

Big data analytics for supply chain risk management: research opportunities at process crossroads

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Abstract

Purpose: The purpose of this study is to map current knowledge on big data analytics (BDA) for supply chain risk management (SCRM) while providing future research needs.

Design/methodology/approach: the research team systematically reviewed 53 articles published between 2015 and 2021 and further contrasted the synthesis of these articles with four in-depth interviews with BDA startups that provider solutions for SCRM.

Findings: The analysis is framed in three perspectives. First, supply chain visibility - i.e., the number of tiers in the solutions. Second, BDA analytical approach - descriptive, prescriptive, or predictive approaches. Third, the SCRM processes from risk monitoring to risk optimization. The study underlines that the forefront of innovation lies in multi-tiered, multi-directional solutions based on prescriptive BDA to support risk response and optimization (SCRM). In addition, we show that research on these innovations is scant thus offering an important avenue for future studies.

Originality: This study makes relevant contributions to the field. We offer a theoretical framework that highlights the key relationships between supply chain visibility, BDA approaches and SCRM processes. Despite being at forefront of the innovation frontier, startups are still an under-explored agent. In times of major disruptions such as covid-19 and the emergence of a plethora of new technologies reshape businesses dynamically, future studies should map the key role of such actors to the advancement of SCRM.

Keywords: Big data analytics, supply chain risk management, startups, literature review

Paper type: Literature review

1. Introduction

Since the 1950s, research has looked at the analytical treatment of information, but only in the last decade its application as a driver of performance and as support for information flow was better understood (Chen *et al.*, 2012). Today, it became almost mandatory that firms develop their capacity to collect information, analyze data and gather knowledge to support decision-making (Sanders, 2016). The large amount of data available has led to the term Big Data Analytics (BDA) to represent the set of new techniques to manage large volumes of data. BDA could be defined as a field of information science that brings together how to capture, storage, organize, process, analyze, disseminate, and manage

data and information in high volume, elevated variety and transacted in high speed (Chen *et al.*, 2012; Sanders, 2016).

Among many applications of BDA, one of critical relevance and yet under-researched is supply chain risk management (SCRM). SCRM is “*an inter-organisational collaborative endeavour utilising quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain*” (Ho *et al.*, 2015 p. 6). Large amounts of data can be organized, structured and analyzed to support supply chain management (SCM) (McAfee and Brynjolfsson, 2012). More importantly, BDA can help scanning the business competitive environment to minimize supply chain risks.

The International Data Corporation (MacGillivray and Reinsel, 2019) forecasts that by 2025 the number of devices connected to the internet will reach 41.6 billion, while generating 80 zettabytes of data per year. The recent the rise of environmental complexity (Chen *et al.*, 2016) and the availability of new technology (Chen *et al.*, 2012) have allowed firms to manage an exponential volume and variety of data sources and types. In addition, technology has allowed handling such data in a much faster pace, as well as including unstructured information in data analysis (Chen *et al.*, 2016; Sanders, 2016). Mastering the analytical capacity to analyze and to make sense of a large amount of data in a dynamic environment has become a valuable capability. Such capability is labelled by many authors as the biggest competitive differential for the years to come (Waller and Fawcett, 2013; Fawcett and Waller, 2014; Chen *et al.* 2016; Richey *et al.*, 2016; Sanders, 2016; Matthias *et al.*, 2017).

If initial exemplars of BDA were concentrated in firms’ internal data (Matthias *et al.*, 2017), the covid-19 pandemic has raised the importance of BDA for SCRM, and yet, this is an under-researched topic, despite a peak of attention since March 2020. Research after covid-19 has raised attention to the potential of BDA to improve supply chain visibility and responsiveness to such disruptions (Bag *et al.*, 2021; Belhadi *et al.*, 2021; Zouari *et al.*, 2020). There is a need to offer structured to such discussion to advance the field.

It is important to note that given the BDA radical depart from traditional methods, current models for SCRM might have become obsolete (Kai Chan *et al.*, 2016). Most of these models presupposed the formalization of input and output structures that are somewhat prearranged, which clashes with the dynamic reality and the availability of techniques to analyze unstructured data. Effective models need to allow real time

revisions, which can be hard to be done without adequate technological support (Kai Chan *et al.*, 2016; Choi *et al.*, 2017).

