Smart supply chain management: a review and implications for future research

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Abstract
Purpose – As traditional supply chains are increasingly becoming intelligent with more objects embedded with sensors and better communication, intelligent decision making and automation capabilities, the new smart supply chain presents unprecedented opportunities for achieving cost reduction and enhancing efficiency improvement. The purpose of this paper is to study and explore the currents status and remaining issues of smart supply chain management.

Design/methodology/approach – A literature review is conducted to synthesize the earlier work in this area, and to conceptualize and discuss the smart supply chain characteristics. Further, the authors formulate and investigate five key research topics including information management, IT infrastructure, process automation, advanced analytics, and supply chain integration.

Findings – Studies in those aforementioned subject fields are reviewed, categorized, and analyzed based on the review questions defined in the study. It is notable that while the topics of converging atoms with digits are increasingly attracting attention from researchers and practitioners alike, there are many more interesting research questions needing to be addressed.

Originality/value – The paper provides original and relevant guidance for supply chain management researchers and practitioners on developing smart supply chains.

Keywords RFID, Supply chain management

Paper type Literature review

1. Introduction
Supply chain management (SCM) speaks of "having the right item in the right quantity at the right time at the right place for the right price in the right condition to the right customer" (Mallik, 2010). However, due to the complexity, uncertainty, and other factors involved, most of the real supply chains are known for having many supply-demand mismatch problems such as overstocking, stockout, and delivery delays which have long been popular research topics in the business management literature (Wong *et al.*, 2012).

As always, cheaper, faster, and better has been the mantra for supply chain managers. Meanwhile, supply chains are becoming more complex, costly, uncertain, and vulnerable. To deal effectively with the increasing challenges, supply chains must become a lot smarter (Butner, 2010). Taking full advantage of improvements in such areas as semiconductor, computer science, and other engineering technologies, the new version of

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supply chain seeks to establish a large-scale intelligent infrastructure for merging data, information, physical objects, products, and business processes together (Schuster *et al.*, 2007). For example, the factories equipped with smart equipment and instruments can fulfill orders with global teams, intelligent analytics, and dynamic systems all across the farthest stages of the value chain (Hessman, 2013). For sure, companies that take advantage of these aforementioned capabilities stand to gain against competitors that do not. No wonder there are abundant examples of smart supply chain applications in existence, for example, smart transportation management system, and smart factory.

In the literature, a number of distinctive terms were used to describe the new communicated global business systems to fulfill customer orders, such as e-supply chain (Akyuz and Rehan, 2009), ambient intelligence (Kloch *et al.*, 2010), Internet of Things (IoT) (Ma, 2011), industrial internet (Evans and Annunziata, 2012), physical internet (Montreuil, 2011), smart factory (Hessman, 2013), smart environment (Weiser *et al.*, 1999), and smarter supply chain (Butner, 2010). While e-commerce promotes transactions performed on the traditional internet, the concept of "e-supply chain" makes one further step to integrate processes across supply chain stages (Akyuz and Rehan, 2009). Further, IoT refers to the next generation internet where connecting physical things through a network has the capability of exchanging information about themselves and their surroundings (Gubbi *et al.*, 2013). These things may include artifacts, machines, products, and gizmos (unstable, modifiable things) (Sundmaeker *et al.*, 2010). It is evident in the literature that the current IoT research focusses on technologies (such as signal, network, communication, security) and applications (Sundmaeker *et al.*, 2010). GE's industrial internet converges global industrial systems with the power of advanced computing, analytics, low-cost sensing, and new levels of connectivity permitted by the internet (Evans and Annunziata, 2012). In addition, a smart environment is defined as "the physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network" (Weiser *et al.*, 1999). IBM particularly proposes three characteristics (e.g. instrumented, interconnected, and intelligent) for the next generation smarter supply chains (Butner, 2010).

It is evident that these aforementioned concepts such as e-supply chain, IoT, smart factory, and industrial internet, have been used to represent larger and more complicated business systems: from isolated RFID application to local IoT implementation, to smart factory, and then to part of the global supply chain network within the same company. Following this trend, we intend to define a "smart supply chain" as the new interconnected business system which extends from isolated, local, and single-company applications to supply chain wide systematic smart implementations. The smart supply chain would possess most of the features we discussed above, including technologies such as IoT, smart machines, and intelligent infrastructure, and capabilities such as interconnectivity, fully enabling data collection and real-time communication across all supply chain stages, intelligent decision making, and efficient and responsive processes to better serve customers.

As the physical world itself is becoming a type of information system where sensors and tiny devices are linked through wired and/or wireless networks, business models based on today's largely static-information architectures face many challenges as new ways of creating customer value arise (Bughin *et al.*, 2010). The deep integration of the digital world with the physical world holds the potential to bring a profound transformation to global supply chains. However, despite the consensus on the great potential of the smart concept and the significant progress in a number of enabling technologies, there is a general lack of an integrated vision on how to realize the system and the associated value (Lopez *et al.*, 2012).

We intend to conduct a systematic review in this paper to examine the relevant literature on smart supply chain management (SSCM): business management topics related to the design, management, and improvement of smart supply chains. Specifically, the paper aims at summarizing the key SSCM research findings in existence and discussing the remaining research issues. In particular, this paper has the following objectives:

(1) to complete a survey of the literature associated with SSCM;

(2) to conceptualize the key issues and develop a framework pertinent to SSCM;

(3) to identify several key emerging phenomenon in the smart supply chain applications and to associate the prior academic research with these developments; and

(4) to highlight the remaining research issues in this field.

