Supply Chain Systems—Recent Trend in Research and Applications

SUPPLY chains consist of a number of autonomous companies that make decision independently [1], [2]. Each of these individual companies is already a complex system. The formulation of a collection of these systems is sometime known as enterprises system [3]. The operational performance of a supply chain, however, relies heavily on the integrated activities among the companies [4]. Hence, a supply chain system can be viewed as a system of systems. Traditional methods in solving supply chain problems, in particular inventory management problems, are centralized in nature, which means information sharing among different entities is a pre-requisite [5]. In reality, however, achieving information sharing is not that easy and is not costless across a supply chain. Therefore, there is a need to employ system approaches for modeling and analyzing the performance of decentralized or distributed supply chain systems.

In line with the scope of the IEEE SYSTEMS JOURNAL, which is "to provide a systems-level focused forum for application-oriented manuscripts that address complex systems and system-of-systems of national and global significance" [6], this special section dedicates to examine applications of various system approaches from theoretical to implementation issues of supply chain systems. This special section is a collection of original research that addresses various aspects of supply chain systems design, implementation, and applications.

In view of the, relatively, distinctive scope of this special section, the call for papers had attracted significant high quality submissions. The review process follows the prestigious tradition of IEEE Transactions, which is in fact very rigorous, in order to make sure that selected papers are with high quality. Majority of the papers have been gone through three rounds of review and each paper has been reviewed by at least three reviewers, not including the guest editor. Finally, after a stringent selection process, five outstanding research studies are selected for publication. In fact, they also represent five important areas in the application of system approach to supply chain systems to be discussed as follows.

- Multi-agent Systems.
- Internet, Information and Emerging Technology.
- Complex Adaptive Systems.
- Distributed Planning and Control.
- Optimization (cost analysis of supply chain systems).

Multi-agent Systems: One of the primary reasons behind the surge of research in the field of distributed manufacturing supply chains in recent years is owing to the fact that efficient ways of handling and managing the supply chain network of geographically dispersed production units is a challenging task and manufacturers often strive hard to meet these challenges, since it requires an effective communication between the different components of the system [2], [7], [8].

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Among many techniques, agent-based technology is one of the commonly employed techniques to model supply chains that can facilitate such communication (e.g., [7]–[10]). This is because the underlying principle behind any multi-agent systems is coordination, and hence to solve problems in a cooperative manner [2], [5]. This is analogous to almost any supply chains in reality. Kimbrough *et al.* [11] employed agent-based simulation to prove that it could reproduce the "bullwhip effect," a famous supply chain phenomenon from system dynamics point of view [12]. To probe further, readers are referred to Lee and Kim's review [13] for a general review of applications of multi-agent systems in various supply chain applications.

With the understanding that material flow management plays an important role in reducing cost, meeting due dates and in better execution of the manufacturing process, Kumar and Mishra [14] propose a self correcting multi-agent architecture framework, where autonomous agents communicate among themselves and work collaboratively to handle various supply chain issues. The proposed architecture is capable of generating an effective manufacturing plan and minimizing manufacturing and supply chain costs, while exploring the algorithm portfolio concept. Thus, this framework can act as a tool for practitioners to handle the complex decision-making processes and lead to a cost effective production in the distributed manufacturing supply chain environment. This research is definitely aligned with the aims of this special issue and contributes to designing intelligent, cost-effective and well coordinated supply chain systems.

Internet, Information and Emerging Technology: Arguably, the Internet is the most important development regarding process technology, which can enable business-to-business supply chain applications, in the last decade [15]–[17]. Combined with the advance in information systems or emerging technology, it not only facilitates the flow of information, but enables many cross-platform and inter-organizational applications. The effect is even prominent with the trend of globalization [18]. Radio Frequency Identification (RFID) is a typical example [19], together with some other wireless communication technology [20]. For example, Tu *et al.* [21] combined the agent-based concept discussed above with RFID technology to provide a mass customization framework for manufacturing supply chains.

In the last few years, development of service-oriented supply chains introduce another stream of research which is cloud computing, which has been introduced with the opportunity to allow businesses and users to access information and applications in a real-time manner regardless of where they are, and possibly without the restriction of owning the underlying resource by the users [22].

In this issue, Leukel *et al.* [23] examines supply chain coordination by referring to and adopting key concepts of cloud computing. The rationale behind that is to represent supply chain systems electronically as service offerings and service requests, which need to be matched. This matching is not limited to 1-to-1 matches, but determining complex compositions of supply chain services. This paper proposes a service-oriented modeling approach for supply chain services, linkages, and compositions, as well as reports experiences made in implementing this approach in a use case of airport operations. By grounding supply chain systems on loosely coupled services and middleware standards of service-oriented computing, the decentralized nature of supply chain systems and limitations of information sharing are respected. One major contribution is the demonstration that cloud computing can serve as both an analytical perspective and technology stack for solving coordination problems in supply chain systems.

Complex Adaptive Systems: In reality a supply "chain" is never as simple as a linear operation along a "chain" of members [24]. In contrast, it is always a network of members and hence the coordination among the members is of vital importance. Obviously, operations of such systems could not be easy and hence Choi *et al.* [25] advocate that modeling supply chains should be based on the concept of complex adaptive systems, which will increase the strategic "fit" between the members. Consequently, relationship and performance of the supply chain could be improved. This can be achieved partly by introducing flexibility to the operations, which is almost always coupled with uncertainties that are not uncommon in reality [26]. In fact, this philosophy has its roots in the *industrial dynamics* school of thought, which is originated from Forrester's work [27].