In an increasingly complex world, expose to threats such as covid-19, firms need to master tools that allow monitoring, rapid exchange of information and effective action to prevent and mitigate risks (Mani *et al.*, 2017; Kai Chan *et al.*, 2016; Choi *et al.*, 2017). BDA tooling tended to be of great relevance in this scenario. Mani *et al.* (2017), for example, showed how BDA could be used to monitor and treat actions of distributors in India to avoid potential social and environmental impact. According to Wang *et al.* (2016), BDA technology had the potential of improving managerial understanding about changes and reflexes in supply chain risks. Monitoring social media for example might also help firms in SCRM.

According to Hazen *et al.* (2016) and Mani *et al.* (2017), the application of BDA could improve traceability throughout the supply chain, reducing vulnerability. In a survey with 531 SCM professionals, Schoenherr and Speier-Pero (2015) found that the greatest benefit of BDA was related to decision-making capacity due to a more strategic perspective. In addition, professionals with experience in BDA tools and predictive analytics rated higher the relevance of BDA to SCRM. Choi *et al.* (2017) argued that the use of BDA had the potential to provide managers real-time qualified information that allow course correction and shorter response times. BDA includes tools such as data mining, text mining, machine learning, radio-frequency identification, and soft sensors to make processes safer and more responsive to risks and disruptions.

Despite all discussed examples, research on the potential of BDA to SCRM has been scarce. The present study has the objective of better understanding the BDA influence on SCRM processes through a systematic literature review contrasted with in-depth interviews with BDA startups. This article contributes to the field by answering the research questions (RQ):

RQ1: What is the state-of-the-art of research on BDA applications to SCRM processes?

RQ2: How can we advance knowledge on how BDA can support SCRM processes?

Our study offers a robust revision of the literature contrasted with interview with startups and concludes with a theoretical framework that captures the relationships between BDA and SCRM while underlining the key areas for future research.

The remainder of this article is structured as follows. First, the study presents the research methodology and the analytical framework that guides the literature review and

the interview analysis. Second, the literature review is presented descriptively and synthetically. Third, the analysis of the interviews is presented. Fourth, both parts of the analysis are combined into a proposed theoretical framework and finally study limitations and conclusions are presented while offering directions for future research.

2. Methodology

The analytical phase of this article is structured in two key parts. In first stage, a systematic literature review has been performed, analyzing the main dimensions that relate BDA to the SCRM processes. In the second stage, the authors conducted interviews with BDA startups to contrast the field maturity against the innovation frontier represented by implementations by these solution providers.

2.1. Systematic review of the literature

The data search was conducted in five relevant scientific databases: EBSCO, Emerald, ProQuest, Science Direct and Web of Science, in May 2019 and again in Feb 2022 (numbers were combined in the steps below). The search query: "supply chain" and "risk" and ("big data" or "data science") was aimed at capturing articles that related BDA and SCRM. In each database, the authors had defined some criteria for the selection of studies: (i) articles published in scientific journals; (ii) with full texts available; (iii) peer-reviewed by academics; (iv) and written in the English language. The search resulted in 564 articles.

As a second step, the main author read the abstracts, introduction, and conclusion of all 564 articles to verify match between the studies and the research objective. At this stage, the sample was reduced to 162 articles. As examples of exclusions, some articles did mention BDA's potential to SCM without a properly addressing the issue, other articles did mention supply chain risks, but did not cover SCRM processes.

At the third step, these 162 articles were read in full to verify which articles were focused on empirical efforts to establish relation between BDA and SCRM. In this process, some articles were excluded for two main reasons: (i) theoretical articles, and (ii) articles that did not actually discuss BDA and SCRM but were focused on one of the two concepts while mentioning the other one briefly. At this stage the sample was reduced to 50 articles.

At a fourth step, the detailed analysis of these 50 articles led to the addition of three articles using the snowballing technique. Figure 1 summarizes the above-described research steps.