The reminder of the paper is structured as follows. The next further introduces the methodological aspects of the literature review. This is followed by the content analysis of the literature in each of the five key research areas including information, IT, process automation, advanced analytics, and supply chain integration. Then, a discussion of current status and remaining research issues of SSCM is presented. The paper concludes by summarizing the key findings of the review and identifying the implications for practitioners and researchers.

2. Review methodology

A literature review is a systematic, transparent, and reproducible design for identifying, evaluating, and interpreting the existing literature (Fink, 2005). The critical analysis of the research papers identifies systematic patterns, synthesizes knowledge, reveals unnoticed trends, and gaps in the literature, all contributing to theory development (Meredith, 1993). We recognize that SSCM is a quickly evolving concept that is researched and discussed in many relevant disciplines, e.g., isolated smart hardware applications are often studied in engineering field, and advanced analytics is repeatedly investigated in data analysis and information system research. The research field has been quite fragmented and divergent. In order to guide our literature review, we begin with defining the following review questions:

RQ1. What is the current status of smart supply chain research and applications?

RQ2. What are the major issues and debates about the topics?

The answers to the above questions can provide building blocks for a conceptual framework along with a basis of theory development. While trying to place the study in a broader context, we admit SSCM has deep roots in many traditional fields such optimization and supply chain network. When conducting literature search, we find using generic search words such as inventory, network, logistics, and e-business resulted in an overwhelming number of articles which are less relevant to SSCM and relatively outdated. Instead, we use a retrospective approach to find the most recent articles on smart supply chain and work backwards to refine our search keywords, which include supply chain, smart, information system, IoT, advanced analytics, big data, automation, and supply chain integration. These keywords are frequently used in the recent smart supply chain literature.

Subsequently, these keywords are searched in major databases including ABI/Inform Research and Business Source Complete (EBSCO publishing). The focus is on searching title, keywords, or abstract in relevant refereed journals with regard to smart supply chains. The papers were either selected or rejected after performing a content check based on these delimiting conditions: papers published in peer-reviewed journals in English; papers addressing SSCM and relevant operational issues. Considering the relative infancy of the topic, it is not deemed appropriate to exclude unpublished studies, newspaper reports, among others. As such, we use the same keywords to search non-academic sources including the practitioner journals to collect the most recent smart applications in practice.

We take inputs from the literature to formulate the structural attributes and then categorize papers into relevant SSCM research topics. The following four-step process is followed to perform the content analysis where the first level analyzes the manifest content of documents by statistical methods and the second level excavates the latent content (Seuring and Gold, 2012):

(1) Material collection: the papers were collected and later subjected to delimiting criteria defined earlier.

(2) Descriptive analysis: formal aspects of the collected material are analyzed to provide the base for theoretical analysis. Selected papers are sorted according to the year of publication, publication outlet, etc.

(3) Category selection: structural attributes and corresponding analytic categories are selected to categorize the collected material. Structural attributes constitute the analytical categories to form the major topics of analysis.

(4) Material evaluation: the collected papers are analyzed to find relevant issues and trends in the literature.

The above clear and purposeful structure is followed iteratively to complete the review process. Our overall research process flow is illustrated in Figure 1.

The 189 research papers that qualified the delimitation criteria were selected as the most relevant and significant research relating to SSCM, then analyzed for the descriptive attributes. It is revealed from the review that most of the literature is fragmented and is in silos that makes synthesis a difficult process. Among them, most (168) were published in the recent ten years, with an increasing slope of two articles per year between 2003 and 2012. Figure 2 shows the number of refereed articles published over the years (until April 2013). Table I presents the list of the popular journals that published most of the refereed papers selected in our survey.

As a full review of all papers is neither feasible nor does it offer any further insights (Seuring and Gold, 2012), we focus on the selected 189 refereed articles for content analysis.

3. SSCM research

Why are the smart supply chain applications being quickly developed and used today? Despite the difficulties and complexities, smart supply chain applications surely provide many benefits otherwise not available. For example, unprecedented amount of information can be collected and used to make better business decisions. Better business processes are developed to support higher efficiency and quicker response. In addition, the dynamic complexity has outstripped the possibility of human intervention to identify and solve many system issues, smart supply chains can possibly take out much of the persistent inefficiencies. As such, it is harder to achieve performance