As discussed above, one of the driving forces to model a supply chain as a complex adaptive system is because of the presence of uncertainty, which can take many forms in real-life applications [28]. Supply networks often face various types of disruptions, such as accidents, natural disasters, and terrorist attacks. These disruptions may disable entities and affect the normal operations of the system. Traditional optimization-based approaches to improve resilience are generally centralized in nature, while the structure of a supply network often emerges from the distributed decisions of individual entities. Meanwhile, lacking knowledge of the network topology at a macroscopic level, individual organizations' optimization of their local networks may not necessarily lead to a globally resilient network.

In this issue, Zhao *et al.* [29] present a research that connects system-level resilience of supply networks with local connection strategies of individual entities. Inspired by network growth models in complex network research, they develop a localized heuristic strategy that provides guidance for individual entities to connect to others. They also design new metrics to evaluate the resilience to supply networks. Computer simulations of a military logistic network shows that supply networks constructed using our heuristic perform well against both random and targeted disruptions. In addition to the heuristic strategy, the research can also help supply network managers understand how network design strategies at the micro level affect the resilience of the whole supply network at the macro level.

Distributed Planning and Control: Partly because of globalization, the boundaries of supply chains have switched from within a local area to a large coverage like regional, and then to a global context nowadays [30]. Under this setting, traditional planning and control activities have also been migrated from centralized approaches to distributed approaches [31]. In other words, manufacturing environment has been shifted from traditional single factory production to the decentralized multifactory production network in the last decade.

Many studies have demonstrated that distributed manufacturing benefits manufacturing companies in reducing production cost, increasing production flexibility and responsiveness to changes, reducing management risk, and achieving better customer service quality, and so on [32]. This is achieved by better utilization of resources among the network including manpower, facilities, machines, raw materials, and so on. However, operating successfully in distributed manufacturing is also a very challenging task [32]. It involves the collaboration of all the production parties among the network and many cooperation among various planning and control activities in different parties.

Distributed planning and control usually involves two determinant factors. The first factor is to determine the most suitable and available factory for a job. The other factor is the schedule of job operations to machines in all the factories. Manufacturing operations of products and jobs must be carefully planned and scheduled since it is one of the most critical ones in the distributed manufacturing environment. Effective assigning and scheduling of jobs within the physical constraints of each party is regarded as the first foremost step towards successful manufacturing operations and is regarded as one of the important future research areas.

Distributed planning problems are commonly found in today's production environment because of supply chain integration. Different factories vertically partner up and work collaboratively to increase their overall competitiveness. However, since they belong to different companies, a collaboration strategy is required for collaboration. The objective of Chung *et al.*'s paper [33] is to study different collaboration strategies, and propose a new strategy for better collaboration for the companies partnering. This paper is highly related to the scope of this special section in the sense that the authors study how companies independently make their decisions under the same supply chain in order to minimize the tardiness of new orders from the end customers. The main contribution of this paper is to propose collaboration strategic for companies in supply chain partnered up to minimize the total tardiness of new orders from the end customers.

Optimization (cost analysis of supply chain systems): This is perhaps the most basic form of traditional supply chains research. Various study regarding inventory management [34], [35], inter-organization information systems [18], [36], order picking policy [37], facility location [38], and searching [39] among many others, have been published in the literature. Particularly, efficient and cost effective shipment of goods between geographically dispersed supply chain partners is a key to ensure strong competitiveness of the companies within the supply-chain. With the bulk of these goods shipped in containers onboard containerships across a multiports voyage, the quality of the stowage planning of containers onboard containerships directly affects shipping lines' operating cost, which in turns affects the competitiveness of the of the supply-chain companies whose goods are handled by these shipping lines.

In this issue, Low *et al.* [40] present an automated stowage planning system that significantly reduced the time taken and improved the quality of stowage plan generation (both in terms of cost, as well as safety and stability) by existing planners for large containerships. The stowage plan generation problem described in this paper is relevant to the special issue in two ways. Firstly, the stowage plan generation for large containerships on a multiport voyage is a complex problem of national and global significance which involves the supply and demand of goods by geographically dispersed companies. Secondly, the wide range of factors that needs to be considered to generate good stowage plan necessitate a problem solving approach that considers not only static physical constraints such as the types of bays in a containership and the types of containers to stow, but also dynamic constraints such as the safety and stability considerations (such as minimizing bending moment, establishing line of visibility) of the containership due to the placement and weight distributions of the containers.

The contribution of Low *et al.* paper [40] to the theme of this special issue is the real world application of the automated stowage generation system to generate efficient and effective stowage plans for large containerships with more than 7000 TEUs on a multiport voyage using only a fraction of the time required by human planners. This paper also serves to highlight how automation can be used to improve the stowage planning process for container shipments, a vital link that connects participating entities in the overall supply-chain system.

I am sure that you will find this special section insightful and useful. I also hope that this special section can deepen the readers' knowledge regarding the fundamental of designing supply chain systems effectively and efficiently, and can facilitate future research in this area. More importantly, the articles in this special section highlight recent achievement in these areas.

I would like to take this opportunity to thank Professor Mo Jamshidi, Editor-in-Chief of the IEEE SYSTEMS JOURNAL for accepting to publish this special section and also the assistance the editorial and publishing team, Dariush Shahgoshtasbi and Siu Ying Shaneyfelt, provided to me. This special issue would not have been published without their support. In addition, the guest editor is grateful to all reviewers for their valuable time and effort dedicated throughout the review process. Their timely feedback definitely have resulted in on time completion of the reviewing process, and have further improved the quality of the papers published in this special section. They are listed together with their affiliations in the table listed on this page.

Finally, the guest editor would like to thank all the authors for their contributions.

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