Big data in Supply Chain Management – Applications, Challenges and Benefits

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Abstract

This paper focuses on Big Data (BD) applications, challenges and benefits (ACBs) in Supply Chain Management (SCM). While BD-related research has attracted a growing number of Business Intelligence and Analytics (BI&A) researchers, SCM-specific research on BD is yet to receive their full attention. By combining relevant frameworks from SCM and BI&A, this paper proposes a new research framework for BD in SCM. The combined framework is then used to identify, classify and analyze ACBs of BD in SCM, using insights from a multi-disciplinary literature review from the fields of BI&A and SCM. Based on the main research findings the paper also suggests further SCM-specific research related to BD, by identifying synergies across business functions and value dimensions of SCM.

Keywords

Big Data, Supply Chain Management, Applications, Benefits, Challenges

Introduction

The challenges of managing and making sense of increasing volumes, variety and velocity of data continue to draw the attention of a growing number of researchers interested in the emerging multidisciplinary area of Big Data (BD). The Information Systems (IS) community is no exception. BD-related research can be found in all leading journals and conferences, with prominent IS researchers researching BD from many different perspectives. Recent notable examples include research by Abbasi, et al. (2016), Muller et al. (2016), Chen et al. (2012), Watson (2014), Yoo (2015), Markus (2015), Zuboff (2015) and many more.

Leading industry practitioners are also discussing the existing and potential BD applications in various organizational processes, business functions, and domains (Bughin et al., 2011; Lavalle et al., 2011). The promise of BD includes many expected benefits, such as improved business processes, increased efficiency and cost reduction (Davenport and Dyche, 2013).

Very often BD-related research found in the Business Intelligence & Analytics (BI&A) is not focused on any specific industry domain, with applications, benefits and challenges discussed in isolation from their industry contexts. We term them “domain-neutral” applications of BD. However, with a growing understanding of BD potential and rapidly increasing applications across various industry domains, examples of prominent domain- or industry-specific BD research can be found beyond BI&A. An example of domain-specific BD research, include BD in Supply Chain Management (SCM) that is also the main focus of our research. This is an important area of BD research, because SCM is considered to be a company’s major value contributor (Xu et al., 2014; Rozados and Tjahjono, 2014), but still lagging behind current developments in BD applications, as discussed by the mainstream BI&A research.

While many SCM researchers argue that BD offer a great potential for SCM innovation (Leveling, 2014), the required transformation into data-driven supply chain guided by BD analytics is very challenging and yet to be achieved (Pearson, 2014; Christopher and Ryals, 2014; Mehanna and Rabe, 2014; Samuelson, 2014). Therefore, further research is needed to gain a better understanding of SCM-specific BD challenges and opportunities in order to help companies with assessment of their BD potential.
Taking the business rather than technical perspective of BD, our research focuses on the following research question:

**What are the current applications, challenges and benefits of BD in SCM?**

We answer this question by providing an in-depth review of the relevant literature published in two research fields: SCM and BI&A, focusing on BD. Our analysis of the applications, challenges and benefits (ACBs) of BD in SCM is guided by a new framework we propose by combining two existing frameworks from SCM research and industry practice (Sanders, 2014; DHL, 2013; T-Systems, 2014).

In terms of a research contribution, our analysis of the related literature across two research fields (SCM and BI&A) contributes to a more comprehensive understanding of the current research on BD in SCM and offers some important insights into existing research gaps and opportunities. The outcomes of this research could be also used by industry practitioners to identify possible applications, consider relevant challenges, and learn about the expected benefits, as discussed in the relevant literature.

The remainder of this paper is structured as follows. The next section focuses on the foundation concepts including SCM-specific challenges and benefits of BD. This is followed by a brief description of the relevant research frameworks and their proposed combination. The subsequent section introduces the research methodology used to guide our literature review. The main findings include various applications, challenges and benefits of BD in SCM, followed by the discussion section. The final section offers the main conclusions, states the limitations of this study and opens up several research topics for future studies on BD in SCM and beyond.

**Foundation Concepts**

Supply Chain Management (SCM) has been identified as a very promising area for innovative applications of BD (Bange et al. 2013; Chircu et al. 2013; Sanders and Ganeshan, 2015). The existing literature on BD published by both SCM and BI&A community offers numerous examples of the existing and potential applications, expected benefits and current or potential challenges.