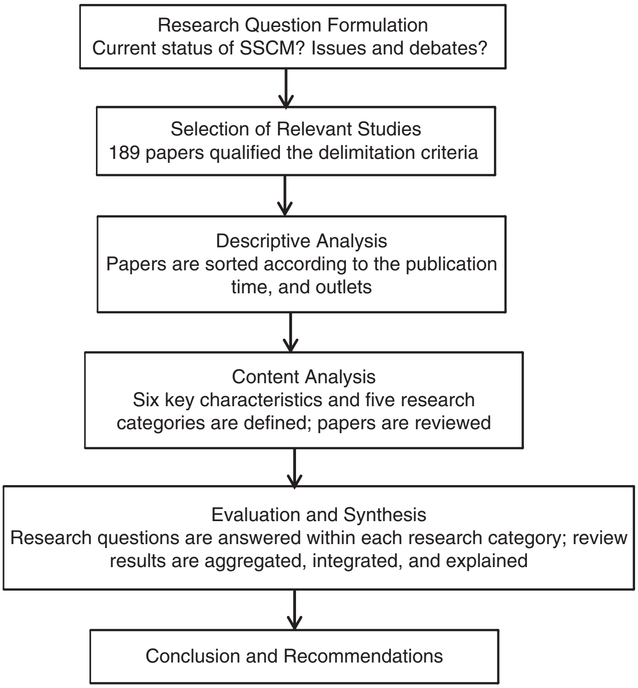
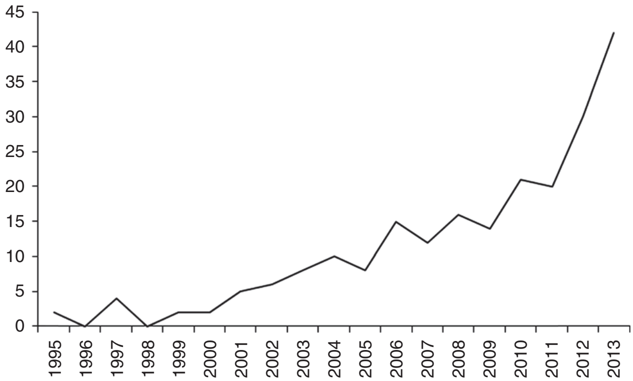


Figure 1.
Research process flow diagram



Notes: The literature search was completed in April 2013. The number for 2013 was projected based on 14 articles found for the first quarter of 2013

Figure 2.
Number of selected referred journal articles published over the years

improvements through the traditional means and companies clearly see the critical need to develop newer solutions arising from technology and business model-based innovations. Further, the costs of instrumentation have declined dramatically in recent years and smart devices are being deployed everywhere (Zhu *et al.*, 2012). Computing and information technologies (IT) can now support widespread instrumentation, monitoring, and perform analytics.

Journal name	Number of publications
Management Science	10
European Journal of Operational Research	9
International Journal of Production Economics	9
Production and Operations Management	9
Supply Chain Management: An International Journal	9
Harvard Business Review	8
Journal of Operations Management	8
International Journal of Information Management	6
International Journal of Physical Distribution & Logistics Management	5
International Journal of Production Research	5
Omega	5
International Journal of Operations & Production Management	4
MIT Sloan Management Review	4
Business Process Management Journal	3
MIS Quarterly	3
McKinsey Quarterly	3
Manufacturing and Service Operations Management	3
Operations Research	3
Journal of Business Logistics	2
International Journal of Logistics Management	2

Table I.
Refereed journals with the most articles selected in the literature review

Based on our definition of smart supply chain and earlier discussions on relevant applications, we summarize that smart supply chains collectively possess the following six distinctive characteristics:

(1) instrumented: information in the next generation supply chain is overwhelmingly being machine-generated, for example, by sensors, RFID tags, meters, and many others;

(2) interconnected: the entire supply chain, including business entities, and assets, IT systems, products, and other smart objects are all connected in a smart supply chain;

(3) intelligent: smart supply chains make large-scale optimal decisions to optimize performance;

(4) automated: smart supply chains must automate much of its process flows by using machines to replace other low-efficiency resources including labor;

(5) integrated: supply chain process integration involves collaboration across supply chain stages, joint decision making, common systems, and information sharing; and

(6) innovative: innovation is the development of new values through solutions that meet new requirements, inarticulate needs, or even existing needs in better ways.

Among all critical resources, information systems continue to play a critical role in SCM as supply chain performance is often characterized and facilitated by the real-time collaboration and sophisticated integration. SCM would not even be possible without the advances in information systems and technology. In fact, smart supply chains will create new value by developing new business models, improving business processes, and reducing the associated costs and risks (Chui *et al.*, 2010). More information, better decision, better process, even better product would be what smart supply chain can and should produce. SSCM research should certainly focus on the business management of smart supply chains. Using the six characteristics as structural attributes together with the above discussions on information, we take the liberty to classify the main research topics of SSCM into the following five categories:

(1) information in supply chains;

(2) IT;

(3) process automation;

(4) advanced analytics; and

(5) process integration and innovation.

It is evident that categories (2-4) fully capture the six distinctive characteristics we discussed early, e.g., IT includes hardware (instrumented) and network (interconnected), and the intelligent feature is facilitated by advanced analytics. Information in supply chains really refers to what "smart" is all about. Furthermore, these five categories are all well-established research themes extensively studied in the literature. As such, they are used as a convenient way to represent SSCM research and group relevant papers reviewed in the study. Under this structure, we find the most popular research methodologies are conceptual/framework for addressing IT infrastructure topics (39 papers), and analytical modeling method for addressing advanced analytics topics (22 papers). Some topics such as IT obviously attracted more researchers' attention than others in recent years (Table III). We will attempt to address the *RQ1* and *RQ2* in the context of each of the above five topics (Tables II and III).

