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New flexibility drivers for manufacturing, supply chain and service operations

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Increasing product proliferation, customisation, competition and customer expectations, as well as supply side disruptions, pose significant challenges to firm operations. Such challenges require improved efficiency and resilience in manufacturing, service and supply chain systems. New and innovative flexibility concepts and models offer a prospective route to such operational improvements. Several emerging issues in flexibility, such as risk and uncertainty management, environmental sustainability, optimal strategies under competition, optimal operations with strategic consumer behaviours are being examined in this regard. This overview provides a concise review of these critical research issues, and discusses related papers featured in this special issue. Four *major flexibility drivers* are classified: disruption risks, resilience and the ripple effect in the supply chain; digitalisation, smart operations and e-supply chains; sustainability and closed-loop supply chains; and supplier integration and behavioural flexibility.

Keywords: flexibility; flexible manufacturing; supply chain management; supply chain risk management; supply chain coordination; Industry 4.0; manufacturing systems; service supply chain; ripple effect

1. *Flexibility in manufacturing, service and supply chain systems*

With increasing product proliferation, reduced unit demand volumes and next-day delivery expectations, flexibility in operations, service and supply chains has become an important focal area for research and industry. This special issue of IJPR aims to present state-of-the-art research in the field of flexibility in manufacturing, supply chain and service operations.

A brief background on flexibility is provided in this section. *Flexibility* refers to the ability of a system to change (adapt) in dynamic environments. Operational system flexibility has been studied extensively in the manufacturing, service and supply chain literature from various strategic, tactical and operative perspectives (Slack 1987; Bordoloi, Cooper, and Matsuo 1999; Koste and Malhotra 1999; D'Souza and Williams 2000; Das 2001; Van Mieghem 2003; Zhang, Vonderembse, and Lim 2003; Wu, Erkoc, and Karabuk 2005; Alp and Tan 2008; Chang 2012; Jain et al. 2013; Choi, Cheng, and Zhao 2016; Cobb 2016; Ivanov, Tsipoulanidis and Schönberger 2017).

A substantive part of this research studies capacity flexibility, classifying investigations into two main areas, i.e. decisions on investment in dedicated versus flexible capacity (Li and Tirupati 1994; Bish, Muriel, and Biller 2005), and process flexibility (or capacity adaptability). Process flexibility (Jordan and Graves 1995; Chou et al. 2010) analyses the ability of a company to change manufacturing setups at flexible lines according to demand or supply changes. It relies, in part on the capability to produce multiple products on multiple production facilities or lines (Jordan and Graves 1995; Simchi-Levi and Wei 2015). In particular, the design of a flexible production network under stochastic demand has been studied by Jordan and Graves (1995), Chou et al. (2010), Simchi-Levi and Wei (2012); while the design of a flexible production network under worst-case (robust) demand has been studied by Simchi-Levi and Wei (2015). The findings bring the discussion further towards sparse flexibility designs that perform well under expected sales and have lower risk measures. *Operational flexibility* of the company or capacity adaptability, i.e. the ability to dynamically change capacity allocations among different product families over time, has been examined in various studies (Angelus and Porteus 2002; Kouvelis and Milner 2002; Tan and Gershwin 2004).

Flexibility can be used to hedge against variability in customer orders. For that purpose, production levels must be adjusted each period, to match current demands, to give priority to the higher margin product, or to satisfy the closest customer. Simchi-Levi and Wei (2015) develop a method for worst-case analysis of process flexibility designs. Bożek

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and Werner (2017) developed an optimisation method for flexible job shop scheduling with lot streaming and sublot size optimisation.

The *measurement* of manufacturing flexibility and adaptability has given rise to different frameworks, and various dimensionalisations such as production, capacity, volum, and logistics flexibility (Shepherd and Günter 2006). Additionally, Ramasesh and Jayakumar (1991) suggest measuring manufacturing flexibility in terms of value for customers. Zhang, Vonderembse, and Lim (2003) analyse manufacturing flexibility through defining and analysing relationships among competence, capability and customer satisfaction. Related works can also be found in assembly line balancing (Battaïa and Dolgui 2013; Borisovsky, Delorme, and Dolgui 2014) and the supply chain flexibility literature (see further in this article).