The often quoted examples of BD-related applications in SCM include real-time route optimization, demand sensing, geo-tagging are just some of many SCM applications, now made possible by BD (Sanders, 2014; Manyika, 2011; Hseush et al. 2013). Furthermore, the increased ability to capture data from new sources, including social media streams, sensor data, video, and telematics, opens up new opportunities for their value-adding use from purchase to sales (Leveling, 2014; DHL, 2013). BD also enhances and enables data applications across the SC due to the versatile data sources and transmitting devices such as RFID tags, telematics and sensors (Handfield et al. 2013; Sanders 2014). Telematics offers new applications within risk and transportation management, such as detection of fraud, tracking and tracing of parts and products within the company and across the SC, routing optimization, prediction of exact delivery times and providing comprehensive delivery histories (Chircu et al. 2014; Waller and Fawcett 2013). Additionally, sensors attached to machines and vehicles provide information on the resource’s status to enable proactive maintenance (Waller and Fawcett 2013). Also, the more detailed information about products and processes enables virtual collaboration and co-creation with suppliers and customers (Obitko et al. 2013). BD-enabled machine-to-machine communication could align and automate physical processes by recognising product parts and transmitting this information to the respective machine to continue the production process (Böhm and Heininger 2014).

In terms of benefits, BD is expected to make a positive impact on SCM in terms of improved quality, increased efficiency and process automation (Fink et al. 2012; Manyika et al. 2011; Nedelcu 2013). Major impact is expected to be found in the area of industrial automation and manufacturers, which depend on Just-in-time (JIT) supply due (Obitko et al. 2013; Zhong et al. 2015). Furthermore, transportation and distribution are expected to benefit from BD due to the integration of heterogeneous data captured from the origin, the transport route and its circumstances, and the destination (Obitko et al. 2013). BD is expected to affect all actors in a supply chain thanks to advanced applications of BD analytics (Böhm and Heininger 2014; Fawcett and Waller 2014; Manyika et al. 2011; Moore 2014; Rozados and Tjahjono 2014).

However, in spite of very innovative applications and promised benefits, BD adoption in SCM is still lagging behind other industry sectors (Chae 2015; Lu et al. 2013; Zhong et al. 2015) due to numerous challenges. Subsequently, the actual adoption rate of BD in SCM remains at the very low level.
(Christopher and Ryals 2014; Mehanna and Rabe 2014). At the same time, industry expectations regarding BD's impact on SCM remain high, while knowledge transfer from relevant research to industry remains slow (Goes 2014; Gunasekaran 2015). We argue that this knowledge transfer is very much needed in order to inform and guide industry practitioners beyond the current BD-related hype characterized by numerous potential applications and expected benefits being discussed, but not easily realized due to many yet-to-be discovered challenges. This particular argument offers a very strong motivation for our research on BD in SCM, with the first step being a multi-disciplinary literature review across two research fields: BI&A and SCM, as described in this paper. The following section introduces our proposed research framework.

Research Frameworks

As a starting point for this research we selected two existing frameworks previously proposed to examine BD applications in SCM. This section provides an overview of these frameworks and our approach to combining them into a more comprehensive framework designed to overcome their individual limitations.

The first framework was originally proposed and used by DHL (2013) and T-SYSTEMS (2014) to identify potential value of BD applications. This industry-based framework consists of the three value dimensions (1) Operational Efficiency, (3) Customer Experience, and (3) New Business Models (as shown by Table 1).

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<th>Value Dimensions</th>
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<td>Operational Efficiency</td>
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<td>Customer Experience</td>
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<td>New Business Models</td>
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*Table 1. BD Value Dimensions (DHL, 2013)*

However, it is possible to observe that the proposed value dimensions are too generic to describe all aspects of value creation in a SCM. For example, ‘Operational Efficiency’ is not sufficient since SCM includes four major business functions (Procurement, Production, Distribution, and Sales). BD can impact those functions in different ways and therefore they need to be investigated individually. The value dimensions also need to include Supplier experience to take into account collaboration and decision support of some or all actors across the supply chain. Furthermore, ‘New Business Models’ is a domain-neutral dimension and as such not specific to SCM. It is also important to note that some applications, benefits and challenges of BD are not limited to SCM, but are organization-wide. To distinguish these from SCM-specific ACBs, we use the term ‘generic ACBs’.

The second research framework was originally proposed by Sanders (2014) in the SCM field. The framework considers the four supply chain levers (Buy, Make, Move, Sell) that correspond to the general SCM business functions (as shown by Table 2). Note that the same four levers are also named by other researchers, such as Fleischmann and Meyr (2003), as Procurement, Production, Distribution, and Sales.

Although increasingly used in SCM, Sanders’ framework also has some important limitations. First of all, as already stated BD offers new applications that change the scope of traditional SCM. For example, the scope is extended beyond operations to include information. Also, some BD applications in SCM create value for the whole company, beyond individual business functions captured by the listed Supply Chain Levers. In addition, BD enhances collaboration with suppliers, customers, and other production facilities. Therefore, it is important to differentiate between internal and external impacts of BD in SCM. Yet this distinction is not considered by Sanders’ framework.

