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Mobile supply chain management in the industry 4.0 era: An annotated bibliography and guide for future research

Abstract

Purpose – We identify avenues for future research in mobile supply chain management (mSCM) in the advent of Industry 4.0.

Design/methodology/approach – A Systematic Literature Review was used to identify, classify, and analyse current knowledge, identify trends, and propose recommendations for future research.

Findings – Other research fields, such as operations, production, industrial engineering, and computer science seem to have a head start in research into Industry 4.0. Several avenues are suggested for investigation under a IS lens.

Research limitations/implications – Despite the care taken in the Systematic Literature Review, the language (English), the selected keywords, and selected databases represent a natural limitation.

Practical implications – With Industry 4.0 at the top of the agenda of managers and countries, it is important to identify relevant research avenues.

Originality/value – A gap between the extant literature on mSCM and new concerns raised by Industry 4.0 is presented, and some research opportunities to close those gaps are proposed.

Keywords mSCM, Mobile supply chain management, Mobile technologies, Industry 4.0, Systematic literature review

Paper type Literature Review

INTRODUCTION

A fourth industrial revolution is currently taking place, shaping a future that will heavily rely on data acquisition and sharing throughout the supply chain (Brettel & Friederichsen, 2014; European Commission, 2016). This vision of interconnected business services, processes, and information systems (IS) is only possible due to exceptional technological developments, especially in mobile (Bharadwaj et al., 2013). Mobility is, thus, a top priority for the industrial supply chain (Eng, 2006; Brettel & Friederichsen, 2014; Scornavacca & Barnes, 2008). As noted by Mourtzis et al. (2016, p.4) "*the general set of supply chain problems are ideal candidates for mobile solutions*", leading to the emergence of mobile supply chain management (mSCM).In Industry 4.0, mobility and real-time integration are critical. We can find this evidence in scientific contributions pointing to the importance of mobile computing (Oesterreich & Teuteberg, 2016) and to the need of horizontal integration in collaborative networks and end-to-end digital integration across the supply chain (Brettel & Friederichsen, 2014). The European Institutions (Smit et al., 2016), the industry (Isaka et al., 2016), and multinational consulting companies (PwC, 2016) put real-time integration in decentralized supply chains at the top of the Industry 4.0 agenda. New challenges emerge from the use and adaptation of Industry 4.0 technologies and the decentralized business processes in the supply chain, which is at the core of the IS discipline (Paul, 2007) and enterprise information management publications (Dwivedi & Mustafee, 2010).

Oddly, while there have been solid contributions by the IS community to the topic of mSCM in the past, the major impacts that Industry 4.0 will have in this key area are currently understudied. In fact,

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despite the rising popularity of Industry 4.0 across the fields of operations, production, industrial engineering, and computer science, only recently did it capture the attention of IS researchers. The first IS journal article that we have found was published in 2014 (Lasi et al., 2014), and only in 2016 did we find a paper published in a top IS conference (according with the CORE 2014 conference ranking), namely by Hermann et al. (2016). With three papers in the period 2014-2016, Business & Information Systems Engineering (BISE) and HICSS are the leading IS outlets addressing this topic.

Meanwhile, researchers from other fields have been identifying developments in Industry 4.0 such as virtualizing the process- and supply-chain, ensuring supply chain flexibility, raising supply chain visibility, establishing collaborative networks, achieving end-to-end digital integration, and use of individualized traced data, while leveraging technologies and concepts less common in old supply chains, such as, for example, the Internet-of-Things (IoT) and services, and cloud computing (Brettel & Friederichsen, 2014).

In an effort to promote a wider study of mSCM in the context of the emerging Industry 4.0, this paper aims at identifying avenues for future research by the IS community.

We organized the remainder of the text as follows: in the next section we describe the research methodology, mainly consisting of a 4-phase systematic literature review. Then, we interpret the data, by classifying the papers according to their prevalent category, performing a full text content analysis, and looking for trends where data is missing (e.g. in industry 4.0-related issues). A series of avenues for future research in mSCM in the advent of Industry 4.0 are listed in the subsequent section, just before conclusions.

RESEARCH METHODOLOGY

To ensure a rigorous analysis of the extant literature and the traceability of our suggestions for new research avenues, we have resorted to a Systematic Literature Review. According to (Webster & Watson, 2002), systematic literature reviews analyse the past to prepare the future, uncovering the body of knowledge by identifying, evaluating, and interpreting research [primary studies] that is relevant to a specific topic area (Kitchenham, 2004). They are essential for academics and for practitioners, as described by Tranfield et al. (2003, p.220), "*the aim of systematic review is to provide collective insights through theoretical synthesis into fields and sub-fields. For academics, the reviewing process increases methodological rigour. For practitioners/managers, systematic review helps develop a reliable knowledge base by accumulating knowledge from a range of studies*". Several researchers, for example Webster and Watson (2002) or Levy and Ellis (2006), have called for more systematic reviews in IS research, and there is specific guidance for IS researchers to conduct this type of studies.

Webster and Watson (2002) propose the concept-centric approach for classification of articles, suggest backward searches reviewing citations of relevant articles, and forward searches to identify the ones citing them. Kitchenham (2004) and Okoli and Schabram (2010) provide a detailed sequence of steps to conduct systematic reviews, namely to (1) identify the need for the research, (2) establish a review protocol, (3) search the literature, (4) study selection and screening, (5) assess quality, (6) extract and monitor data, (7) make a synthesis, and (8) write the review. Other authors, such as Levy and Ellis (2006), provide practical examples in the IS field on how to find valid IS sources and how to read, annotate, and present the literature review.

Three researchers participated in this study, which encompassed the review process of four phases depicted in figure 1.