Supply chain flexibility includes system, process and product flexibility (Tang and Tomlin 2008; Simchi-Levi and Wei 2012, 2015; Dolgui, Ivanov, and Sokolov 2018; Ivanov 2018). System flexibility is composed of strategy and structural components. Companies implement product and process flexibility extensively (see e.g. Volkswagen's new production system strategy). Coordination and sourcing strategies in supply chains are also typical in practice. Many companies also invest in structural redundancy – for e.g. Toyota extends its supply chain subject to multiple-sourcing and building new facilities on the supply side. All these elements of flexibility can be seen as strategies for dampening the ripple effects of disruption at the mitigation stage, as well as for reactive actions at the post-disruption stage. Coordination and postponement are two other aspects of supply chain flexibility. Integrating and coordinating customer actions with supply chain considerations has resulted in the development of effective build-to-order supply chains. Knoppen and Christiaanse (2007) show that flexibility in the supply chain (unlike in manufacturing systems) is primarily interrelated with adaptation through managerial actions. Therefore, in supply chains, coordination plays an important role in flexibility and distinguishes this issue from classic automatic control theory. Simchi-Levi and Wei (2015) develop a method for worst-case analysis of process flexibility designs. *Finally,* a set of postponed decisions (product postponement or rolling/adaptive planning) can be used (Olhager 2003) to increase supply chain flexibility.

Tachizawa and Thomsen (2007) empirically investigated the aspects of flexibility related to the upstream supply chain. Coronado and Lyons (2007) investigated the implications of operations flexibility in industrial supply chains and the effect it has on supporting initiatives designed for build-to-order manufacturing. Wadhwa, Saxena, and Chan (2008) presented a study on the role of different flexibility options (i.e. no flexibility, partial flexibility and full flexibility) in a dynamic supply chain model based on key parameters and performance measures. The findings of these studies pose different dimensions of supply chain flexibility and bring the discussion further towards understanding of flexibility role in supply chain dynamics. Swafford, Ghosh, and Murthy (2008) showed that information technology integration enables an organisation to tap into its supply chain flexibility, which in turn results in faster supply chain response and ultimately higher competitive business performance.

Optimisation provides yet another perspective on studying supply chain flexibility. Kauder and Meyr (2009) provided a mathematical optimisation framework for a mutual analysis of flexibility and efficiency of supply chain design for an automotive manufacturer. Tanrisever, Morrice, and Morton (2012) proposed a stochastic programming model for a multi-stage supply chain regarding capacity flexibility in made-to-order production environments.

Supply chain flexibility links to other flexibility dimensions including production, capacity, volume and logistics flexibility (Beamon 1999; Shepherd and Günter 2006), as well as quantity, supply, product, transport and innovation flexibility (Beamon 1999; Naim et al. 2006; Shepherd and Günter 2006).

One of the major new research initiatives in supply chain flexibility is the study of its role in disruption risk management frameworks (Dolgui, Ivanov, and Sokolov 2018; Ivanov 2018). In this setting, flexibility engages indirect usage of redundancies in terms of changing the system behaviour by re-allocating inventories, capacities and sourcing facilities in the supply chains. The disruption impact on supply chain performance depends on both proactive resilience measures and recovery contingency plans (Tang and Tomlin 2008). Ozbayrak, Papadopoulou, and Samaras (2006) and Tang and Tomlin (2008) consider flexibility as a capabiltiy that enables timely and responsive reaction to changes in the supply chain environment.