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<th>Supply Chain Levers</th>
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<td>Buy</td>
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<td>Move</td>
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<td>Sell</td>
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*Table 2. Supply Chain Levers and BD Applications (Sanders, 2014)*
Using the previously described frameworks we propose a new combined and extended framework as depicted by Table 3. The framework includes SCM-specific operations (Procurement, Production, Distribution, and Sales) as well as the “Generic SCM-related” business value dimension used to acknowledge the cases of BD applications in SCM creating value for the whole company i.e. beyond individual operation.

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<tr>
<th>SCM-Specific Operations</th>
<th>Generic (SCM-related)</th>
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<td>Procurement</td>
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<td>Production</td>
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<td>Distribution</td>
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Table 3. A Proposed Framework for BD in CRM

Operations consider material/product/service-related impacts from sourcing items (Procurement), to making the product (Production), to delivering the product/service (Distribution), to demand planning and other marketing related activities (Sales). The generic value dimension includes creation of general business insights, support in decision-making, impact on the overall network, and covers domain-neutral ACBs that cannot be directly linked to the business functions but remain important for SCM.

The framework also differentiates between internal (focusing on the company) and external (focusing on the overall cross-organizational supply chain) impact of ACBs. For this purpose, we use different codes to indicate whether ACBs relate to the value dimensions internally “I”, externally “E”, both ways “I, E”, or have no impact in the respective value dimension “-”.

Research Method

In order to gain a better understanding of the existing applications, challenges and benefits of BD in SCM, we completed a literature review of the relevant research published in two different fields SCM and BI&A. Our research method was guided by the previous work by Webster and Watson (2002) and vom Brocke et al. (2009).

In order select the relevant papers we performed search of multiple databases (IEEE, Ebsco, Web of Science, Science Direct, Disco (a proprietary university database) as well as Google Scholar). We also considered relevant publications from the leading IS conferences AMCIS, HICSS, ACIS, PACIS, ECIS, and ICIS. We also conducted a forward and backward search on papers considering BD in SCM.

The papers were first filtered by title, year (after 2010), key words and the content of the abstracts. This process resulted in 42 relevant papers that were further split into two groups. The first group included 20 BD published in BI&A describing various generic applications, challenges and benefits of BD that could be applied to SCM. The second group included 22 papers specifically related to BD in SCM.

The previously described research framework (Table 3) was used to analyze and categorize the resulting relevant papers. Finally, our main focus was on the business rather than technical or data science perspectives.

Through thematic analysis of these papers we identified 23 applications, 19 challenges, and 25 benefits. They were further grouped into 9 main categories of ACBs. Using the previously introduced combined framework we were able to map the identified ACBs as described by Table 4. The following section describes the main findings in more details.
Findings

(A.1) Applications of BD within material flows - Operational applications affecting the Material Flow range from procurement to distribution. Accessing more data about suppliers’ and items’ characteristics offers more bargaining power in supplier negotiations. BD also enables better evaluation of suppliers in order to determine the right supplier and even control the sourcing progress (Sanders, 2014; Manyika, 2011; Hseush et al. 2013). This is made possible by sensors that enable real-time monitoring of production and distribution processes for quality and status. Consequently it is possible to immediately detect failures (or even prevent those with predictive modeling), track the current progress, measure efficiency, and undertake instant production changes or route optimizations (Bughin et al., 2011; Manyika, 2011; DHL, 2013). Furthermore, the alternative products/scenarios in production and distribution can be simulated, prototypes can be tested and refined with the latest insights, bottlenecks can be identified, and production can be conducted virtually in full detail and across multiple production sites (Bughin et al., 2011; Sanders, 2014; Manyika, 2011; Hseush et al. 2013). BD Analytics can make use of i) crowd solutions for procurement and distribution (i.e. crowd sourcing, crowd based delivery and pickup) and ii) predictive analytics to act proactively to (maintenance and error) situations and events; (Fawcett and Waller, 2014; Chen, et al., 2012).

(A.2) Applications of BD in information flows: In addition to operational applications, BD enables new business insights to be derived for decision-making. The variety of analysis techniques and the amount and diversity of available data are also used for Generic (SCM-related) applications. The overall Information Flow is enhanced to make processes transparent, manage risk, become more responsive to the supply chain and its events, identify fraud and other issues, automate process decisions, and evaluate efficiency of processes, forecasts and marketing initiations, supply chain partners, and employees (Sanders, 2014; Brown et al., 2011; Hagen, 2013; Probst et al., 2013; Russom, 2011).