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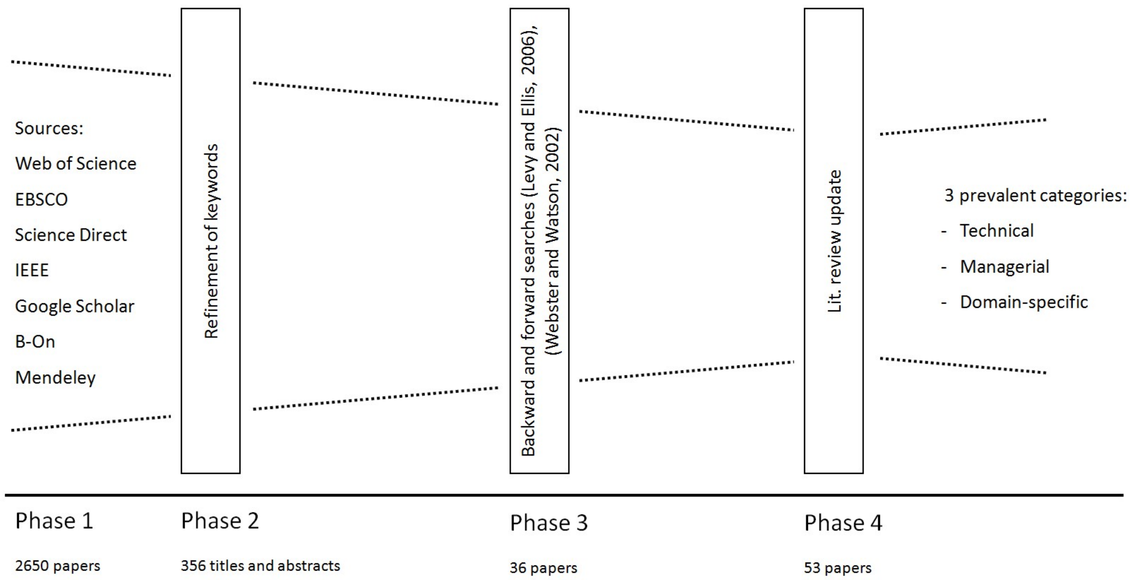

Figure 1. The 4 phases of the systematic literature review process.

Previous literature reviews conducted in the IS field support the importance of the phases presented in Figure 1 for the review process (Dwivedi et al., 2008; Mustafa Kamal & Irani, 2014), although different approaches can be used. In phase 1, one of the authors conducted a preliminary search for publications in English language addressing Supply Chain and Mobile Technologies in Web of Science, EBSCO, ScienceDirect, IEEE, Google Scholar, and Mendeley. The search space included journals and conferences, with no time restriction. Specific books were considered, for example, Sathyan et al. (2012) and Li (2006), even if not included in the literature coding, due to the variety of topics included in their work. Given the generic nature of the terms “supply chain management” (407000 matches obtained in Google Scholar in 13-05-2017) and “mobile technologies”, the search keywords were combined using operators to refine the sample (e.g. “information systems” + “supply chain” + “mobile technologies” with the 4330 matches in Google Scholar, dropping to 2650 if restricted to years more recent than 2012).

In phase 2, the initial insights were discussed by two researchers to decide on more precise keywords. We focused our search on the terms “mobile supply chain management” and “mSCM”, according to Eng (2006). There are differences in the results from each database. For example, Mendeley returns 10 papers for “mobile supply chain management”, however, Eng (2006) appears twice and Chan and Chong (2013) appear three times in that list. The same keyword sequence leads to 286 results in Google scholar (which partially covers other search engines), 43 in EBSCO, 9 in Web of Science, and 8 in ScienceDirect. Nevertheless, we found benefits in probing multiple sources of data because it (1) strengthened our evidences about the most relevant indexed publications, and (2) allowed us to evaluate the same contribution at distinct moments in time, contrasting the findings with previous reflections about the topic and other related documents. At this phase of the research, we screened 356 titles and abstracts that included mobile technologies for supply chain management.

In phase 3, backward and forward searches were performed for each of the 356 articles identified in phase 2, according to the guidelines provided by Levy and Ellis (2006) and Webster and Watson (2002). Backward searches included the sub-steps of backward references search, for example the work of Eng (2006) cited in Tomislav et al. (2014) and Chan and Chong (2013), backward authors search (e.g. Giaglis et al. (2002) and Giaglis et al. (2004)) and keywords (e.g. RFID is a popularly

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cited term in our sample). Forward searches included other articles that have cited the initial paper set and additional work published by identified authors.

Additionally, in this phase, we performed a content analysis of the full paper text, searching for specific technologies in the context of mSCM. For example, the combination "supply chain" + mobile + RFID + Smartphone + tablet, which returned 1890 matches in Google Scholar (1660 when restricting to years later than 2012). Examples of other combinations tested where "mobile supply chain management" + adoption + model (142 matches in 13-05-2016, 64 since 2012); "mSCM" + "mobile" + "supply chain" (80 matches, 33 since 2012); "information systems" + "mobile supply chain" (268 matches, 104 since 2012). In this phase, our inclusion criteria addressed the mobile technologies presented above and their possible integration in supply chain management (Mentzer et al., 2001; Eng, 2006). We used Mendeley to perform additional keyword search in the full text of the articles, with the aim of identifying if/how specific words were mentioned by the authors. For example, the term "cloud" appears in 5 of the initial sample of 36 papers (14%), however, only 2 of them (6%) focus on cloud in mSCM (Grzybowska et al., 2014; Srinivasan & Dey, 2014), the others merely mention the importance of the general concept.

At the end of the third phase of our systematic literature review we obtained a set of 36 publications that were tagged and annotated using the Mendeley free reference manager tool. Analysis of trends in the literature are important to identify opportunities for new contributions and understand the field under study (Avison et al., 2008). Therefore, we included chronological searches about technologies in mSCM. We aim at "*observing and understanding the past trends and extant patterns/themes (…) evaluating contributions, summarizing knowledge, thereby identifying limitations, implications and potential further research avenues to support the academic community in exploring research themes/patterns*" (Sivarajah et al., 2017). Our preliminary findings were discussed with colleagues from industry and presented to the academia during the <*removed for refereeing*> conference.

In phase 4, three researchers revisited and updated the literature review, which allowed us to revise the preliminary results, ensure consistency, and contrast their three perspectives during content analysis. We also included B-On in our search databases (67 matches in 13/05/2017). At the end of this final round we included seventeen new studies in our review, obtaining a total of 53 papers.