Classification criteria	Conceptual/ framework	Analytical modeling	Empirical	Case study	Others
General SSCM strategy	21	1	0	1	1
Information	13	14	4	1	1
Information technology	39	8	6	5	1
Automation	2	4[a]	2	2	0
Advanced analytics	13	22	3	1	0
SC integration	11	8	7	0	0

Note: [a]Including one paper using simulation approach

Table II. Number of papers using different research methodologies in the literature review

	Information	IT	Automation	Advanced analytics	Integration and innovation
2003	2	0	1	3	2
2004	2	3	1	1	3
2005	2	1	2	0	2
2006	3	7	2	1	2
2007	3	6	1	0	2
2008	1	3	2	3	3
2009	4	3	5	2	0
2010	3	11	3	1	3
2011	6	5	0	6	3
2012	1	11	5	4	8

Table III. Number of papers published in various fields in ten recent years

3.1 Information in supply chains

While data can be considered as "raw facts" that reflect the characteristics of an event or entity, information can be viewed as "meaningful data" to support decision making (Detlor, 2010). The goal of information management is always to help organizations create, access, process, and use information so that they can complete their business tasks more efficiently and effectively. Meanwhile, delayed, scarce, or distorted information can create serious problems in supply chains (Chow *et al.*, 2008).

There is a rich collection of literature on supply chain information management (see, e.g. Pereira 2009; for a review). Researchers have long advocated the notion that information is critical to the success of SCM (Chopra and Meindl, 2013). Most of the existing literature available in this area focusses on demand (or order) information management along the supply chains (Kumar and Pugazhendhi, 2012). Information is even more important in a dynamic environment that involves uncertainties and disruptions (Mithas *et al.*, 2011). Specifically, demand information visibility can cut lead times, reduce associated costs, improve responsiveness, and enhance decision making (Handfield and Nichols, 2002).

Information in business world can be classified in a number of ways, for instance, proprietary or public information, tactical (e.g. purchasing orders, production schedule, logistics data), or strategic (e.g. facility capacity, supply networks). A great deal of attention in the current SCM literature is devoted to the investigation of material and demand information flows and their respective coordination (Pedroso and Nakano, 2009). As all supply chains are essentially demand-driven, final customer demand information is widely considered as the most important information in supply chain systems. Other typical information generated may also include inventory, cost, pricing, shipping, location, capacity, quality, and technical information (Pedroso and Nakano, 2009). In a broad context, every firm serves as a producer as well as a user of information. In addition to the information they receive from their partners, firms also need to generate and analyze much of the information they use internally and share externally with respective partners. While some of the information items like lot size and lead time have been extensively studied individually, it is evident that the current literature lacks comprehensive research at broader scales, e.g., how to collectively manage all the full-scale information items the manufacturer needs. The economic value and accessibility of different information items need to be systematically assessed from different angles to provide insights for full-scale information management in smart supply chains.

In order to develop the information system for a smart supply chain, one should probably start with asking questions about what information the firm and other supply chain partners need, and answering questions about what information they can provide to benefit themselves and other partners. Without defining what information to produce, it would be very difficult to share data across supply chain stages as the partners might not have the right type of information. Consequently there would be no communication at all, even when companies want to communicate. As the interconnected supply chain networks link data from customers, products, company assets, and the operating environment, they can generate more high-quality information much quickly. The trend is that machine-generated sensor data will become a far larger portion of the big data world (to 42 percent of all data by 2020, up from 11 percent in 2005) (Loher, 2012). Smart supply chains are geared toward producing better information which possesses the following properties (Pedroso and Nakano, 2009):

- the right type of information (e.g. creating more value);
- improved information quality (e.g. accuracy about actual demand quantity, precision about order arrival time);
- better timing (e.g. much earlier than previous);
- speed (e.g. real-time transmission over network);
- ease of accessing the needed information; and
- controllability for information sharing and privacy protection.

We just discussed what better information to generate. In practice, however, good information is often not available or passed through to other supply chain partners for practical, political, and/or competitive reasons. As a result, this may undermine a particular enterprise in terms of functional decision making as well as risk mitigation. To enable transformative opportunities, firms will increasingly need to integrate information from different sources. Since the value of information is an important subject matter when facing demand uncertainty, there has been abundant research supporting that information sharing is a key supply chain performance driver (Cachon and Fisher, 2000). By taking advantage of the information available and sharing them with other parties in the supply chain, a firm can improve coordination to enable efficient material and information flows (Damiani *et al.*, 2011).

While information sharing is important, the significance of its impact on the performance of a supply chain depends on what information is shared, when and how it is shared, and with whom (Holmberg, 2000). It is found that both information sharing and information quality are influenced positively by the trust built in supply chain partners, but negatively by supplier's uncertainty (Wang *et al.*, 2013). While favorable costs structure like low-operating costs may facilitate more information sharing (Chu and Lee, 2006), there are many risks associated with sharing item-level data and lacking of trust is still one of the major obstacles for information sharing in general, and for sensitive information in particular (Eurich *et al.*, 2010). It is worthwhile noting that in some cases sharing a lot of information may guarantee that nobody has the right information when it is needed (Liker and Choi, 2004). As such, it is very important to identify what information should be shared when creating supply chain visibility (Handfield and Nichols, 2002). Modern IT has made information sharing possible in a convenient manner. Due to the complexity and costs associated with the increasingly complicated information flows, it is only possible to make full-scale applications for information sharing and collaboration in smart supply chains where information is produced and managed by machines and devices (Evans and Annunziata, 2012).

Overall, the majority of the prior studies on supply chain information management focus on the upstream flow of demand information and its effects on material flows. Lacking of visibility and collaboration in traditional supply chains is clearly one of the fundamental issues smart supply chains need to address. To help mitigate the issue, full-scale high-quality information needs to be collected, analyzed, shared, and used in the right manner to create more value (e.g. system cost reduction), such that win-win situations can be possibly established to promote supply chain partnerships.