Kleindorfer and Saad (2005) consider sourcing flexibility, inventory and capacity excessiveness as major resilience drivers in the supply chain. Supply chain flexibility and resilience are interrelated. Ivanov, Sokolov, and Dolgui (2014) and Dolgui, Ivanov, and Sokolov (2018) developed a ripple effect control framework that provides evidence on the role of flexibility in supply chain disruption management.

Robustness is a characteristic of supply chain flexibility. Stevenson and Spring (2007) distinguish robust network flexibility as the range of events that the existing supply chain structure is able to cope, and the adaptability of supply chains. Yadav et al. (2011) analysed the flexibility of supply chain in the context of robustness regarding flexible product families and diversification. Seifert and Langenberg (2011) also consider supply chain flexibility and adaptability with product decisions.

From a dynamics perspective, robustness elements can also be considered as flexibility elements and vice versa (Ivanov et al. 2017). Both robustness and flexibility serve as an 'uncertainty cushion' in a supply chain. Balancing the elements of flexibility and robustness in proactive and reactive control loops allows analysis of different configurations of service level, costs and stability in risk and supply chain management strategy.

2. New flexibility drivers and introduction to this special issue

The focus of this Special Issue is on *new* antecedents of flexibility – human, machine, process and information technology based – and their singular and combined impacts on flexibility outcomes. The methodology encompasses a multidisciplinary operational perspective that includes different modelling and quantitative methods as well as empirical studies.

This special issue of IJPR looks at various flexibility drivers that derive from new advances in fields such as information technology, business analytics and additive manufacturing. The special issue also generates new ideas in lean management, novel quantitative techniques, resilience and risk management, in the general context of flexibility capabilities.

Submitted papers covered a variety of topics that include but are not limited to:

- operations flexibility with the help of new information technology
- reconfigurable supply chains and manufacturing systems
- business analytics and operations flexibility
- additive manufacturing and operations flexibility
- lean management and operations flexibility
- strategic sourcing and operations flexibility
- flexibility, resilience and risk management
- service operations flexibility
- supply chain flexibility

The papers in this special issue are classified into four major flexibility drivers:

- Disruption risks, resilience, redundancy and the ripple effect in the supply chain;
- Digitalization, smart operations and e-supply chains;
- Sustainability and responsiveness; and
- Supplier integration and behavioural flexibility

An expanded discussion of these papers follows.

2.1 *Risks, disruptions, resilience and the ripple effect in the supply chain*

Jiho Yoon, Ram Narasimhan and Myung Kyo Kim's 'Retailer's Sourcing Strategy under Consumer Stockpiling in Anticipation of Supply Disruptions' analyses a retailer's sourcing strategy under consumers' stockpiling behaviour, and the factors associated with the selection of an optimal strategy in multi-tier supply chains in the presence of supply disruption risk. Assuming that consumers attempt to mitigate the negative impact of a supply shortage, the authors argue that stockpiling behaviour become stronger if consumers have experienced similar problems earlier, and weaker, as inventories are hoarded. More specifically, single sourcing versus dual sourcing settings are analysed from the retailer's perspective. The results indicate that the superiority of single vs. dual sourcing is highly dependent on supplier's volume flexibility, retailer's purchasing price and supplier reliability.

Ju Myung Song, *Weiwei Chen and Lei Lei's* study 'Supply Chain Flexibility and Operations Optimisation Under Demand Uncertainty: A Case in Disaster Relief', focuses on SC flexibility in a disaster relief scenario. Their approach aims to minimise the total tardiness and peak tardiness of product delivery over a multiple-period planning horizon. Customer demands uncertainty is especially high in disasters. Considering this challenge, the authors decompose the demand into two components: a relatively stable base demand predicted by historical data, and unpredictable demand surges. For the base demand, they develop an optimisation model for production and distribution operations, as well as inventory replenishment policy for manufacturers and distribution centres. The model minimises total tardiness. SC flexibility deployment is proposed to cope with unpredictable demand surges.