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Topic novelty is exposed by the fact that the first work relating BDA and SCRM was developed in 2015 by Schoenherr and Speier-Pero (2015) in the *Journal of Business Logistics* carrying the title “*Data Science, Predictive Analytics, and Big Data in Supply Chain Management: Current State and Future Potential*”. Most articles lie within the operations and SCM field. The *International Journal of Logistics Management* was the Top 1 with five articles. However, it is possible to notice high dispersion across journals and publication in journals from the information systems and technology field.

In terms of empirical context, most articles analyzed the Asian context (26 articles), followed by Europe and North America (14 and 9 articles respectively). The African continent was studied in four articles while Oceania and Latin America in only one article each. Multi-continent data collection was identified in four articles (Chen *et al.*, 2016; Bienhaus and Haddud, 2018; Festa *et al.*, 2018; Thöni *et al.*, 2018).

In terms of industry sector, once again high dispersion. 11 articles took a multi-sectorial perspective. The agribusiness and automotive were the sectors with more than three articles (ten and five articles respectively). This fact is probably related to the high potential issues and risk of supply chain disruptions such as large quantity of suppliers, global logistics environment, road accidents problems, diseases, climate conditions, safety, and sanitary legislations (Mani *et al.*, 2017; Jayashankar *et al.*, 2018; Elavarasan *et al.*, 2018).

In terms of firm size, most studies focused on large firms (38%). 15 articles explored all sizes and only six articles focused on small and medium enterprises (SMEs). SMEs have their own barriers such as limited access to capital and qualified people (O’Connor and Kelly, 2017).

In terms of theoretical lenses, it is noteworthy that 50% of the articles did not adopt any theoretical framework to ground their studies. Within those that explicitly adopted a theoretical lens, half of them opted for theory lenses focused on competitive advantage: 17 studies (resource-based view in 10 articles and the spin-offs dynamic capabilities in five articles and knowledge-based view in two articles). This aspect denotes the view of BDA as a relevant capability for generating competitive advantage. Theories related to information systems such as information processing theory appeared less frequently (five articles). Other popular lenses included contingency theory (four articles) and

technology-organization-environment (three articles), and isolated uses include institutional theory, transaction cost economics, normal accident theory and game theory.

The articles utilized a wide range of research methods. It was possible to observe more diversity of methods in quantitative methodologies. Survey was the most utilized in these articles (15 articles), and it is clear that this method has become more common in recent years, with ten of these 15 studies being published in 2020 and 2021. Other quantitative methods include clustering with secondary data agriculture (Majumdar *et al.*, 2017), Markov framework with public data about traffic (Mehmood *et al.*, 2017), scenario analysis (Mehmood *et al.*, 2017; Zhao *et al.*, 2017), and prototyping for ranking suppliers (Yang and Liu, 2018). Qualitative methods covered mostly case studies (11 articles), Delphi analysis (five articles) and interviews with experts (five articles).

Appendix A provides the full list of articles alongside their classification.

2.2. Interviews with BDA startups

The literature review revealed a lack of discussion regarding more advanced elements of both BDA (i.e., the prescriptive approach) and the SCRM processes (namely, risk response, planning and optimization). In order to enhance comprehension of the phenomena, the authors conducted interviews with Brazilian BDA startups that are currently offering solutions combining these advanced elements of BDA and SCRM.

The choice of startups is grounded exactly on the fact that one single startup engages with multiple firms in multiple industry sectors thus each interview can represent more broadly what happens at the innovation front in the market.

The choice of the Brazilian market was especially for two reasons: (i) despite being one of the ten largest economies in the world, Brazil is not well represented in studies that relate BDA and SCRM, as will be verified through the literature review; (ii) Brazil is a country with continental dimensions, large urban areas, high variety of reliefs and low logistics infrastructure (Worldbank, 2018) which offers a high diversity of risk to be exploited by providers of technological solutions.

Twelve startups were invited to participate in this article. Four accepted to participate. To better understand the relationship between BDA and SCRM, the authors carried out an investigation with startups that applied BDA technologies for SCRM proposes to understand their potential and possibilities. Four in-depth interviews were conducted with Brazilian startups. Interviews were conducted in October 2021, each lasting between 40 and 90 minutes. Further clarification of interview answers were conducted via e-mail

during October-November. These interviews were complemented with information collected on the startups' websites, social media (Instagram, Facebook, LinkedIn, and YouTube), as well as articles in newspapers and magazines. Table 1 summarizes the key characteristics of the four BDA startups.