3.2 IT

After determining what information we need, the next question would be how to access and use it. IT clearly plays a backbone role in facilitating information flows in supply chains. In fact, in an era of big data, large volumes of high velocity, complex and variable data do require advanced technologies to capture, store, distribute, and analyze information (Savitz, 2013). However, information management is not so much about the management of technology, but rather more related to the management of the processes, specifically, the creation, acquisition, organization, storage, distribution, and usage of information (Detlor, 2010).

The IoT is a network of hardware, software, devices, databases, objects, sensors, and systems, all working at the service of humanity (Marshall, 2012). The IoT is a technological revolution in computing and communications which leads to vision of "anytime, anywhere, any media, anything" communications (Atzori *et al.*, 2010). As such, IoT allows digital and physical entities to be linked to enable a whole new class of applications and services.

One of the key IoT applications is RFID technology. In recent years, the topic of RFID has been extensively researched in the literature (e.g. Zhu *et al.*, 2012). By embedding short-range mobile transceivers into a wide array of additional items, this technology enables improvement on reliability, usability, and productivity. By doing so, IoT would add a new dimension to the world of information and communication and create a unique value for all supply chain stakeholders, e.g., smart devices and sensors like RFID tags prove to effectively reduce inventory shrinkage, prevent stockouts, avoid excess stocks, and improve data accuracy. Further, the existing literature still lacks a detailed view on how to assess the impact of technologies such as RFID, at the process level (Bendavid and Cassivi, 2010).

By carrying radio signals of product identification and other information, RFID technology can provide unprecedented visibility to the supply chain (Masciari 2012), improve manufacturing efficiency and effectiveness (Zelbst *et al.*, 2012), and reduce the negative impact of theft and terror (Kevan 2004). Lee and Ozer (2007) argue that there is a huge credibility gap of the value of RFID, and that a void exists in showing how the proclaimed values are reached and how those values can be realized. The empirical evidences in prior literature show that the major effects of using RFID are automational effects on operational processes followed by informational effects on managerial processes (Visich *et al.*, 2009). With IoT smart devices, supply chain firms would be able to reduce the information acquisition costs (Fu and Zhu, 2010). However, if the RFID benefits are not symmetrically distributed, conflict might arise and coordination mechanisms are therefore needed (Gaukler *et al.*, 2007). As such, optimal design of RFID deployment by optimizing the number and locations of RFID systems in the network might also be warranted (Chang *et al.*, 2010).

The widespread adoption of the smart supply chain will take time, but the time line is advancing rapidly thanks to improvements in underlying technologies, for instances, advances in wireless networking technology (Oudenhoven *et al.*, 2012). For instance, mobile devices with new functionality enhance operational efficiency (Shibi, 2011) are increasingly being adopted at slow but steady rate in various supply chains (McCrea, 2012).

Based on the extensive interconnection, IoT allows for easy access to extensive information sources, which supports more comprehensive intelligent services (Ma, 2011). The IoT infrastructure has a great promise, yet business, policy, and technical challenges must be tackled before these systems are widely embraced. In particular, much of the IoT benefit depends on what information is collected in which manner.

To make business sense, IoT applications have to be investigated in terms of the value created in the entire supply chain context (Souza *et al.* 2011). Currently, for the most part, the existing internet is a static repository of unconstructed data that is accessible only through human interventions. In general, HTML does not provide a means for presenting rich syntax and semantics of data (Schuster *et al.*, 2007). In building the IT infrastructure of smart supply chains, the main technical issues still remain, for example, how to achieve a full interoperability between various interconnected devices (Weber, 2010).

3.3 Process automation

Now we turn to business processes which handle supply chain flows. The industrial revolution, in which muscle power was replaced by mechanical power, has greatly improved productivity and efficiency. With the rise of computing and other technologies, further productivity gains appear to be promising in the adoption of automating processes based on better information. Process automation hereafter refers to either automated analysis of big data or automated processing of physical products. Coupling cyberinfrastructure with physical infrastructure not only begets smart infrastructure but also offers collateral benefits to the infrastructure systems, industries, and assets to which they are economically linked (Kim and Heller, 2006).

However, if making no process changes, it is clear that no benefits would be received when replacing bar code system with the new RFID system (Hardgrave, 2013). In fact, automation typically comes into the equation for two interrelated reasons: the need to optimize processes like order fulfillment and a desire to control costs. To fully appreciate the automation potential, it is important to consider how large the size of the global supply chain system has become. There are now millions of factories across the world, ranging from small shops with a few machines to highly advanced petroleum refinery plants. In addition, there are thousands of complex networks ranging from power grids to railroad systems, which tie factories, fleets, and retail facilities together (Evans and Annunziata, 2012). By connecting machines and other assets to the IT system via software, data is produced and insight is obtained, but what is needed to study more is that these machines are now part of a cohesive intelligent network that can be architected to automate the delivery of key information and even physical product. This represents hundreds-of-billions of dollars saved in time and resources across industries (Savitz, 2013). No wonder companies have been integrating machines with sensors and wider networks for years.

Previous research shows that the e-marketplace supply chain applications enable the majority of companies to automate transaction-based activities and procurement-related processes rather than strategic supply chain activities (Eng, 2004). Now, assisted by the vast amount of information available and the new infrastructure, the pace of process automation implementation will only be accelerated. In the literature, abundant supply chain automation applications can be found in areas like data analysis, manufacturing, sourcing, warehouse, distribution, and retailing (e.g. Li *et al.*, 2013; Trebilcock, 2013).