(A.3) Applications of BD in financial flows: When used in financial flows, BD enables a comprehensive analysis of customers with a main objective to understand their behavior, sense and shape demand, analyze social media data, conduct geo-targeted marketing and refine customer segmentation. BD applications also enable design of new business models and revenue streams (Mehanna and Rabe, 2014; Sanders, 2014; Manyika, 2011; Vanauer et al. 2015; Brown et al., 2011; Robak et al., 2013).

These applications impact both the internal and external perspectives of a company. Virtual collaboration in Production, crowd sourcing and delivery in Procurement and Distribution, design-to-value in Sales, and customer segmentation in Domain-Generic are all examples of very specific Supply Chain applications. On the other hand, supplier evaluation, real-time monitoring, real-time tracking, new business models, and automated decision-making, in the respective value dimensions are all relevant at the level of company.

(C.1) Challenges of BD Requirements: Requirements are found to relate to the internal Generic (SCM-related) value dimension. With traditional IT systems unable to manage BD a new IT infrastructure is needed to enable innovative applications of sensors or processes automation through remotely controlled machinery (Sanders, 2014; Robak et al., 2013; Chen and Zhang, 2014; Khan et al., 2014). This also calls for huge investments in software and hardware to make full use of BD. It is also necessary to investment in human capital (that is currently still lacking), such as data scientists with both skills in analytics and SCM (Lavalle et al., 2011; Probst et al., 2013; Russom, 2011; Bange et al., 2013). Furthermore, cultural change is crucial since the investment has to be backed up from management. The BD transition requires an improved collaboration within the company (and across its supply chain partners) as well as a cultural shift from intuition-based decision-making backed up with data to data-driven decision-making. It is also necessary for management to recognize BD enabled opportunities while not restricting BD's potential to the improvement of current applications (Lavalle et al., 2011; Leveling, 2014; Probst et al., 2013; Chen et al., 2014; McAfee and Brynjolfsson, 2012).

(C.2) BD Complexity: Complexity of BD is not limited to processing the increasing volume and variety but includes issues related to transparency, availability, and access. It is also necessary to manage data quality including inconsistency, incompleteness of data. Effective data integration requires organizations to overcome organizational silos and share data within the company and across the supply chain including customer sensitive data. Finally it is necessary to manage the trade-off between quality and quantity.
(Leveling, 2014; Sanders, 2014; Hazen, et al., 2014; Kaisler, 2013; Probst et al., 2013; Chen and Zhang, 2014; Khan et al., 2014; Rowe, 2013).

(C.3) BD Use: To use BD the company has to have identified the suitable application areas and established a BD strategy. They also needs to comply with internal regulations (e.g. privacy, governance, and security) and consider the trade-off between near real-time and real-time processing and analysis (i.e. taking into account costs vs. additional benefits for minimizing/eliminating latency (Sanders, 2014; Manyika, 2011; Brown et al., 2011; Giles, 2012; Probst et al., 2013; Russom, 2011; Chen et al., 2014; McAfee and Brynjolfsson, 2012; Bange et al., 2013; Rowe, 2013).

BD skills are needed to recognize and realize potential applications but SCM-specific background is also important in order to identify potential applications and obstacles within SCM. This is especially the case with an interpretation of more complex algorithms in SCM.

(B.1) Benefits in Product and Services: Products and Services are found to benefit from i) resource efficiency and further cost reductions - both within the company and across the supply chain; ii) increased product/service quality due to monitoring and value addition; iii) accelerated go-to-market time; iv) data-driven processes; and v) simulations and what-if scenarios to check alternatives (Leveling, 2014; Sanders, 2014; Kaisler, 2013; Brown et al., 2011; Probst et al., 2013; Zhong et al., 2015; Sanders and Ganeshan, 2015; Russom, 2011; Chen et al., 2014; Khan et al., 2014; Bange et al., 2013). Thus, the main advantages can be found in quality improvement and faster and less error-prone processes.

(B.2) BD-enabled Analysis: BD-enabled analysis helps to identify bottlenecks, risks, and associated costs. Additionally it enables root cause analysis, analysis of strategic directions and new business models and alternative revenue streams. It could be also used to automate real-time process decisions resulting in increased responsiveness (Christopher and Ryals, 2014; Sanders, 2014; Kaisler, 2013; Vanauer et al., 2015; Brown et al., 2011; Giles, 2012; Probst et al., 2013; Fawcett and Waller, 2014; Sanders and Ganeshan, 2015; Russom, 2011; Khan et al., 2014).