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3. Part 1: Synthesis of the literature

3.1. BDA and supply chain visibility

Table 2 presents the definitions of the BDA process stages – namely data collection, data preparation, data integration, data processing, data analysis and data visualization – alongside how many articles address each stage.

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It must be noted that data analysis was present in 100% of the sample. Alongside data analysis, data processing comes second, while on the other extreme less attention is paid to data visualization. The early steps of BDA are key to ensure data accuracy (Wu and Chaipiyaphan, 2019). And data processing is indeed at the core of BDA, and research has exposed companies overall limited capacity to process information and the urge to focus data analysis to produce better results (Matthias *et al.*, 2017). Yet, data visualization is the last step that is critical to drive managerial action. Zhu *et al.* (2018) noted that effective BDA derives not only from effective data collection but also do rapid processing, low level of error, and the quality of data visualization. Effective data visualization is a core driver of supply chain visibility (Richey *et al.*, 2016; Verma and Bhattacharyya, 2017; Russell and Swanson, 2018).

Barratt and Oke (2007) posits that sharing information with external supply chain linkages could have a significant impact in firm efficiency and a potential impact in competitiveness. They define supply chain (SC) visibility as “*the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit*” (Barratt and Oke, 2007 p. 1218). SC visibility is a challenge in both directions – both upstream and downstream in the supply chains (Sodhi and Tang, 2019). SC visibility at both intra-firm and inter-firm levels can improve responsiveness, planning capacity and decision making

(Barratt and Barratt, 2011), as well as flexibility and propensity to innovate (Caridi *et al.*, 2013). An end-to-end BDA implementation that starts with data collection and data preparation and ends with data visualization can improve SC visibility by not only improving the speed of information flow and data processing, but also data traceability and disclosure (Caridi *et al.*, 2013).

BDA can drive SC visibility and make it a decisive tool to control and monitor the supply chain supporting SC planning and performance (Richey *et al.*, 2016). The use of BDA tools to drive SC visibility allows real-time SC management as well as to rapidly respond to potential risks in the supply chain (Bienhaus and Haddud, 2018). Therefore BDA-driven SC visibility goes beyond a tool for disclosure and advances towards building flexibility and responsiveness for risk management (Blackhurst *et al.*, 2005). SC visibility permits agents to align responsibilities and nudges firms to work in a fairer and transparent manner (Bienhaus and Haddud, 2018).

Marques (2019) and Marques *et al.* (2020) offer a typology for supply chain linkages and the relevance to expand the firm visibility and relationship beyond the first-tier, vertical and unilateral perspective. They present three dimensions of supply chain linkages: (i) vertical ties, between a firm and your supplier; (ii) horizontal ties, between competitors – main-firm with main-firm or supplier with supplier, for example, and (iii) diagonal ties, with firms that develop a complementary activity in the supply chain, as regulatory agencies, and non-governmental organizations. Such ties could be established forward or backward along the supply chain – and the analysis of such ties can help map the extent that BDA is used to drive SC visibility.

A majority of 48 of 53 articles were focused only on the main firm. The exceptions are described below (*in chronological order*):

- Wu *et al.* (2017) explore first-tier visibility with the use of BDA in social media to prevent reputational risks in the supply chain of light-emitting diode
- Zhao *et al.* (2017) explore second-tier visibility with the use of BDA to optimize sustainability indicators in the supply chain of sanitary products
- Engelseth and Wang (2018) present the use of BDA in offshore maritime industry to increase second-tier transparency
- Engelseth *et al.* (2019) discuss a case study of banana supply from Costa Rica to Norway that emphasizes the limitations and challenges of BDA to SCM, and the key role of IoT as an enabler of an end-to-end supply chain perspective

- Belhadi et al. (2021) provides insights into the impact of the covid-19 outbreak on the automobile and airline supply chain. They emphasize the role of BDA in providing real-time information to overcome the challenges posed by covid-19.