While supply chain objects can both sense the environment and communicate, they become the tools for understanding complexity and responding to situations swiftly. What is revolutionary in all this is that these physical information systems can now work independently in general without human interventions (Chui *et al.*, 2010). For example, retailers are suggested to move to zero Human Intervention in Operations (Hardgrave, 2013). Firms can develop smart applications at all possibility to do the job without human intervention and errors.

Several great opportunities could be noted for research in this area. Most of the recent work cited here appears in practitioner-based journals including *Logistics Management* and *Modern Materials Handling*. It is understandable that the technological advancements are driving the process automation revolution. However, technological development alone does not always translate into overall cost savings or increased revenue. Thus, more business management research, such as economic analysis for a certain application and automation system design, is particularly desired to develop better technological applications which do make business sense.

3.4 Advanced analytics

Business analytics is a process through which mathematical techniques and functional knowledge are combined to yield actionable insights. Analytic techniques are being increasingly used today because of the factors like the need for faster and better decisions; the sheer volume of data being collected by organizations across their extended enterprises; and the availability of low-cost data storage and computing power and tools (Khan, 2013). It is widely agreed that big data can potentially create significant value for the world economy, enhancing the productivity of companies and the public sectors, and creating substantial economic surplus for consumers (Manyika *et al.*, 2011). Survey shows top-performing organizations use analytics five times more than lower performers (Hopkins *et al.*, 2011). Advanced analytics is likely to become a decisive competitive asset and a core element in improving supply chain performance.

However, it is a mistake to assume that acquiring the right kind of big data is all that matters (Barton and Court, 2012). In fact, effective information management must be integrated with process changes to promote value creation (Bytheway, 2011). To do so, one key is to use business analytics to create better information and make better decisions to enhance performance. That is, to use data, IT, quantitative modeling, optimization, and computer programming to help managers gain improved insights about their operations and make better fact-based decisions (Waller and Fawcett, 2013). Moreover, the smart devices and sensors are getting the data we never had before. Advances in "big data" software tools and analytics techniques provide the possible means to process the massive quantities of data generated by numerous intelligent devices (Evans and Annunziata, 2012). Mathematical models are especially useful in dealing with the complex situations like those often encountered in supply chains, for example, suggesting explanations for observed events such as unanticipated build-ups of inventory.

Big data is unique because of the volume, variety, and velocity of the data. To capitalize on big data, firms need to source the right data, build models that predict and optimize business outcomes, and transform organizational processes (Barton and Court, 2012). Data mining is an important approach in advanced analytics to discover and interpret patterns in data (Leventhal, 2010). Whereas industry focusses on scalable and integrated systems and implementations for applications in different organizations, the academic community needs to continue to advance the key technologies in analytics. It is suggested that emerging analytics research opportunities can be classified into five critical technical areas – (big) data analytics, text analytics, web analytics, network analytics, and mobile analytics (Chen *et al.*, 2012).

The existing *OR/MS* literature provides a rich source of analytical algorithms and models. However, the results often come with assumptions not found in the traditional supply chain settings which make them difficult to apply. It is evident that the existing studies lack insights about which scientific models fit which industrial applications (Quante *et al.*, 2009). It is reported that the leading obstacle to widespread analytics adoption is lack of understanding of how to use analytics to improve the business (Hopkins *et al.* 2011). In fact, the adoption barriers that organizations face most are managerial and cultural rather than related to data and technology (LaValle *et al.*, 2011).

There are a gigantic number of analytical papers published in *OR/MS* (such as optimization research) which can be possibly employed in smart applications and it is impossible to review all of them here. Instead, we focus on three most relevant areas. First, smart supply chains, equipped with numerous sensors and devices, may provide unprecedented opportunities to retrieve advance demand information for various supply chain firms. Customers with positive demand lead times who place orders in advance of their needs may result in the situation of advance demand information or ADI (Karaesmen *et al.*, 2004). Advance demand information is known to improve inventory performance if shared among supply chain stages (Zhang and Cheung, 2011). Early orders can be used to significantly improve demand planning in many industries where make-to-order characteristics are present. Further, Hariharan and Zipkin (1995) shows that such "demand lead times" may improve operational performance in precisely the same way that replenishment lead times degrade it.

The second relevant area is supply chains dealing with perishable goods where lack of demand forecasting, demand and supply mismatch, less integrated approach are main causes of concerns (Shukla and Jharkharia, 2013). It is reported that the perishable supply chain should be more responsive in the early supply chain stages and then efficient in later stages (Blackburn *et al.*, 2004). It would be interesting to investigate how the new smart information and automation capabilities could change the performance of perishable supply chains, for example, reducing the post-harvest wastage for fresh produces.

Finally, supplier selection is another vital issue studied in SCM which advanced analytics may offer help. For instance, Koul and Verma (2011) provide a mathematical system that captures the uncertainties associated with human cognitive processes in order to select the vendor. In broad sense, specific hybrid neuro-fuzzy methodologies can be developed to identify appropriate global logistics operational modes used for global SCM.

Concerning the advanced analytics techniques, a better understanding about the existing literature and their applicability to smart supply chain application is particularly needed. A comprehensive literature on each specific application would help in this regard. How to incorporate the vast existing analytic research outcomes to benefit the development of smart supply chains would be a highly complicated yet extremely critical task.