G. Behzadi, M.J. O'Sullivan, T.L. Olsen and A. Zhang in their study 'Allocation Flexibility for Agribusiness Supply Chains under Market Demand Disruption', analyse supply chain allocation flexibility in light of disruption risk management strategies. They develop a multi-commodity multi-period optimisation model to analyse market demand disruption

risk in agribusiness supply chains. The objectives combine expected profit and risk in a risk-averse setting solved by a robust optimisation formulation. A real-life case study of Zespri's kiwifruit supply chain is used to illustrate the developed method. More specifically, three risk management strategies, namely diversified demand market, backup demand market and flexible rerouting are considered. The results indicate that while diversified demand market- and backup demand market-strategies are equally important for all decision makers, flexible rerouting is especially significant for less risk-averse decision makers.

Dmitry Ivanov's research 'Revealing interfaces of supply chain resilience and sustainability: a simulation study' utilises a discrete-event simulation model develop in anyLogistix to study the interfaces of the ripple effect and sustainability in the supply chain. A multi-stage supply chain with suppliers, factory, distributions centres and customers is considered. The results indicate that (i) sustainable single sourcing enhances the ripple effect; (ii) facility fortification at major employers regionally mitigates the ripple effect and enhances sustainability and (iii) a reduction in storage facilities in the supply chain downstream of a high disruption-risk facility increases sustainability, but creates a ripple effect. His study also finds a time lag between recovery launch and recovery impact on service level gap reduction suggesting the need for proactive supply chain policies in regard to disruption durations. The results further suggest that human aspects need to be considered concerning coordination complexity analysis and recovery impact on disruption duration.

Jiho Yoon, Srinivas Talluri, Hakan Yildiz and William Ho in their paper 'Models for Supplier Selection and Risk Mitigation: A Holistic Approach' focus on supplier selection in the context of upstream disruption risks. Awide range of quantitative and qualitative risk factors are considered for potential use in supplier selection. Moreover, the authors evaluate the efficiency of alternative risk mitigation strategies in this context. The authors find that both upstream and downstream strategies should be utilised simultaneously for improved outcomes, rather than relying on a single type of strategy. The alignment of upstream and downstream risk-mitigation strategies is therefore suggested as a significant consideration in reducing supply chain disruption risks. A multi-objective optimisation-based simulation is used in developing a decision-support model, which is examined with data from an automotive parts manufacturer.

2.2 *Digitalisation, smart operations and e-supply chains*

Christoph Müller, Martin Grunewald and Thomas Stefan Spengler's study 'Redundant configuration of robotic assembly lines with stochastic failures', investigates the operation of robotic assembly lines is the presence of process failures. The authors point out that the inter-connectivity of stations (via material handling systems) cause failures at any one station to often result in system throughput losses. Proactive installation of buffers requires considerable investments and consumes scarce factory space. Citing advances in manufacturing technologies ('Industry 4.0'), the authors call for new solutions to reduce failure-related throughput losses. More specifically, they focus on one possible solution, namely a redundant configuration, in which downstream (backup) stations automatically take over the operations of failed stations during repair time. The throughput loss in these situations depends on the flexible allocation of operations and the assignment of backup stations. The genetic algorithm developed for the redundant configuration of robotic assembly lines with stochastic failures, allows maximisation of the line production rate.

Konstantin Biel and Christoph H. Glock's paper 'Governing the dynamics of multi-stage production systems subject to learning and forgetting effects: A simulation study' investigates managing production systems where production rates change over time due to learning and forgetting effects. Such learning and forgetting effects interact across different stages in multi-stage production systems – however, rigid production management rules are unable to capture the dynamic character of constantly changing production rates. The study explores how typical key performance indicators, such as the number of setups, in-process inventory, or cycle time, are affected by learning and forgetting effects in serial multi-stage production systems. It analysis the parameters of such production systems, evaluating how Goldratt's OPT (Optimised Production Technology) flexible production control approaches can maximise the benefits learning offers, in such systems. The results indicate that learning and forgetting have relatively minor influence on the number of setups in serial multistage production systems. The influence of learning and forgetting on in-process inventory and cycle time, in contrast, is significant, albeit ambiguous in the case of in-process inventory. The proposed buffer management rules are shown to effectively counteract this ambiguity.