In the five articles cited above, the authors cover different facts of BDA – namely reputation management, sustainability, transparency, and responsiveness, but all limited to vertical ties. Horizontal ties with competitors and diagonal ties with non-traditional stakeholders such as academia, consultants, and other service companies were either absent or under-discussed in the mapped studies. This indicates a major open opportunity to map the extent that BDA can be used to engage with a broader supply network that reaches out beyond vertical ties to include competitors for example (Marques, 2019; Marques *et al.*, 2020). These striking results demonstrate the urgent need to explore BDA at the extended supply chain, and a gap of a relevant element for a more amplified understand his relationship with SCRM.

After tracing the link between BDA and SC visibility, we turn our attention to how SC visibility can support an effective SCRM, as noted by Dubey *et al.* (2018).

3.2. BDA and SCRM processes

BDA has been developed as a key support to managerial decision making. The study by Souza presents three approaches to develop SC analytics: (i) “*Descriptive analytics derives information from significant amounts of data and answers the question of what is happening*”; (ii) “*Predictive analytics in supply chains derives demand forecasts from past data and answers the question of what will be happening*”; and (iii) “*Prescriptive analytics derives decision recommendations based on descriptive and predictive analytics models and mathematical optimization models. It answers the question of what should be happening*” (2014 p. 596). *Descriptive analytics* focuses on ex-post analysis, and it is typically applied for monitoring, reporting and dashboards activities. *Predictive analytics* entails producing models that help predict the future, detecting patterns in data and generating forecast. Finally, *prescriptive analytics* can support proactive control of processes based on simulation and optimization tools that drive flexibility and responsiveness (Brintrup *et al.*, 2019; Jebble *et al.*, 2018; Krumeich *et al.*, 2015).

All three approaches to BDA can support SCRM by improving SC visibility and responsiveness thus helping to trace the roots of disruptions and observe disruption propagation and driving decision making and stabilization actions (Zouari *et al.*, 2020).

Manuj and Mentzer (2008) propose to implement SCRM in five processes: (a) risk identification, (b) risk assessment and evaluation, (c) selection of appropriate risk management, (d) implementation of SCRM strategies and (e) risk mitigation. Ho *et al.* (2015) presented a similar characterization, having as identical phases risk identification, risk assessment, and risk mitigation, while adding risk monitoring.

Table 3 provides a map of how the articles have addressed the SCRM processes side-by-side with the three BDA approaches defined above.

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It stands out that the large majority of articles in the sample included elements of descriptive analytics (48 out of 53), while 58% of articles (31 out of 53) presents some considerations related to BDA capability to predict events to subsidize SCRM. Only, 17% of articles (nine studies) presented any discussion about prescription power of BDA applied to SCRM.

Most studies are concentrated in the use of *descriptive analytics* to drive risk monitoring, risk control and risk mitigation, in line with definitions. This share of studies addresses the question ‘*what is happening?*’ (Souza, 2014) as BDA can help mapping the SC and inform management improving monitoring and control (Chen *et al.*, 2016, Wu *et al.*, 2017). Descriptive analytics control over external sources of risk, which is essential to minimize SC disruption (Olson and Wu, 2010). However, descriptive analytics offers limited support to further stages of SCRM such as risk planning and risk optimization, as such processes demand foresight tools to discuss the future.

A good parcel of studies moves forward to include *predictive analytics*, where there is dialogue with risk response, risk planning and risk optimization. Risk response is an essential part of SCRM and often a weak link (Zhang and Fan, 2014). Predictive analytics can support all SCRM processes with statistical analysis and forecasting. Statistical modeling is a consolidated field of knowledge and here, what BDA does is to expand significantly the dataset size, offering more capacity, variety, and volume to present more possibilities to foresee ‘*what will be happening*’ rather than simply what has happened (Souza, 2014).

A minority covers *prescriptive analytics* and its impact to SCRM at all stages. This approach is particularly useful for the last stages of SCRM – risk planning and optimization. Bandaly *et al.* (2012) state that the quality of the risk planning is a direct

consequence of the firm's simulation capabilities. Rockafellar and Uryasev (2013) state that the use of sophisticated statistical models is essential for optimizing risk, helping firms to correct routes and anticipate potential problems. Prescriptive analytics builds on predictions to take action to move towards a more desirable state. Such tools can forecast volatility of traded goods in price and volumes or use traffic data to anticipate logistic disruptions and take prescriptive action to set alternative logistic routes (Brintrup *et al.*, 2019). Such approaches support answering the question '*what should be happening?*'.