3.5 Integration and innovation in smart supply chains

SCM, in its definition, includes integrated processes for purchasing, manufacturing, logistics, and distribution. All supply chain components must be coordinated to promote system efficiency. As IT continues to evolve, individual firms tend to become more integrated in what they do. Similarly, integrating effective supply chain practices with information sharing across supply chain stages becomes a critical point for improving performance in supply chains (Kumar and Pugazhendhi, 2012). For instance, supplier integration (Danese, 2013) and reverse-logistics integration (Cardoso *et al.*, 2013) are considered key managerial strategies for improvement.

In the meantime, IT needs to be integrated with other technological, human, and organizational capabilities to obtain a competitive advantage in the value creation process (Carmichael *et al.*, 2011).

In smart supply chains, integrating IT, advanced analytics, and process automation could provide unprecedented opportunities to maximize the supply chain surplus. Companies can stand to realize the gain from big data only if they have the capability to make these data accessible and useable in improving processes. In other words, that is to collect, store, and manage large volumes of data sets; and then transform them into real time, smart decisions, implement them; and finally achieve a better operational performance. Without appropriate system integration, this aforementioned task can be hardly done.

Integration is a multidimensional concept that covers the different organizational levels of the company: corporate through attitudes; strategic through patterns; and operative through practices (Vallet-Bellmunt and Rivera-Torres, 2013). The so-called third industrial revolution is essentially the integration of advanced analytics, adaptive services, and digital manufacturing in supply chain settings (Tien, 2012).

At the same time, supply chain integration is a difficult task as it involves many managerial aspects in terms of both "hard" and "soft" information exchange mechanisms in support of the logistics integration activities (Prajogo and Olhager, 2012). Wong *et al.* (2012) argue that the performance outcomes of information integration are contingent upon both external environmental conditions and internal operational characteristics. It would be very interesting to investigate how information and material flow interactions produce any new value in the smart supply chain setting.

IT, together with process automation can greatly promote inter- and intra-organization process integration (Wamba, 2012). The breadth of supply chain integration significantly correlates with increased performance, yet in practice, the majority of supply chains are not well integrated (Childerhouse and Towill, 2011). It is interesting to note that researchers also doubt that the more supply chain integration might not improve performance (Fabbe-Costes and Jahre, 2008).

On the other hand, smart supply chains will definitely call for more innovations in smart products (services) and processes. For instance, smart services are innovative and wholly different from the past in the sense that the actions are based on hard field-intelligence (e.g. something is about to fail). Based on this connectivity, the future retailers will need to successfully engage customers through omni-channel retailing which combines digital and physical channels. Supply networks have shifted from a linear structure to a "complex adaptive system" that is presumed capable of autonomously adapting in timely fashion to environmental changes (Wycisk *et al.*, 2008).

Research shows that supply chain performance and supply chain stability positively influence the volume of innovations (Modi and Mabert, 2010). Further, facilitated by the IT infrastructure and processes, elevated supply chain trust is the catalyst for collaborative innovation. When customers collaborate with suppliers, they can build trust, reduce stress, and increase innovation-related activities (Henke and Zhang, 2010).

Innovation has always been the single most powerful ingredient in business management to help create more with less, to ease the constraints, and generate more value for all stakeholders. The smart supply chain is the outcome of innovations already underway, some of which are innovations of technology, and others may be the innovations of systems, networks, and/or processes. Although the specific innovations that will be needed are yet unknown, it is clear that collectively, they represent a set of vital catalysts and enablers (Evans and Annunziata, 2012).

While many executives believe business model innovation will become more important for success than product or service innovation (Johnson *et al.*, 2008), the smart supply chain holds the great potential to drive the next wave of innovation for the world by pushing even further the boundaries of digits and atoms. It is notable that the world is on the threshold of a new era of innovation and change with the rise of the smart supply chains.

4. Discussions

In the previous section, we investigated the current status of SSCM research and applications. We specifically study how smart supply chains add value and provide the following basic elements for developing a smart supply chain:

- big data implementation including IoT infrastructure, data collection and processing;
- information system (IoT, etc.) redesign/replacement;
- advanced analytics, data mining, and business intelligence;
- business process redesign/improvement including digitalizing, standardizing, and streamlining;
- process automation and improvement based on new information availability;
- supply chain collaboration including data sharing, connectivity, partnership;
- supply chain integration; and
- process innovation and product innovation.

In order to seize the new opportunities, companies need to develop an overall strategy to identify resources and make strategic choices on smart capabilities (Bughin *et al.*, 2011). The promise of real benefits rests on the potential for seamlessly integrating data flows and work processes. Before making investing decisions, companies should decide which elements of the chain could produce the greatest efficiencies and then choose the smart applications most likely to promote them. In particular, we propose three smart supply chain implementation phases: early phase, intermediate phase, and advanced phase (see Figure 3).

A smart supply chain is more than an e-supply chain equipped with big data and advanced analytics functionalities. Instead, a smart supply chain should possess all

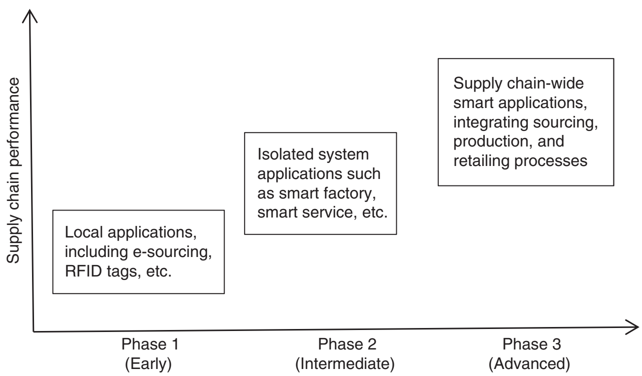


Figure 3. Phases of smart supply chain implementation

six main characteristics we presented early. Most of the current reported smart supply chain examples such as food retailing (Prater *et al.*, 2005) and smart factory (Hessman, 2013), are local and isolated applications, belonging to the early or intermediate phases in Figure 3. The relevant barriers for applications include not a top initiative, fear of change, insufficient skills and knowledge, immature technologies.