Liang Qu, Michael B. C. Khoo, Philippe Castagliola and Zhen's study 'Exponential cumulative sums chart for detecting shifts in time-between-events' by investigates deterioration and improvements in the process flexibility. They apply the time-between-events (TBE) charts to monitor process shifts (or failure rates). More specifically, two-sided TBE cumulative sums (CUSUM) weighted charts are used, leading to the development of a new type WCUSUM chart. Construction of the WCUSUM chart is illustrated by considering random process shifts (including both increasing and decreasing shifts) in the flexible process design.

Shailesh S. Kulkarni and David Francas's research 'Capacity Investment and the Value of Operational Flexibility in Manufacturing Systems with Product Blending' aids manufacturers that seek to increase flexibility via blending of intermediates. Using stochastic programmes under demand uncertainty, the authors provide analytical insights into trade-offs when range and mobility are interdependent. The results allow analysing the complementarity and substitution effects between dedicated and shared resources in the presence of blending. In particular, their analysis suggests that there is a degradation in the cost performance of such systems with an increase in correlation. A moderate level of blending can significantly improve flexibility.

Javad Navaei and Hoda ElMaraghy examine 'Optimal Operations Sequence Retrieval from Master Operations Sequence for Part/Product Families'. The authors elaborate on commonalities between members of a product family that can increase the speed, consistency and efficiency of constructing a master operations sequence as well as optimal operations sequences for new product variants. Using two novel mixed integer programming models, the authors show how their model can help reduce the time, cost and effort required for developing new operations sequences, hence, improving planning efficiency and productivity. While the first model is developed for variants with serial operations sequence, the second model is a generalised model for serial, networked operations sequences, or a combination of both structures. The authors also propose a novel algorithm to tackle the computational complexity of generating master operations sequences for product variants, agnostic to process sequence structure (i.e. serial, networked, or combination).

Bo Feng, Wei Liu, and Zhaofang Mao's study 'Use of Opaque Sales Channels in Addition to Traditional Channels by Service Providers' is motivated by the recent opaque selling trend promoted by Priceline and Hotwire. They design a game in which two collaborative service providers may use an opaque selling channel to satisfy demand from both leisure and business customers. The results are driven by the strategic interaction between two service providers and by the heterogeneity of customers. For example, a dual channel offers advantages over the single traditional channel, as opaque selling allows service providers to utilise customers' heterogeneity, and thus facilitates price discrimination and customer segmentation.

2.3 *Sustainability and responsiveness*

Tsan-Ming Choi and Shu Guo in their paper 'Responsive supply in fashion mass customisation systems with consumer returns' show how quick response systems improve mass customisation programmes. The setting is the fashion industry. The authors consider the presence of consumer returns. They uncover how the rate of consumer returns rate relates to the optimal inventory decision, as well as the values of information under quick response for the supply chain and its members. The authors show that consumer returns can improve the value of quick response to the manufacturer. They also show that a more responsive supply can reduce environmental costs.

Hau-Ling Chan, Bin Shen and Yajun Cai study 'Quick Response Strategy with Cleaner Technology in a Supply Chain: Coordination and Win-Win Situation Analysis', examines optimal choices of clean technology investment together with a quick response strategy. They identify the impact of a quick response strategy (QRS) with clean technology on production, across supply chain members, deriving ga coordinated and win–win situation under QRS with cleaner technology. The study finds that inventory fill rate affects profits of both manufacturer and retailer, under QRS with cleaner technology. The authors also survey industrial practice, examining two contracts, namely the minimum ordering quantity (MOQ), and MOQ with buyback (MOQ-BB). They show that the MOQ-BB contract is more versatile than the MOQ contract in achieving supply chain coordination.

