)	Modelling	Examined the effect of (*s*, *S*) ordering policy on the order variability in a supply chain and provided quantitative tools for the estimation of the variability increase.	Op
15	Analytical framework for the management of risk in supply chains	Gaonkar and Viswanadham (2007)	Modelling	Developed a conceptual framework for the classification of supply chain risks and associated approaches to handling them.	Stra De D Manag
16	Schumann, a modeling framework for supply chain management under uncertainty	Escudero et al. (1999)	Modelling	Presented a novel modelling approach for the Manufacturing, Assembly, and Distribution (MAD) supply chain planning optimization problem under uncertainty for very large-scale instances.	Op
17	Applicability of optimal control theory to adaptive supply chain	Ivanov et al. (2012)	Conceptual	Analyzed the applicability of control theory (CT) approaches to the supply chain domain through review of	A Lagran Ber Dec

	planning and scheduling			literature on existing evidence.	ap
18	Application of fuzzy mathematical programming approach to the production allocation and distribution supply chain network problem	Bilgen (2010)	Modelling	Developed a sophisticated mixed integer linear programming (MILP) model able simultaneously to form production and distribution networks, and further to demonstrate the usefulness and significance of the fuzzy programming through a flexible programming approach.	Fuzzy pro
19	Integrated supply chain planning under uncertainty using an improved stochastic approach	Bidhandi and Yusuff (2011)	Modelling	Developed an integrated modelling the design of multi-commodity, single-period supply chain network problems under uncertainty.	Accele dec appr sam app t
20	Dynamic supply chain scheduling	Ivanov and Sokoloy (2012)	Modelling	Described the important issues and perspectives that delineate dynamics in SC scheduling, comment on methodical issues, and describe one specific context, model and algorithm in the dynamic SC scheduling area.	Ma pro

3. Advances in stochastic programming and robust optimization for supply chain planning

Uncertainties in supply chain planning

Uncertain environments in accordance with Govindan et al. (2017) can be categorized in three main groups as follows:

1- Decision making environments with random parameters in which their probability distribution are known. Stochastic programming approaches including two-stage stochastic programming, multi-stage stochastic programming, and chance-constrained programming approach belong to this group. Further, many risk-averse methods are developed for this type of uncertain decision making environment.

2- Decision making environments with random parameters in which decision makers do not have any information about their probability distribution. Robust optimization models belong to this group. Several studies considered continuous uncertain parameters within pre-specified intervals, named as interval-uncertainty modelling, in this area.

3- Fuzzy decision making environments. Flexible and possibilistic programming are two well-known approaches to model ambiguity and vagueness under a fuzzy decision making environment.

In the area of supply chain planning under uncertainty, these decision making environments are widely taken into account. Escudero et al. (2017) presented a multi-period stochastic mixed 0–1 problem arising in tactical supply chain planning (TSCP). A deterministic equivalent model was proposed to represent the parameters' uncertainty in multi-stage scenario tree. They suggested the add value of the new risk averse strategy using stochastic dynamic programming for TSCP. Likewise, Megahed and Goetschalckx (2017) developed a two-stage stochastic programming model for the comprehensive tactical planning of supply chains under demand and supply uncertainty with the application of the wind turbine industry. This proposed model was further validated with theoretical and numerical findings. Generally, uncertainties arise with the consideration of sourcing in supply chain. Among other operations, sourcing involves high uncertainties due to supply disruption. Hence, Li and Li (2017) investigated the supply disruption through stochastic programming with the objective to maximize the expected utility under loss aversion and to characterize the unique optimal order quantities. In the supply chain context, supply chain network (SCN) redesign gains an important focus due to its sensitivity over the physical configuration. Hence, it is necessary to deal with the SCN redesign under the concern of supply chain planning. Fattahi et al. (2017b) developed a multi-stage stochastic program (MSSP) with the concern of SCN redesign. This paper addressed two main issues: i) that constructing an appropriate scenario tree to

model existing uncertainty in stochastic parameters is a challenging task, and ii) even with a suitable scenario tree, a MSSP can lead to a large-scale optimization problem, such that commercial solvers may not be easily utilized to solve it. However, this study contributes to the literature through various key innovations. These innovations include:

- A SCN redesign problem is introduced in which the customers' demands for different products are stochastic and price-dependent in accordance with plausible price demand relationships. Embedding the pricing and SCN redesigning issues in an optimization problem helps us to understand the influence of price decisions on the strategic redesign decisions.

- A novel multi-stage stochastic program is proposed as a mixed-integer linear programming (MILP) model in which potential demands of customer zones are stochastic for various products.

- For the first time in the context of SCN design/redesign, discrete scenarios for stochastic potential demands are generated by the Latin Hypercube Sampling approach and then a scenario tree is obtained by applying a forward scenario tree construction method.

- The MSSP is decomposed into a master problem and several sub-problems, and then it is exactly solved for large-sized test problems using BD algorithm.