Integrating the digital and physical worlds will create great opportunities for new business models. In the future, about 46 percent of the global economy or $32.3 trillion in global output can be benefited from these smart applications like smarter homes and offices (Evans and Annunziata, 2012). Since the implementation of smart technologies is mostly driven by process changes, a business process management approach is needed to support practitioners and researchers in their understanding of potential of adopting smart supply chain models (Bendavid and Cassivi, 2010). Smart business network processes should be more designed around communications and distributed intelligent capabilities, but not traditional computing applications. They must be operated with strategic issues and time in focus, and not only to sub-optimize specific business process attributes like cost and time (Pau, 2012). In a nutshell, business models need to be revised in order to adopt the full potential of smart applications, in particular, what new resources (information and processes) and operational capability are needed to produce new value for customers (Johnson *et al.*, 2008). In fact, the leading companies are already focussing on reshaping customer value propositions and transforming their operations using digital technologies (Berman, 2012).

To consolidate some of the discussion threads presented early, we provide a sample list of future research issues for further investigations:

(1) What full-scale information does a smart supply chain need to employ? When and how to collect, share, analyze, and use? It should be noted that the final demand information is hardly the only thing supply chain firms need to make sensible operational decisions.

(2) What is the economic value of smart supply chain applications, such as real-time supply information sharing and process automation improving perishable supply chains? How does technology development benefit from insights provided by systematic economic analysis? Overall, it is the potential benefit which will ultimately determine how fast smart applications will be deployed. The hidden benefits or added values by using smart applications in supply chains like process automation are still waiting to be explored in systematic ways. As such, economic analysis on the value added by these applications would be an intriguing research stream.

(3) How to incorporate the vast existing analytic research outcomes to benefit the development of smart supply chains? How to convert the excessive data availability in smart supply chains into more business insights? The traditional dilemma of "too much data, too little information" still persists. Companies are struggling to figure out how to turn all these bits and bytes from a bothersome liability into a competitive advantage. To accomplish that, smart supply chains can help by developing innovative algorithms and creative approaches to handle those challenges.

(4) What are the practical hurdles preventing smart supply chain partners from collaborating? How to overcome? How to integrate smart supply chain processes? How can business process innovation support technological

innovation? For now, the industrial internet is really more of an intranet with which most data never leaves a factory or a company's firewall (Fitzgerald, 2013). Data for one firm can be the gold mine for its competitors, and thus, in many cases companies must innovate to pursue these opportunities. A major hurdle in establishing the collaborative supply chain relationships is a better understanding of the potential benefits of the relationships, the distribution of the benefits among different players, and the risks associated with the collaborative relationships (Sahin and Robinson, 2005). Consequently, the call for more research endeavor in this regard is a necessity.

(5) What are the technological challenges and management challenges in implementing smart supply chains? How can supply chain analysis assist better technological development? Can technology be a possible solution to the long lasting management problems like lack of trust in supply chains?

Changes happen everywhere. Almost overnight, supply chains may no longer be positioned to buy, make, move, or sell the right items in the right quantities in the right places. An adaptable structure embraces change and IT offer never-seen-before learning abilities to logistics systems. The future supply system can be understood as complex adaptive logistics systems to adapt to changing environment requirements (McKelvey *et al.*, 2009). Perhaps the easiest way to understand adaptable structure is to envision a supply chain environment in which products, processes, and systems are easily modified in response to changing conditions (Pearson, 2013). One of the best ways to do so is to build smart supply chains.

The discussions presented in this paper definitely depict some of the beautiful outlook and promising improvements we expect to witness in the business world. In fact, Helmuth Ludwig, CEO of Siemens Industry in North America, said that the future of smart manufacturing is today (Hessman, 2013). However, there are still numerous technical and non-technical obstacles and challenges waiting for us to tackle. We hope pursuing some the research paths described in this paper could be a great starting point.

5. Concluding remarks

We presented a review of the SSCM literature in this paper. Our contributions are threefold. First, we conceptualized six key characteristics of smart supply chains and developed a research framework pertinent to SSCM. Second, we aggregated, integrated, and synthesized the latest research outcomes and applications for smart supply chains from 189 papers selected. In particular, this paper presents significant perspectives describing models, methods, and technologies with both solid theoretical developments and practical implications on topics like information, IT, advanced analytics, process automation, and supply chain integration. Third, we identified several key emerging phenomenon in SSCM and highlighted the remaining research issues for future endeavor.

We show the impact of smart supply chain applications can be revolutionary and breathtaking. However, we are still facing tremendous technological and management obstacles in practice and significant knowledge gaps in smart supply chain research. It is authors' belief that the future research issues reported here are particularly exciting because of the unfilled value-creating opportunities described in the study. The increased use of smart functionalities in various supply chains also provides more opportunities for empirical research, which can be extremely valuable in providing further practical insights.

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