Yanhui Li, Hao Guo and Ying Zhang consider 'An integrated location-inventory problem in a closed-loop supply chain with third-party logistics' in their paper. They investigate a closed-loop supply chain (CLSC) system in the presence of a third-party logistics (3PL) company. The study determines s optimal location-inventory decisions with the 3PL company, using a mixed-integer non-linear programming model. The authors develop a heuristics method by employing the concept of differential evolution. They report numerical computational results to demonstrate gains from their proposed method.

Nasim Zandi Atashbar, Nacima Labadie & Christian Prins present an overview of 'Modelling and optimisation of biomass supply chains: a review' – a survey of bioenergy supply chain modelss, focusing on greenhouse gas emissions and increasing energy demand. A variety of models and methods to optimise biomass supply chains are surveyed in this article.

Hardeep Chahal, Mahesh Gupta & Subhash Lonial's research paper 'Operational flexibility in hospitals: Scale development and validation' discusses an operational flexibility construct with theoretical underpinnings, in a hospital industry setting. The effects of management capability and competitive intensity on operational flexibility and performance relationships are explored.

Lei Xu, Yongjian Li, Kannan Govindan & Xiaohang Yue's study 'Return policy and supply chain coordination with network-externality effect' researches the potentially damaging impact of a return policy on retailers. They develop an analytical framework to examine the economic impact of consumer returns on consumers, retailers and supply chains. Conditions of no network-externality, fixed network-externality and variable network-externality contingent on return amount, are analysed with reference to the retailer selling price, refund and inventory policies. The results show that optimal policies take the form of contingent models in which policies depend on consumer initial return and network-externality return. The influence of the consumer return network-externality effect on buy-back contracts of the supply chain is also investigated. The results show that while the traditional buy-back contract fails to coordinate the supply chain, the network-externality effect does not render the differentiated buy-back contract less effective.

2.4 *Supplier integration and behavioural flexibility*

Gholamreza Bodaghi, Fariborz Jolai, Masoud Rabbani in their study 'An integrated weighted fuzzy multi-objective model for supplier selection and order scheduling in a supply chain' investigate an integrated supplier selection, order quantity allocation and customer order scheduling problem. Given a make-to-order manufacturing system, they analyse supply chain responsiveness whereby total cost and quality of purchased parts as well as the reliability of on-time delivery of customer orders are included into the objective function. The study develops a mathematical measure for evaluating the volume flexibility of suppliers. The study provides guidance on supplier selection for purchase of parts needed to assemble the customer orders, allocation of demand for parts among selected suppliers, and scheduling of customer orders for assembled products over the planning time horizon.

Meng Li and Tao Li's study 'Consumer Search, Transshipment, and Bargaining Power in a Supply Chain' by examines a decentralised supply chain system consisting of a single manufacturer and two retailers. Retailers are symmetric and may share excessive inventory by transshipment among themselves, subject to a transshipment price. The authors show some interesting results such as the retailer's profit function being unimodal in the transshipment price. They find the manufacturer's profit function increasing in the search probability of consumers. They also find that the retailer tends to prefer the adoption of transshipment in all cases, and that the manufacturer prefers to control the transshipment price.

Aghil Rezaei Somarin, Sobhan Asian, Fariborz Jolai and Songlin Chen's 'Flexibility in Service Parts Supply Chain: A Study on Emergency Resupply in Aviation MRO' focuses on complexity and decentralisation in service parts logistics systems in the commercial aviation industry.Since MRO service providers engage in service parts sourcing and demand fulfilment for customers with different service level requirements, cooperative agreements with other service providers are formed to pool inventories. Such agreements enable providers greater flexibility in delivering services to multiple airlines, under different contractual terms. Highlighting a trade-off between flexibility and complexity, the authors develop an optimal emergency resupply policy for a repairable service parts inventory system with multi-customer classes and. The results are useful in assessing the effectiveness of emergency resupply policy.