(B.3) Supply Chain Relationships: BD intensify supply chain relationships, especially on the customer side. For example, it makes it possible to recognize customer preferences, establish customer patterns and offer customized treatment due to geo-targeting and refined segmentation. BD also enables mass customization, collection and analysis of extensive customer feedback across different channels, new ways of managing customer loyalty and through improved transparency, demonstrate to customers quality and value added product/service advantages compared to competitors (Sanders, 2014; Giles, 2012; Probst et al., 2013; Russom, 2011; Chen and Zhang, 2014; Khan et al., 2014; Bange et al., 2013). On the supplier side, more transparency and the respective bargaining power support negotiations while an improved assessment of supplier performance enable companies to identify the right supplier match (Sanders, 2014; Manyika, 2011).

Discussion

While most of the applications found in the literature focus on the primary SCM flows (i.e. material and information flows), operational and informational applications are both present. The same applies to company's internal and supply chain wide interactions.

A strong emphasis on the SCM-Specific Operations value dimension can be observed in Production, Distribution, and Sales but not the Procurement business function. This could be linked to the sensor-driven support in the other three functions, process automation potential, and the problem of accessing supplier data. While social media data are, in many cases, publicly accessible, sensor data can be retrieved internally within the company.

In contrast to applications and benefits, BD-related challenges are more generic (rather than SCM-specific) and occur primarily within company. More specific challenges are likely to occur through further adoption of BD, enabling companies to uncover individual application problems yet to be considered.
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<tr>
<th>A – Applications</th>
<th>Value Dimension</th>
<th>B - Benefits</th>
<th>C – Challenges</th>
<th>Summary of Findings</th>
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<td>SCM-Specific Operations</td>
<td>Generic (SCM-related)</td>
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<td>A1. Material flows</td>
<td>Procurement</td>
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<td>A2. Info flows</td>
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<td>A3. Financial flows</td>
<td>Procurement</td>
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<td>C1. BD requirements</td>
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<td>C2. BD complexity</td>
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<td>B1. Products and services</td>
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<td>B2. BD-enabled Analysis</td>
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<td>B3. SC relationships</td>
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Table 4. BD Applications, Challenges and Benefits – Key Findings
The BD-related benefits are relatively balanced between Generic (e.g. real-time analysis and resource efficiency) and SCM-specific ones (e.g. tighten supply chain relationships and sensor supported processes in production and distribution). Furthermore, some applications and benefits are difficult to distinguish, e.g. real-time tracking can be seen as an application to monitor deliveries whereas it can be seen as a benefit in order to provide current status, measure efficiency, and offer the transportation history to customers in terms of quality assurance (e.g. assuring cold chain). Additionally, it is important to differentiate between SCM-specific ACBs and generic ones that also occur in other domains.

We also observed that in some instances BD act as an enabler of new ACBs while in other instances BD enhances the existing ones. This is important especially with regards to SCM-specific BD-enabled ACBs because new applications and capabilities are possible, yet the required skill set is not available. Examples of new applications include real-time applications (e.g. monitoring and tracking), supply chain wide applications (e.g. virtual collaboration and social media analysis), simulations, and predictive and advanced analytics due to the instant data capturing, transmission, and analytical processing capabilities. The existing applications could also benefit from BD due to more comprehensive insights (e.g. supplier negotiations, efficiency measurement, and product lifecycle management). At the same time BD is found to create additional complexity due to issues related to data privacy, quality, and access.

Finally, many of the observed challenges turned out to be generic in nature rather than SCM-specific. This is likely to be a reflection of the current emerging nature of BD. As BD maturity grows across all industry sectors, one could expect new SCM-specific applications as well as new challenges and opportunities that need to be investigated through future research.

Conclusions, Limitations and Outlook

The aim of this literature review was to demonstrate a possible framework that identifies and structures the main applications, challenges and benefits of Big Data in Supply Chain Management, including both SCM-specific and generic ones investigated in the field of Business Intelligence and Analytics but applicable to SCM. The framework could be used to provide a direction for further research including more in-depth studies of specific applications and the associated challenges and benefits in a particular organizational context. Such studies would lead to design of a more comprehensive framework that could be used by companies to identify new BD applications suitable for their context, recognize real and potential benefits and raise their awareness of the associated challenges.

Our literature review was limited to research publications only. Although comprehensive, such a review still remains limited, due to a very dynamic nature of BD-related research. We did not consider current industry publications that are likely to offer more up-to-date BD-applications in SCM. Our future research includes an in-depth analysis of cross-industry trends of BD in SCM using various industry sources. We are currently conducting industry-specific research of BD in SCM in automotive industry and healthcare

REFERENCES