MAKING SENSE OF THE LITERATURE

Paper Classification

As recommended by Webster and Watson (2002), we classified the papers according to their most prevalent category, namely (a) Technical, (b) Managerial, and (c) Domain-specific. In the first category we included studies that describe the mobile technologies available for mSCM and their benefits/opportunities. Examples of mSCM technologies are RFID (Meydanoğlu & Klei, 2013), smartphones (Szymczak, 2013), and GPS (Giaglis et al., 2002). The second category of papers presents models and frameworks for mobility management, for example, to evaluate mSCM adoption (Rathore & Ilavarasan, 2014; Doolin & Ali, 2008) and the process of evolving mSCM in organizations (Basole, 2005; Pousttchi & Gumpp, 2005). Finally, we identified studies addressing specific domains of the economy (Nourbakhsh, 2012) or areas of activity (Lu et al., 2006), where authors discuss both, technical and managerial models, for selected activity sectors. Figure 2 presents the paper distribution according to the three identified categories of mSCM publications.

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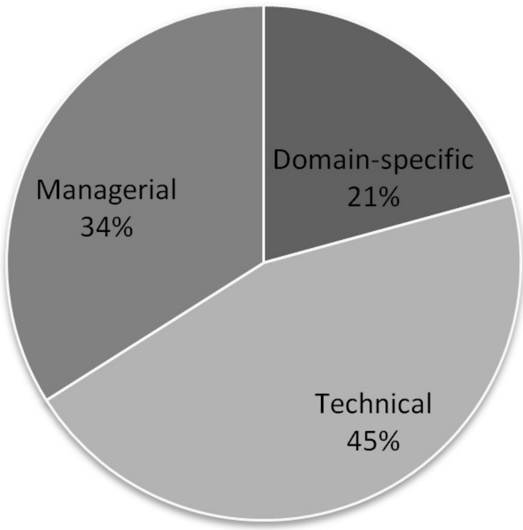

Figure 2. Distribution of the 53 mSCM papers across the 3 categories.

It is worth noting that nearly half of the analysed studies address technical aspects of mSCM. Despite that technical nature, conceptual studies are more frequently found (62%) when compared with the empirical ones (38%).

We performed a full text search analysis to identify specific technologies and platforms. The keyword "wireless" can be found in 38 of the 53 studies (72%), while smartphone/PDA/Tablet occur in 30 (57%), RFID in 28 (53%), and GPS and combinations of GPRS/3G/GSM in 30 (57%). Platforms such as ERP are mentioned in 21 of the selected papers (40%). Oddly, cloud was only mentioned in 12 (23%) of the papers, "Internet-of-things" in 12 (23%), and "augmented reality" in 2 (4%). However, when we deepen the analysis and exclude the papers that only make superficial mentions to the concepts (e.g. "cloud" is mentioned in 12 studies but only 3 of them include it in their contributions), then the results are considerably different as presented in figure 3.

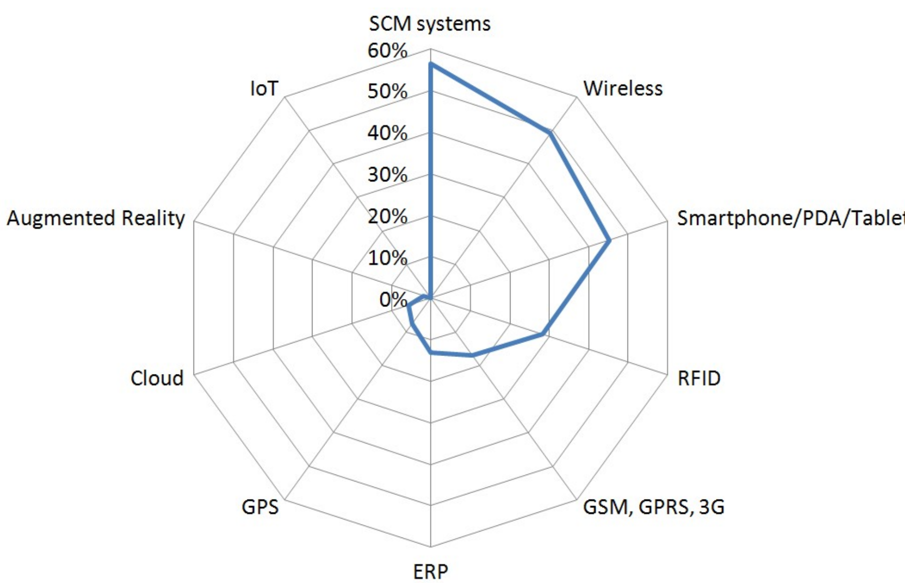

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Figure 3. Distribution of mSCM technologies in the 53 studies.

This type of radar charts have already been used in supply chain benchmarking studies (Colicchia et al., 2011), and are particularly useful for comparative analysis by providing a visualization of the selected technologies as a whole. The analysis highlights a focus on SCM systems, Wireless, Smartphone/PDA/Tablet, and RFID.

Content Analysis

In this subsection, we discuss the content of the papers classified in each of the three identified categories: (a) Technical, (b) Managerial, and (c) Domain-specific. Figure 4 summarizes the most relevant topics in each category.

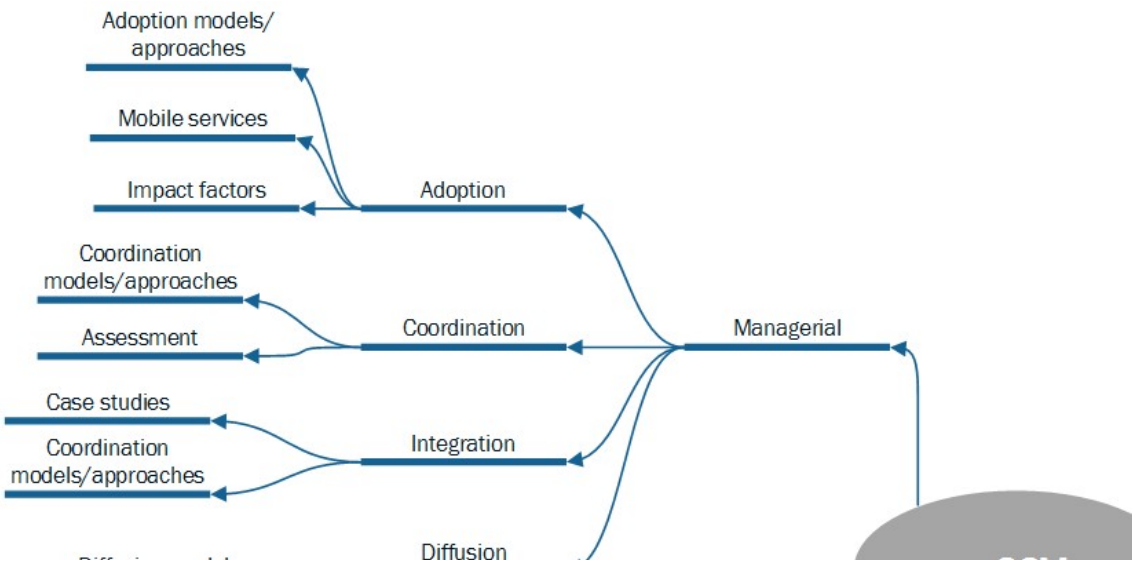

Figure 4. Major categories and related topics.