However, it is essential to explore the application point of view in supply chain planning under uncertainty. With this focus, Kenan et al. (2017) developed a model for integrated flight scheduling and fleet assignment problem (SFSFAM) in the airline industry. This model indicates which fleet family is to be assigned to each scheduled flight leg while accounting for the uncertainties in demand and fares. Further, these indications can help the crew handling decisions. To solve the considered problem, an SAA algorithm was used within statistical bounds.

Sustainability in supply chain planning

Sustainable supply chain is recognized as a key component of corporate responsibility. Hence, in recent years, a greater focus has been paid towards the integration of sustainability in the supply chain. Sustainability in multi-stage supply chain needs to be managed carefully due to the presence of more undesirable factors. Hence, Izadikhah and Saen (2017) presented linear models that obtain lower and upper bounds of efficiencies for stages 1 and 2 levels of a supply chain. In addition, they proposed a linear model that calculates overall efficiency of DMUs. However, the proposed model

was extended to deal with stochastic data in the presence of undesirable data. Finally, they have validated their proposed model with a case study demonstration.

Vendor selection, retail planning, and coordination through supply chain planning

Due to the fluctuating economies in global supply chain, occurrences of disasters or unexpected events have become common in recent years. These risks need to be managed through the four factors of supply, product, information, and demand. Although supply management serves as an important component among these four perspectives, vendor selection plays a crucial role. Hence, Park et al. (2017) proposed a new vendor evaluation framework by incorporating stochastic discrete event simulation and data envelopment analysis (DEA) approaches. Within the stochastic simulation schemes, the uncertainties involved in the entire supply chains were considered. In addition, vendors are assessed through their performance on sourcing and operational policies. With these results, this study contributes to the literature by offering a methodology for the holistic evaluation of vendors. In the supply chain, demand management can be seen as an important operation through various existing studies, especially those with a focus on retailers. Hence, effective supply chain planning on demand management helps retailers to maintain a significant flow through supply chains. With this concern, Taube and Minner (2017) proposed a data-driven method for setting delivery patterns and order-up-to levels for retail stores with stochastic non-stationary demand; their work considered the handling effort incurred in various processes. This proposed methodology highly assists retailers to manage delivery patterns in tactical time horizons. Finally, this SI addresses the importance of supply chain coordination and their relation with lead times. Heydari et al. (2017) proposed a model that features different shaping modes, including one fast mode and one slow mode. Coordination between the buyer and seller of supply chains was considered to manage the lead times. This model employs a group decision making mechanism by which buyer-seller relationships can be improved significantly. The solution for this supply chain coordination may be drawn from a proposed novel cost function based model.

4. Future research directions

This Special Issue, "Advances in stochastic programming and robust optimization for supply chain planning," has collected the possible solutions, models, and methods to deal effectively with the complicated situation that exists in supply chain planning. However, along with major useful findings, this SI provides more possibilities for future enhancements in the field of supply chain

planning. Our objective is to reinforce state-of-the-art scholarship to prompt even more research on the topics of concern; the topics still contain considerable opportunities. Some of the key potential future enhancements available from the study are discussed below.

- A significant aspect in scenario-based stochastic programming approaches is to generate an efficient set of scenarios to model existing uncertainty in an optimization problem. More importantly, evaluating the scenario generation methods in terms of stability and quality criteria should be examined in supply chain planning area. Recently, scenario reduction methods and sample average approximation approaches have been developed in supply chain planning under uncertainty, and this aspect needs greater attention.

- Many stochastic optimization problems in the area of supply chain planning with multi-period setting can lead to a multi-stage stochastic program (MSSP). Developing MSSPs and presenting efficient solution approaches for them is a challenging issue and, recently, Golari et al. (2017), Fattahi et al. (2017a), Fattahi et al. (2017b), and Escudero et al. (2017) have dealt with this issue.

- Robust optimization approach has gained less attention in comparison with fuzzy and stochastic programs in supply chain planning. However, in many real-world applications, historical data may be scarce and may not describe the parameters' distributions accurately. Hence, robust optimization is a suitable tool for handling such a situation. Recently, many developments have been done in the area of robust optimization by extending distributionally robust optimization and multi-stage robust optimization approaches. Developing robust optimization approaches for supply chain planning in scarce-data environments will be another promising research direction.

- In accordance with Tang (2006), there exist two types of risks, operational and disruption risks, in supply chains. Therefore, risk management plays a significant role in reducing these existing risks, and a few papers have addressed this issue. Therefore, risk management in supply chain planning is a potential future research direction. Further, future research works can develop mitigation and contingency strategies for supply chains under disruption events to improve the resiliency of supply chains.

- Generally sourcing with supply disruptions identifies a big problem, one that gets more difficult when multi period situations are considered. In addition, extending the model with

the other supply chain concerns can be developed. That focus area may include channel coordination contracts or profit allocation mechanisms among loss-averse firms and their suppliers.

- Finally, although there are many research studies for supply chain planning under uncertainty, this research area still needs more studies that present realism models based on real-world applications and that handle computational aspects to solve large-sized problems.

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