4. Part 2: Synthesis of the interviews

The interview analysis with BDA startups revealed both similarities and key differences when compared to the literature synthesis. Overall, there is again a prevalence of descriptive analytics. Yet, the startups are engaging in multiple types of ties and they exhibit a more nuanced approach to descriptive vs. predictive vs. prescriptive approaches. A summary is presented in Table 4.

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4.1. BDA and supply chain visibility

Delta offers the narrowest SC visibility. The focus on fraud identification makes the startup acts only vertically with first-tier interactions with suppliers and customers. Alfa, Beta and Omega work with data on different tiers of the SC, but they differ in terms of the breadth of SC visibility.

Beta works mainly with vertical relationships with suppliers, given the nature of the solution to support SCM. *"When you are talking about negotiating with a supplier, we are closing the contract, the supplier has to inform all direct and indirect service providers that will participate in that contract. So, this is all registered in the system and if the client has an approval process, this supplier has to be approved too"*. (Beta).

Omega and Alfa work with a broader of data types, and a wider range of SC actors, such as competitors, regulatory agencies, non-governmental organizations, and solution providers, which would characterize horizontal and diagonal relationships. *"I can look at tiers of the chain, 1, 2, 3, 4, 5, 10 and then the facility of use, in this case the technology can cover any player that makes up the chain, and I'll bring data for it."* (Alfa).

Overall startups still indicate that their customers are still resistant to integrating with SC links beyond direct tiers, even if that would lead to better SC visibility. *"There is a lot*

of resistance. As we talked about the other day, there are many mechanisms for restricting access within the contract itself, confidentiality clauses. We are not opposed to any kind of restriction. We know that there are larger companies that demand it. There are legal issues involved, so there are, maybe, some kind of resistance at first, but even our platform proposal makes this sharing essential for the best use of the product and service” (Omega). The resistance to share information and engage with a wider set of actors in the SC is a long-lasting problem that has hindered demand and inventory planning (Frohlich and Westbrook, 2001), and now it still hinders BDA full potential. This problem will be reflected in the next section on SCRM.

4.2. BDA and SCRM processes

Although most startups emphasize the descriptive approach that maps what has happened – alongside its application to risk monitoring, risk mitigation and risk control. Alfa has high speed data processing and high level of automation, that it applies for pattern recognition features that allow risk response actions by its clients. Delta utilizes his great integration capacity to visualize some possibilities of optimization, but this process is not frequent and semi-autonomous, what reduces its potential to quickly influence clients risk management.

Omega has a set of data analysis features that can support predictive and prescriptive approaches. This aligns to some extent to the literature review but at the same time it shows how startups are moving faster than firms on average and the potential for incumbent firms to explore connections with such dynamic companies to advance towards more complex uses of BDA.

Omega’s unique features offer the possibility of simulation and scenario planning based on BDA. The prediction capacity amplified by BDA can improve SCRM in ways that have not been previously mapped in the literature. For example, the BDA solution helps identifying emerging variables that were not previously considered in the risk management process, evolving data analysis in a dynamic manner. Such a dynamic revision of forecasting models supports predictive/prescriptive analytics and in turn improve risk optimization. Moreover, this is done at a multi-tier level, enhancing the firm’s capacity to anticipate emerging risks in the supply chain.

5. Proposed theoretical framework: BDA for SCRM

The study exposes a lack of literature advancing beyond single-firm data analysis, which clashes with what SCRM is supposed to be and with what BDA can offer. The gap is enhanced when contrasted with BDA startup current solutions. Table 5 offers a comparison between the literature and the startup interviews. The table exposes that while the literature is over concentrated on preliminary steps of both BDA and SCRM, the startups show a more balanced adoption of multi-tier solutions, advanced BDA approaches – such as prescriptive and predictive – as well as more complex steps of the SCRM full process cycle – thus incorporating risk response, planning and optimization.