a) Technical

The technical outlook for mSCM can be found in studies such as Yuan et al. (2008), that present programming languages and standards (e.g. XML), mobile phone technologies (e.g. 3G and GPRS), and communication protocols such as WAP and Bluetooth. The authors propose a conceptual structure for an mSCM platform and conclude with examples for different activities of the supply chain, for example, mobile shipment and mobile sale. A solution to develop mSCM software agents is described by Kern and Braun (2006).

The potential of going mobile is transversal to all supply chain activities. There are examples of solutions for each activity of the value chain, as presented by Barnes (2002), which focused on the business-to-business interaction of the supply chain. Conversely, the review of technologies and future research proposals made by Siau and Shen (2002) concentrated on mobile commerce activities with customers and suppliers. The focus of business-to-consumer was also selected by Markova and Petkovska-Mircevska (2013) to explore the potential of social networks for mSCM.

There are examples internal and external to the organizational boundaries. Internal application cases are provided by Groger and Stach (2014), which present a dashboard for mobile manufacturing, accessible to shop floor workers and production supervisors, while Stefan and Kerins (2014) present a

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practical application of web services and PDA adoption for maintenance management processes. Examples external to the organization include the diffusion of mobile marketing and its success factors presented by Scharl et al. (2005), proposing a model for SMS advertising. Another case is presented by Grzybowska et al. (2014), who show how cloud computing and service oriented architecture (SOA) can assist mSCM implementation in freight and warehouse exchanges. A recent publication presented by Chandra and Grabis (2016) identifies that smart systems, mobile, and cloud technologies combined are key enablers of information sharing with the potential to create a new type of supply chain, merging the digital and physical flows.

RFID is a popular area of research in the scope of supply chain management. Mobile RFID is made possible by the use of mobile devices embedded with micro RFID readers, as presented by Meydanoğlu and Klei (2013). These authors discuss potential advantages of RFID in distinct SCM areas, including different supporting technologies for physical mobile interaction, such as NFC (Near Field Communication), 2D codes, and QR codes. There are opportunities to implement RFID in the supply chain, for example for traceability purposes (Lee & Park, 2008), but the costs are significant. The method developed by Irrenhauser and Reinhart (2014) allows the evaluation of economic viability of RFID implementations. Other authors, such as Miraldes et al. (2015), studied RFID and emergent technologies of augmented reality in mSCM. Big data produced in supply chains is growing, for example through the use of RFID technology (Zhong et al., 2015), however, its potential is not yet fully exploited, since it requires new tools to make it useful for decision making in supply chain management (Zhong et al., 2016).

There are several areas in the supply chain context where smartphones can be used. According to Szymczak (2013), examples include the two most usual applications of scanning bar codes and exchanging photos of products, but there is an increasing interest in adopting smartphones for proof-of-delivery signature, access to dashboards and specific reports, control machinery in industrial settings (Mathew et al., 2006), and social networking. Nevertheless, human-computer interaction is a major challenge in the use of these devices, and there are social aspects to take into consideration. For example, a study presented by Müller et al. (2012) suggests that, presently, the main use of tablets is for personal purposes. According to these authors, it is necessary to (1) improve application design for these devices, (2) conduct studies to promote an integrated experience across all types of devices, and (3) understand the social impact of using this type of devices.

Another perspective is the indoor *vs.* outdoor use of technology. Giaglis et al. (2002) present one of the few studies addressing indoor mobile positioning, and present a taxonomy for different indoor/outdoor positioning technologies, including Cell-ID, Time of Arrival (TOA), Observed Time Difference (OTD), GPS and A-GPS, Infrared sensors, Ultrasound technologies, Wireless LANs (WLANs), Bluetooth, RFID, and Indoor GPS. The authors include mSCM in the B2B solutions category and point to examples of goods tracking and continuous replenishment. In a later study, Giaglis et al. (2004) addressed logistics and vehicle routing. The authors classified relevant literature in the field of vehicle routing problem and propose an architecture for real-time vehicle management with mobile technologies, integrated with a decision support system.

Ruhi and Turel (2005) present a review and taxonomy of mobile technologies in different areas of the supply chain. It includes the internal supply chain (involving internal customers and suppliers), inbound logistics (supplier relations) and customer relations including outbound logistics, marketing, sales, and services. Examples are presented for the distinct areas and drivers (e.g. internal and external integration, globalization, data information management, new business processes, replace obsolete systems, and strategic cost management) and difficulties (e.g. interoperability between mobile devices and mobile standards). In spite of the technological focus, authors conclude that "*case studies investigating the undertakings of these organizations [implementing mSCM] and their experiences with different technologies can provide valuable insights for revising and improving the research exposition*" (p.14).

b) Managerial

Under a managerial lens, there are contributions for different phases of the mSCM lifecycle: adoption, coordination, integration, and diffusion. Eng (2006) examined three critical areas of SCM for successful implementation of mSCM, namely, competitive advantage, customer relationship management, and coordination and integration. The author argues that the likelihood of successful mSCM will be enhanced by (1) the adoption of a process approach to interact with other participants in the supply chain, (2) sharing resources, which can lead to an increase in trust and commitment, and (3) "*cross-functional knowledge of disparate supply chain functions and activities, because higher coordination and integration success in mSCM depends on embedded knowledge of systems*" (Eng, 2006, p.686).