Finally, Shaofu Du, Lin Wei, Yangguang Zhu and Tengfei Nie's study 'Peer-regarding Fairness in Supply Chain' *by* explores a distribution channel flexibility with two retailers and a single supplier. The supplier serves the two retailers who operate at different locations, serving separate markets. The concept of peer-regarding fairness concern (PRFC) is examined in terms of retailer values. The authors find that retailer profits and supply chain performance can be enhanced by 'PRFC for sympathy' whereas they can be reduced by the PRFC for 'schadenfreude' (i.e. the enjoyment obtained from the troubles of others). On the contrary, the PRFC for sympathy has an adverse effect on the supplier, while the PRFC for schadenfreude is beneficial to the supplier. These findings highlight the inherent differences between the effects brought by PRFC on the retailers and the supplier.

Table 1 provides a summary of the papers featured in this special issue.

Table 1 suggests that supply chain and manufacturing system domains dominate the literature. The state of knowledge in service flexibility appears less well developed. Further, many studies integrate multiple flexibility drivers such as resilience and sustainability, robotics and disruption risks, or supplier integration and disruption risks. The studies highlight the complexity of the flexibility concept and its antecedents, and provide new insights on possible remedies and solutions in complex settings.

In conclusion, the guest editors hope that this SI will stimulate fresh research thought and insights on the important capability of flexibility and related areas.

Acknowledgement

The guest editors congratulate the authors for significant and impactful investigations that have advanced the body of knowledge in flexibility research. They also thank the authors of all submissions for considering this special issue of IJPR as their research outlet of

Table 1. Features and core findings of the papers in this special issue.

Scope of the special issue	Authors (surnames)	New flexibility drivers addressed	Core insights and findings
Supply chain	*Yoon, Talluri, Yildiz, Ho*	Disruption risks Supplier integration	Both upstream and downstream strategies should be utilised simultaneously rather than relying on a single type of strategy; the alignment of upstream and downstream risk-mitigation strategies is crucial importance to reduce supply chain disruption risks
Supply chain Service	*Song, Chen, Lei*	Disruption risks Disaster relief	Increasing supply chain flexibility is effective in disaster relief with unpredictable demand surges; for the demand surges, supply chain flexibility deployment is proposed to cope with the uncertainty
Supply chain	*Behzadi, O'Sullivan, Olsen, Zhang*	Disruption risks	Diversified demand and backup demand strategies are equally important for all decision makers, flexible rerouting is especially significant for less risk-averse decision makers
Supply chain	*Yoon, Narasimhan, Kim*	Disruption risks Behavioural flexibility	The superiority of single vs. dual sourcing depends on supplier's volume flexibility, retailer's purchasing price, and supplier reliability; consumer stockpiling behaviours become stronger if consumers have experienced similar problems before and weaker as more inventories are hoarded
Supply chain	*Ivanov*	Resilience Sustainability	Sustainable single sourcing enhances the ripple effect; facility fortification at major employers mitigates the ripple effect and enhances sustainability; a reduction in storage facilities downstream of a disruption-risky facility increases sustainability, but causes the ripple effect; time lag between the recovery launch and recovery impact on service level gap reduction needs to be considered
Supply chain	*Zandi Atashbar, Labadie, Prins*	Sustainability	A survey on the domain of bioenergies, especially focusing on greenhouse gas emissions and increasing energy demand. As logistics is responsible of an important fraction of the biomass cost, models and methods to optimise biomass supply chains are surveyed in this article
Manufacturing	*Müller, Grunewald, Spengler*	Robotics Redundancy	Industry 4.0 enables a redundant line configuration, in which downstream (backup) stations automatically take over the operations of failed stations during repair time; the throughput loss in these situations depends on the flexible allocation of operations and the assignment of backup stations
Manufacturing	*Biel and Glock*	Smart operations	Learning and forgetting effects have a minor influence on the number of setups in serial multistage production systems. The influence of learning and forgetting on in-process inventory and cycle time, in contrast, is significant, but ambiguous in case of in-process inventory
Manufacturing	*Qu, Khoo, Castagliola, He*	Smart operations Disruption risks	A new kind of two-sided time-between-events weighted cumulative sums chart is proposed that allows considering random process shifts (including both increasing and decreasing shifts) in the flexible process design
Manufacturing	*Kulkarni and Francas*	Smart operations	A method to analyse the complementarity and substitution effects between dedicated and shared resources in the presence of blending. It particular, an analytical evidence is provided that there is a degradation in the cost performance of such systems with an increase in correlation. A moderate level of blending can significantly improve flexibility and that well-known guidelines for designing limited flexibility change in the presence of blending
Manufacturing	*Navaei, ElMaraghy*	Smart operations	A novel model and algorithm to generate master operations sequences for product variants with different types of process sequence structure (i.e. serial, networked, or combination)
Service Supply Chain	*Feng, Liu, Mao*	Multi-channel commerce	New game is designed in which two collaborative service providers may use an opaque selling channel to satisfy demand from both leisure and business customers. A dual channel offers advantages over the single traditional channel, as opaque selling allows service providers to utilise customers' heterogeneity, and thus facilitates price discrimination and customer segmentation
Manufacturing Service	*Choi, Guo*	Sustainability Responsiveness	Consumer returns can improve the value of quick response to the manufacturer. A more responsive supply can reduce environmental costs
Manufacturing Service	*Chan, Shen, Cai*	Sustainability Responsiveness	The authors find that the inventory fill rate affects profits of both the manufacturer and retailer under QRS with cleaner technology. They show that the MOQ-BB contract is more versatile than the MOQ contract in achieving supply chain coordination