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The comparison highlights the lack of focus on prescriptive analytics. In other words, current literature is over-focused on descriptive tools that support the observation of predetermined issues. Such emphasis is more suited for a risk mitigation approach than for a risk planning/optimization on the long-term (Jeble *et al.*, 2018). Nevertheless, there are startups out there already offering prescriptive tools, and fighting corporate resistance to novelty. Academia can sure support this endeavor.

In Figure 2, we offer a theoretical framework for effective use of BDA for SCRM that underlines the following three key conclusions.

First, SC visibility needs to advance to multi-tier monitoring and multi-directional interactions with competitors and other actors such as media and NGOs. SC visibility has been studied as a key driver of competitiveness (Barratt & Oke, 2007; Barratt & Barratt, 2011). Most recently, SC visibility – both upstream and downstream – has also become a driver of transparency and corporate responsibility (Sodhi and Tang, 2019). BDA can improve SC visibility at multiple SC tiers to support corporate reputation management (Wu *et al.*, 2017). SC visibility is sought to improve the firm's flexibility and propensity to innovate (Caridi *et al.*, 2013). Such flexibility is key to SCRM and responsiveness to risk and disruption. In order to achieve such flexibility, the firm must implement BDA based on a wider range of data sources resulting from multi-tier and multi-directional ties (Engelseth and Wang, 2018; Engelseth *et al.*, 2019).

Second, improved SC visibility will support the identification of not only ordinary risks, but also extra-ordinary risks. The chances of identification of disruptions improve, thus supporting pre-emptive action (Zhu *et al.*, 2018). One key take-away from the covid-

19 is the need to develop capabilities of SCRM that anticipate major disruptions or quickly react to them while assessing their consequences. Real-time visibility enabled by BDA can reduce forecasting error, improve data visualization, and speed up the cycles of SCRM reducing the impact of similar future crisis (Belhadi *et al.*, 2021; Bienhaus and Haddud, 2018).

Third, only the evolution from descriptive to predictive and finally prescriptive analytics will support the full potential of BDA for risk optimization. Prescriptive analytics can support proactive simulation and optimization practices that improve responsiveness (Brintrup *et al.*, 2019; Jeble *et al.*, 2018; Krumeich *et al.*, 2015). Prescriptive analytics anticipate to problems and drive action to move towards a more desirable state. Such tools can forecast volatility of volumes, prices, traffic and support logistics and supply chain management in ways not available prior to BDA (Brintrup *et al.*, 2019). Ultimately, prescriptive analytics operationalize BDA's full potential to improve responsiveness, resilience, and sustainability of supply networks

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6. Conclusions

6.1. Contributions to theory

This study offers a new framework to understand how BDA can support SCRM, while exposing gaps in SC visibility, the prevalence of a descriptive approach to BDA, and reduced discussion of risk optimization in SCRM. We show that these gaps can be simultaneously addressed by engaging with startups at the fore front of technology development. Such startups already offer BDA solutions that advance towards multi-tier and multi-directional data sources and prescriptive tools that support the key steps of data analysis and data visualization (Engelseth and Wang, 2018; Engelseth *et al.*, 2019).

While startups already have technology available, there is a cry for help as corporate resistance to novelty prevents these new technologies to be fully tested. Academia can play a key bridging role in exposing the problems with a short-sighted view of direct links in the supply chain as well as the limits of descriptive BDA. Advancing from “what has happened”, to “what will”, and “what should” is key to open up the full potential of BDA for SCRM (Souza, 2014). There is thus room for researchers looking at the ‘why’ question in more detail, that is, digging deeper into sources of corporate resistance and finding

ways to highlight the benefits of multi-tier, multi-directional supply chain data sided with prescriptive tools to risk optimization.

The recent covid-19 outbreak has highlighted the potential of BDA (all fronts - descriptive analytics, predictive analytics, and prescriptive analytics) to support SCRM. BDA allows firms to first, manage huge quantities of data which otherwise are not manageable; second, improve SC visibility by tracking suppliers in real time, which can help to reduce risks; third, to obtain quick and reliable answers in time, compared to traditional business process solutions (Bag *et al.*, 2021; Belhadi *et al.*, 2021). Our study underline what are the key processes that need to be in place to explore the full potential of BDA for SCRM.