- *Adoption*

Pan et al. (2013) propose a model for mSCM adoption. It is based on a survey involving 168 executives and managers in the retail industry. The authors conclude that pressures from other stakeholders in the supply chain have an influence in the adoption of mSCM. Top management support and long term relationships are two additional factors that can influence mSCM adoption intention. Shared workshops and training programs to communicate the strategy of the supply chain and shared projects "*may help built inter-organization trust and inter-organization dependence*" (p.184). The authors argue that "*although mobile-enabled supply chain management systems (mSCM) are still in the early development stages, they have the potential to elevate supply chain integration to a higher level beyond what the internet-enabled supply chain management systems (eSCM) have already provided*" (p.172). A contrasting perspective can be found in the cross case analysis presented by Doolin and Ali, (2008), suggesting that technological innovation and the information intensity of the company were the most important factors for mSCM adoption. These authors also highlight top management support, but partner influence was not so relevant in the selected cases (Doolin & Ali, 2008). Later, Chou et al. (2014) showed that firms with online services, economies of scale, and physical outlets are more likely to experience a transition to mobile retailing, innovating their service delivery with new market channels.

Pousttchi and Gumpp (2005) introduce the "Mobility-M" framework for application of mobile technologies at process level. The left pillar of the "M" includes mobile infrastructure, communication techniques, and devices to achieve mobile added value. The right pillar concerns the information added value with systems such as SCM, Customer Relationship Management (CRM), administration, operations, and Business Intelligence (BI). However, we are warned by Clemens et al. (2012, p.14) that the implementation of mobile devices in SCM "*requires thoughtful introspection with regards to fit and viability of a specific firm*".

Other authors focus on the main services provided by mobile technologies in the entire supply chain. For example, Li et al. (2010) suggest mobile data collection, location-based services, scheduling, voice calls, and information dissemination. There are distinct elements to consider for the mobile enterprise, for example the transition from non-mobile to mobile, the value, and best practices to transform the enterprise with mobile technologies (Li, 2006). A long term vision is required for that transformation and it starts with (1) the mobilization to use IS in mobile, continues with (2) the enhancements of mobile services and applications, (3) the reshaping of business models and strategies, and concludes with (4) the redefinition of new core competencies in the organization (Basole, 2005).

- *Coordination*

Soroor et al. (2009) present a model for a mobile real-time supply chain coordination system. The authors highlight limitations of deploying mobile communications for supply chain coordination from methodological, architectural, and technical viewpoints. Methodological perspective requires that information delivery should not be static and must take into consideration the change in people's context and supply network conditions that occur in mobile. To address the problem of uncertainty in

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customer demands, Li et al. (2008) propose an inventory-control model for mobile supply chain. Regarding architectural aspects, the authors mention the lack of integration between mobile applications and the organizational ICT infrastructure, and also inflexibility problems. According to the authors "*most of the commercially available mobile applications for use in real-time coordination of supply networks are designed primarily for internal off-line use*" (Soroor et al., 2009, p.637).

There is a lack of studies about mSCM coordination with technologies such as Semantic Web, Web Services (Jankowska et al., 2007), agents (Teuteberg & Ickerott, 2007), and context aware computing. Soroor et al. (2009) propose an Intelligent Wireless Web (IWW) model and present an implementation scenario. The model uses contextual information of the connected user to provide the relevant information, "*however, a key challenge is to link various technological enabling elements such as those discussed in this paper with methodological, cultural, social, and organizational aspects specific to supply network processes and firms*" (Tarokh & Soroor, 2006, p.36).

- *Integration*

According to the study conducted by Khare et al. (2012) with 197 retailers "*supply chain integration with suppliers and customers is done through extensive use of mobile networks*". mSCM integration may involve strategies of packaging customization, common use of equipments, or shared services, but information systems have an increasing impact in this field, for example with the knowledge of inventory, shared planning systems, and joint networks (Frohlich & Westbrook, 2001; Zha et al., 2008). Shah et al. (2002) studied inter-organizational information systems (IOIS) and proposed a matrix for SCM and IOIS alignment. The matrix includes four levels of SCM adoption, namely the arm's length level for simple exchange relationships (lowest level), Type I – short term relationship, Type II – long term relationship, and the most advanced Type III – coordination, when companies consider other firms as extensions of their own business. There are also four levels of IOIS adoption, starting with no electronic integration, then a sequence of low, medium, and high level of electronic integration between the business and the supply chain partners. Srinivasan and Dey (2014) used the potential of cloud computing for the integration of ERP and SCM systems, proposing a framework for electronic supply chain enabled by mobile technologies.

- *Diffusion*

A model to evaluate mSCM diffusion in manufacturing companies is presented by Chan and Chong (2013). These authors considered three phases of mSCM diffusion, namely (1) evaluation, (2) adoption, and finally (3) routinisation (Chan & Chong, 2013). The model was inspired on the technology–organisation–environment framework and innovation diffusion theory, including four main factors that affect mSCM diffusion: technological, organizational (internal to the company), environmental (company context), and inter-organizational relationships. More recently, Rathore and Ilavarasan (2014) conducted 14 interviews and 47 questionnaires in SMEs - Small and medium-sized enterprises operating in the automobile industry. The authors identified a group of factors that affect the intensity of mSCM adoption aligned with Chan and Chong (2013), namely technology-environment (e.g. competitive pressure), information quality (e.g. accuracy), organizational (e.g. top management support), and partners (e.g. mobile readiness). Moreover, the authors found that, in their sample, the most important motives to adopt mSCM are cost reduction, ease of use, improved partner coordination, and cooperation for new product development.

c) Domain-specific

There are studies addressing the use of mobile technologies in supply chains in specific business sectors, for example, the impact in healthcare service delivery (Free et al., 2013) and potential applications by pharmacies (Clauson et al., 2013). Nourbakhsh (2012) studied mobile adoption in construction, and identified key information requirements from the perspectives of consultants, contractors, and clients. An example of using PDA and barcodes for construction supply chain control systems is presented by Tserng et al. (2005). Salo (2012) presents a case study in the steel industry. It

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highlights the importance of mobile technologies to improve internal/external coordination and to cut costs of interfacing processes between customers and suppliers. Interestingly, mobile technologies allow redesigning business processes while thinking about the context of information use. Maintenance in the mining industry adopting RFID is the focus of Atkins et al. (2010). An example of a commercial application in the hospitality industry is presented by Tomislav et al. (2014).

Other authors selected a specific technology and detailed its domain-specific application. The adoption of RFID in manufacturing has been studied by Lu et al. (2006), who proposed a five-step deployment approach for its implementation in manufacturing companies. Prater et al. (2005) selected the context of the grocery retailing to suggest three main areas of future research for RFID, namely modelling RFID-based supply chains, RFID implementation, and its daily operation.