(*Continued*)

Table 1. (*Continued*)

Scope of the special issue	Authors (surnames)	New flexibility drivers addressed	Core insights and findings
Service Supply chain	*Li, Guo, Zhang*	Sustainability Responsiveness	The authors develop an efficient heuristics method to solve the integrated location-inventory problem in a closed-loop supply chain with third-party logistics
Service	*Chahal, Gupta, Lonial*	Responsiveness	Development of the operational flexibility construct that can serve as a general theory in operations management in the context of the hospital industry; data collected from a sample of 152 administrators of hospitals in the mid-west region of the USA
Service Supply chain	*Xu, Li, Govindan, Yue*	Responsiveness	The optimal policies take the form of contingence model in which the policies depend on consumer initial return and network-externality return. While the traditional buy-back contract fails to coordinate the supply chain, the network-externality effect does not render the differentiated buy-back contract less effective
Supply chain Manufacturing	*Bodaghi, Jolai, Rabbani*	Supplier integration	Decision-support model to decide on from which supplier to purchase parts needed to assemble the customer orders, how to allocate the demand for parts between the selected suppliers, and how to schedule the customer orders for assembled products over the planning time horizon
Supply chain	*Li and Li*	Behavioural flexibility	The retailer's profit function is unimodal in the transshipment price. The manufacturer's profit function is increasing in the search probability of consumers. The retailer tends to prefer the adoption of transshipment for all cases and the manufacturer prefers to control the transshipment price
Service	*Somarin, Asian, Jolai, Chen*	Emergency flexibility Supplier integration	Considering the emergency resupply in the light of a trade-off between flexibility and complexity, the authors study a repairable service parts inventory system with multi-customer classes and develop an optimal emergency r esupply policy. The results can be used to analyse the effectiveness of emergency resupply policy that improves MRO service providers' flexibility and enables them to ensure responsive service parts inventory
Supply chain	*Du, Wei, Zhu, Nie*	Behavioural flexibility	The profits of retailers and the supply chain's performance can be enhanced by PRFC for sympathy whereas they can be reduced by the PRFC for schadenfreude. Oppositely, the PRFC for sympathy is negative to the supplier, but the PRFC for schadenfreude is beneficial to the supplier. The effects brought by PRFC on the retailers and the supplier are totally different

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