Fully fledged BDA applied to SCRM can have great impact to firms both financial results and corporate image (Wu *et al.*, 2017). BDA can be a useful tool to properly explore information and broaden the firm's view of the external environment, in real-time, anticipating risks and making risk mitigation and response more assertive, and effective. Academia can play a key role in deploying capabilities in quantitative methods to support front-runners exploring predictive and prescriptive approaches to BDA.

6.2. Contributions to practice

Our work has implications for startup. For a startup's innovation to be successfully accepted by the market, the adequate design of procedural, technological, and functional requirements of their product is key. An adequate design ensures greater assertiveness and effectiveness when assessing the customer market. Our theoretical framework details key processes and performance to be considered in the procedural, technological, and functional elements of innovative BDA solutions, which can raise startup success rate, particularly when addressing the risk management agenda.

In addition, our framework presents a structured way to conduct the 'onboarding' process of a BDA tool in a customer. Onboarding is the process that startups use to help their customers absorb the new tool, which is essential for the success rate. The presented framework offers direction for customer success teams that are responsible for ensuring onboarding and generating return on investment for the customers.

This study has also implications for incumbent firms. The framework demonstrates in a structured way how the process and technology can be aligned to improve SCRM and resilience in the supply chain. This offers a guide for incumbent firms to design and assess CAPEX projects for the implementation of BDA for risk management, both

internally generated and in collaboration with startups. The guide is particularly useful for industry segments characterized by long supply chains and more sensitive to external disruptions.

6.3. Limitations and future research agenda

This work has two main limitations. The first one is the selection criteria of articles. Restricting the filter to peer review articles ensures reliability but reduces the breadth of studies covered. This research only reviewed English written articles and there is relevant academic work in other languages. Nevertheless, the authors checked all databases to carefully ensure that the most significant journals of the field of operations and SCM were covered. The second limitation is related to the interview part that was restricted to four prominent BDA startups in Brazil. Other startups and other countries could reveal a more complete array of uses and offered solutions. Yet, the interviews in this study were enough to expose the gap between academia and practice and most probably broadening the scope would only enlarge this gap as new startups emerging as we speak will soon offer new solutions to BDA application to SCRM.

This research unveils interesting avenues for future research to advance our understanding of how BDA can support SCRM. Next, we highlight the key ones.

Geographic amplitude. The first aspect that draws attention limited research covering the Latin American and African contexts. These regions include countries among the ten largest economies in the world (Brazil, Mexico, Argentina, South Africa, Nigeria) and many megacities such as São Paulo, Mexico City, Buenos Aires, Lima, Bogotá, Caracas, Lagos, Cairo, Kinshasa, and Rio de Janeiro, all of which have over six million inhabitants. Brazil, for example, is the third country with the largest number of urban concentrations in the world, with 25 cities with more than 700 thousand inhabitants (United Nations, 2018). Such context offers complexity and uncertainty ideal to be tackled by BDA, especially related to SCRM.

Level of analysis. Most publications focus only at the single-firm level of analysis. This aspect has been widely discussed in other systematic literature reviews (Fosso Wamba *et al.*, 2015; Ho *et al.*, 2015; Touboulic and Walker; 2015), and constitutes a relevant gap. The expanded level of analysis may bring different nuances about the practice and effectiveness of BDA for enhancing SCRM. SC visibility has been already framed as key to manage supply chain risks (Bienhaus and Haddud, 2018). BDA projects that foster not only vertical ties, but also horizontal ties (co-coopetition) and diagonal ties

with non-traditional stakeholders can improve SC visibility, which in turn may lead to improved effectiveness of SCRM (Engelseth and Wang, 2018; Engelseth *et al.*, 2019).

Matching BDA and SCRM opportunities. Research has been over-concentrated in data gathering and control, alongside with descriptive BDA tools. Simultaneously moving the emphasis towards predictive/prescriptive BDA and data visualization/risk optimization techniques can fill a current gap in the literature and most importantly offer significant impact to both research and practice.

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