A set of different case studies for enterprise mobility in New Zealand is presented by Scornavacca and Barnes (2008), including mobile supply chain applications for wireless field force automation and wireless sales force automation. The authors describe cases of three companies in the food industry, two trade services organizations, and a real-estate company.

Identification of trends pertinent to mSCM in Industry 4.0

The reduced mentions to Industry 4.0 in the previous content analysis supports our initial argument that mSCM is understudied in this context by the IS community. That was not a surprise, since, even for research fields that are moving faster, according to Brettel and Friederichsen (2014, p.40) "*the term Industry 4.0 is mainly used in popular science and has not been established in the scientific literature to this point* [year 2012]". This is changing significantly now, as the results of a Google Scholar search in figure 5 show.

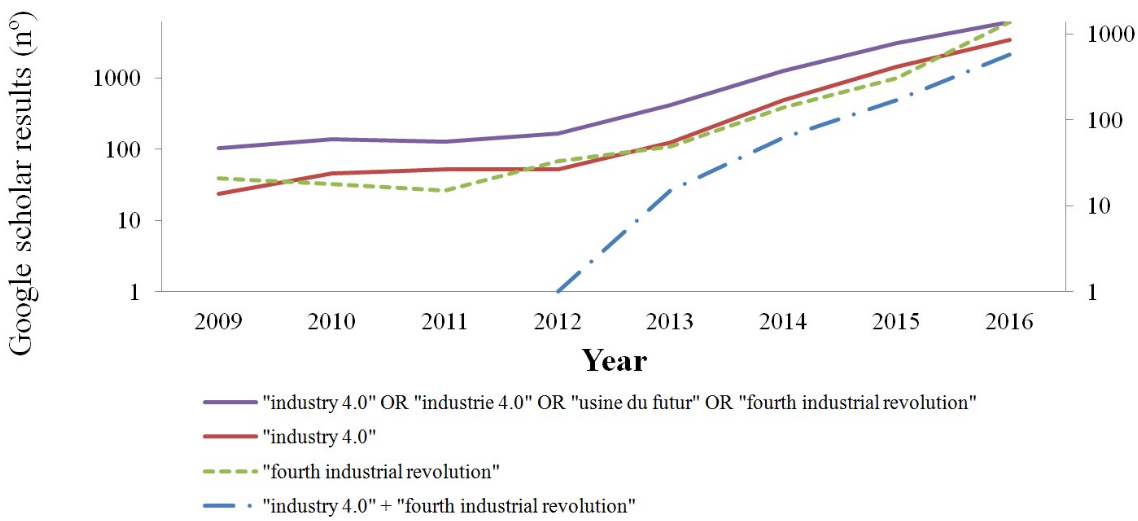

Figure 5. Evolution of Industry 4.0 publications in Google Scholar - axis on the left relative to the two series on the top of the legend, axis on the right relative to the other series[search details in table 1 of the Appendix].

Confirming Brettel and Friederichsen (2014)'s findings, the majority of scientific results emerge after 2012, but are now clearly increasing. The number of publications related with Industry 4.0 more than doubled in each year, for the past three.

If should be noted, however, that these publications are far from exclusive to IS. A search with the keyword combination: "Industry 4.0" + "fourth industrial revolution" + "information systems" (14 matches in 13/05/2017) revealed only two papers in IS outlets in the period 2014. The 54 results that

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appear in 2015 with the above mentioned keywords represent nearly one third of the papers when removing the "information systems" segment of the keyword (172 results). The results from the past three years suggest an increasing interest in IS issues in Industry 4.0. However, only a few (roughly 5%) are presented in IS journals and IS conferences, the majority pertaining to the fields of operations, production, industrial engineering, and computer science. This is an added reason for the IS community to investigate these issues, with its methodologies and philosophical stance and concerns.

Figure 6 shows the research trends when adding the keywords "supply chain" and "mobile" to the Industry 4.0 searches.

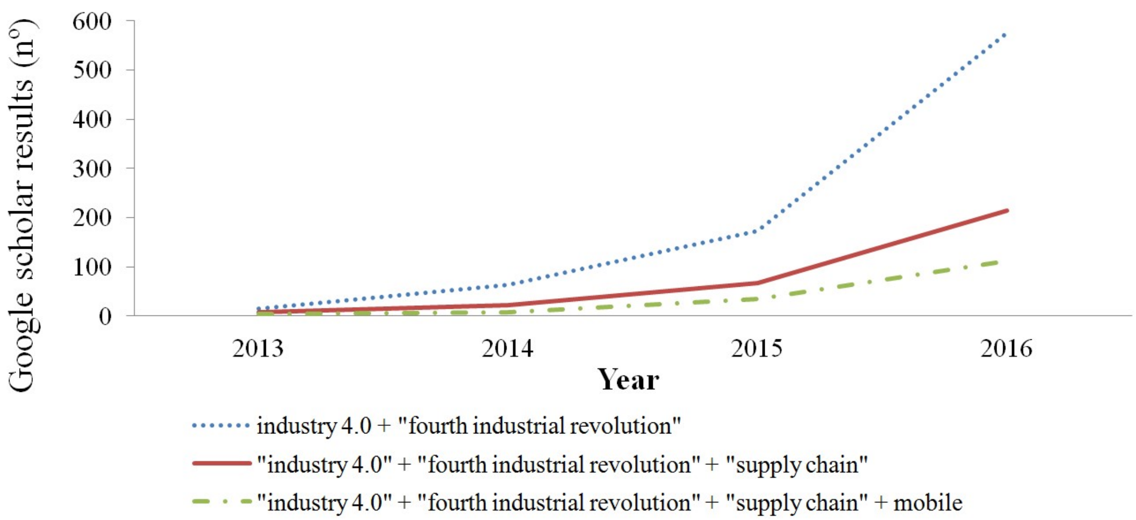

Figure 6. Evolution of Industry 4.0, supply chain, and mobile in Google Scholar [search details in table 2 of the Appendix].

The charts show that there is an increasing interest in the study of supply chain and mobile in the context of Industry 4.0. The results including "supply chain" raised 2588% from 8 (2013) to 215 (2016) and already reached 80 by May 2017. When adding the "mobile" keyword, we find less publications (4 in 2013 and 111 in 2016; 53 by May 2017) but nevertheless representing a proportional increase (2675%). Comparatively, 35% of the Industry 4.0 publications included the keyword "supply chain" in 2014, raising to 37% in 2016 and almost reaching 40% by May 2017. The analysis including the keyword "mobile" reveals more stable results with 13% (2014), 20% (2015),19% (2016), and already reaching 26% in May 2017.

Figure 7 presents the evolution of research on different technologies and concepts related to mobility in supply chains in the context of industry 4.0.

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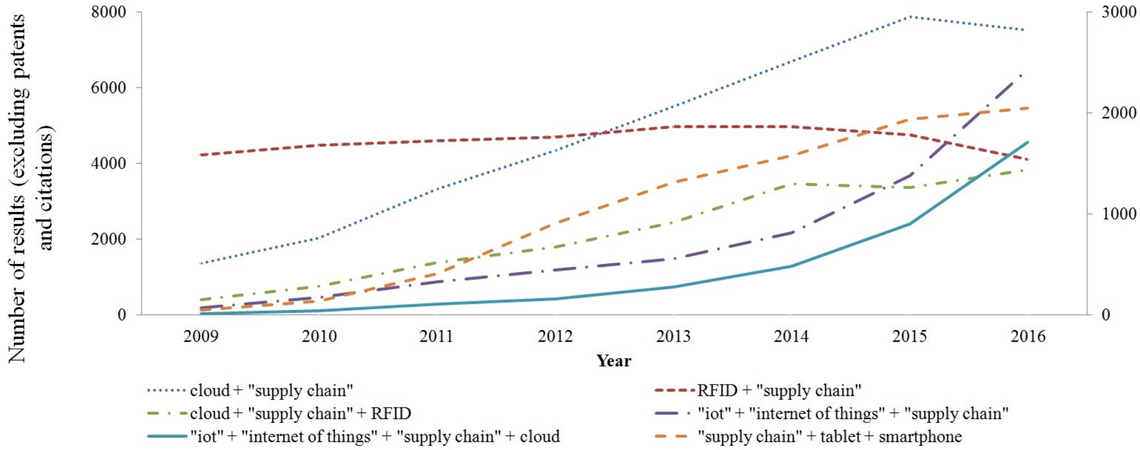

Figure 7. Keyword evolution in Google Scholar for different technologies and platforms (2009 – 2016) - axis on the left relative to the two series on the top of the legend, axis on the right relative to the other series [search details in table 3 of the Appendix].

RFID is still a popular research topic, with a continuous decrease of results between 2013 and 2016 (RFID + "supply chain") but still holding the position of second more popular research area in 2016 (4100 publications). The data also shows stability in the number of studies mentioning cloud + "supply chain" + RFID. Axis on the right is relative to combinations with three keywords (e.g. "iot" + "supply chain" + cloud), in each case scoring bellow 3000 results for the entire period, but with a tendency for continuous increase.

The most significant growth in this period from 2009 to 2016 occurred for the combination of "supply chain", "cloud" and "Internet-of-things", reaching 243% variation between 2014 and 2016. Although referring to less than a quarter (19%) of the papers in 2015 (902 results) when compared to the combination of "supply chain" with RFID (4760 results), the results suggest an increasing interest of combining emergent trends of cloud and Internet-of-Things (IoT) with supply chain issues. In fact, data from 2016 shows that the combination "iot" + "internet of things" + "supply chain" + cloud, almost doubled the matches in a single year (from 902 to 1710), reaching 42% when compared to the combination of "supply chain" with RFID (4100).

The number of publications including "cloud" and "supply chain" quintupled in the period of 2009-2016. It increased at a greater rate in the period between 2010 and 2014, revealing a minor increase of 12% in the period 2014-2016.

Notably, the combination of mobile devices (tablets and smartphones) with supply chain also had a significant increase in the number of results when compared to 2009 (4171%), revealing a 30% increase in the past three years.

Despite the shortcomings of this type of high-level trend analysis, the above results provide a useful complement to the systematic literature review, by providing clues about issues that concern researchers from other fields and that have not been sufficiently investigated from an IS lens.

AVENUES FOR RESEARCH IN MSCM IN THE ADVENT OF INDUSTRY 4.0

A content analysis of the relevant papers that emerged from our systematic literature review and the study of trends affecting mSCM, particularly the advent of industry 4.0 and associated technologies, enabled us to identify the following research opportunities:

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Update existing studies to account for new technologies

RFID, mSCM solutions, and mobile devices, such as smartphones, tablets, or PDAs, are the most cited technologies to achieve SCM mobility. However, the current trends in Industry 4.0 points to the priority of cloud computing, augmented reality, and IoT (Brettel & Friederichsen, 2014), scarcely studied in the mSCM domain (see the gap in figure 3). In particular, little seems to be known about the role of cloud and IoT in the need to balance security and trust in supply chain cooperation, relying in inter-organizational business processes and requirements of data sharing.

Create methods to guide the application of mobile technologies in mSCM

The majority (62%) of the papers identified as Technical in our literature review are conceptual, discussing technologies and their possible applications – e.g. Szymczak (2013); Barnes (2002) –, but lacking empirical evidence and answers for "how to select mobile technologies", "comparison of mobile devices for specific purposes of mSCM", or "the impact of mobile technologies in the redesign of inter-organizational business processes" (Legner & Wende, 2007). We did not find any cases using design science or action research approaches to study mSCM.

Produce exemplars of mSCM cases

While there are examples of case studies using mobile technologies in companies (Sheng et al., 2005), they do not address mSCM nor explain how companies of specific sectors can manage mSCM throughout the lifecycle. A lack of empirical-qualitative studies was also identified by Nysveen et al. (2015), who reviewed 212 articles in the context of mobile services and mobile apps. In their study, 60% of the articles were empirical-quantitative (mostly surveys, regarding mobile service adoption but also including quantitative-econometric), 31% conceptual, and only 9% empirical-qualitative.

Study the implications of regulatory compliance

Regulatory compliance is an increasingly central issue in modern society and also in IS design (Bonazzi et al., 2010). However, in our review, we did not find domain-specific studies addressing the role of mSCM to assist compliance in critical sectors. One example, is the food chain, that represents a priority in Europe (European Commission, 2009). Traceability of food and original products can be supported by mSCM by way of the proper identification of goods and components along the entire supply chain, opening opportunities for future research.

Develop maturity models for diagnostic and guidance

Furthering the study by Chan and Chong (2013) about mSCM diffusion, there is an opportunity to develop maturity models (Becker et al., 2009) for mSCM, assisting companies in the diffusion process, including social and technical aspects of mSCM maturity. For example, using matrices as suggested by Loebbecke et al. (2013) for cloud readiness at Continental AG. These authors found that compliance is one of the main problems for the migration of IT services to the cloud, so it could be interesting to make the parallel analysis regarding mSCM. Interestingly, some studies such as Prajogo and Sohal (2013) point out that the benefits of information and communication technologies are not yet sufficiently recognized, and that the level of IT adoption in the supply chain is still low. This opens up further opportunities for research in mobile IT adoption.

Explore the social aspects

Almost half of the papers identified in the Systematic Literature Review have a technical focus. The social dimension of mSCM is insufficiently studied. For example, the impact of mobile technologies in work conditions (e.g. safety, ergonomics), the permanent interaction with customers and the impact in their satisfaction, approaches and frameworks to assist managers and workers in their transition for mobile enterprise. We found a lack of empirical studies to address these open issues that are relevant for managers. Our review identified important studies addressing managerial aspects of mSCM, however, 62% of those are conceptual in nature. According to Baskerville (2011, p.7) "*the increasing mobility of information devices has also driven perceptions of personal information systems as embodied in handheld devices*", leading to the necessity of studying how people use and adapt these technologies and the business processes (Paul, 2007) in mSCM, as individuals and as a part of specific groups. This means that, on the one hand, it is possible to provide information along the entire supply chain. On the other hand, it is also possible to adapt mSCM information to the context of the user (Gross & Specht, 2001), fostering solutions in context-aware mSCM. A comprehensive IS quality culture and its data quality implications <*removed for refereeing*> are potential areas of future research in mSCM, due to the digitalization and decentralization of supply chains in the Industry 4.0 paradigm.

POTENTIAL IMPACTS

Our study contributes to the industrial practice by developing a knowledge base (Tranfield et al., 2003) of (1) mobile technologies for mSCM, (2) managerial aspects involved in mSCM, and (3) solutions for specific domains. It also contributes to research by identifying gaps in the body of knowledge and pointing out possible avenues to address them.

First, there are different systems and technologies related to industry 4.0 (e.g. cloud, IoT, augmented reality, mobile devices) with the potential to be integrated into commercial supply chain management solutions. Our study points to some of the possible technologies that require additional research and offer more potential to the market.

Second, companies must create transition plans for Industry 4.0 that consider the supply chain requirements, namely, suppliers, partners, and customers. Decentralization of production creates new challenges for real-time integration of business processes. Moreover, the emergence of digital ecosystems (Bharadwaj et al., 2013), with cyber-physical systems, has the potential to drastically change supply chain configurations in short periods. Decentralization and additive manufacturing enable the creation of "temporary supply chains" for specific products (eventually, a single product), constantly changing business partners and information management requirements. Mobile technologies and mSCM management will be crucial in digital markets.

Third, global supply chains that require digital end-to-end integration can create barriers to new competitors using technological developments. Additionally, there are opportunities to change or "extend" traditional supply chains with mobile technologies. For example, a combination of smartphone apps, cloud platform, and IoT can be used to create mSCM solutions for the pharmaceutical industry that enable the integration of many different processes: (1) starting at the medicine compound suppliers (raw materials used to produce medicines), (2) integrating production between different partners (e.g. medicine production and package production in a different company), (3) support logistics to retail pharmacy via mobile devices, (4) offering digital information to the medicine user via smartphone and QR code, and (5) acquiring data with specific wearable technologies (IoT) to monitor medicine effect in daily life <*REF removed for refereeing*>. This example illustrates the major impact of mSCM in the era of Industry 4.0 and the importance of quickly exploring the elicited avenues for research.

CONCLUSIONS

We have conducted a Systematic Literature Review of IS research in mobile supply chain management and found it lacking in what regards the impact of Industry 4.0. A subsequent analysis of the research trends in other more advanced fields, such as operations, production, industrial engineering, and computer science, enabled the identification of topics and concerns that merit attention under an IS lens. Accordingly, several avenues for future work were suggested, including to: (a) update existing studies to account for new technologies, (b) create methods to guide the application of mobile technologies in mSCM, (c) produce exemplars of mSCM cases, (d) study the implications of regulatory compliance, (e) develop maturity models for diagnostic and guidance, and (f) explore the social aspects.

Some limitations of our study should be discussed. First, despite the care taken, the selection of language, search keywords, and databases influences the results that we have obtained. Second, we have restricted our search to papers addressing mobile supply chain management as defined by Eng (2006). Third, due to the scarce publications mentioning mSCM, we did not filter the sources, so the quality of the various papers can differ. Forth, although we present quantitative results from the findings, the trends of future research are merely indicative and extracted from a single search engine, albeit popular and broadly encompassing. Finally, the critical assessment of the papers accounted for the priorities of Industry 4.0 (Brettel & Friederichsen, 2014), reducing the scope of potential technologies and contexts of mSCM adoption. Nevertheless, we argue that Industry 4.0 presents one of the most important opportunities to adopt mobile technologies in supply chain transformations, providing new SCM solutions, in a progressive evolution of the inter-organizational business models and business processes.

We are already working along the lines of contributing with more domain-specific exemplars, as we work in an action research project for mSCM development in a leading supplier of ceramic powder in our country. The supply chain includes several mineral extraction sites, transformation plants, and a complex logistic structure for quality control, distribution, and sales. There are vast opportunities to research different interrelated dimensions of Industry 4.0 that are so crucial to the core of the IS discipline, namely, *Context, People, Process, IT, and Information/Data <REF removed for refereeing>*.

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APPENDIX

We used Google Scholar for the searches supporting our trend analysis because it (a) presented the highest number of results for our search keywords and (b) provides search functionalities according with the year of publications. We excluded patents and citations. We used three different keyword combinations with "industry 4.0" (column 2 and 4 of Table 1) and "fourth industrial revolution" (column 3 and 4), as the concept is also known. On the one hand, the use of "fourth industrial revolution" eliminated noise in data, for example, a paper from 2009 appeared in the results because included a table with "Fishing industry" in the first column and "4.0" in the second column that was related with a specific parameter. On the other hand, it also returned results where authors were considering different topics pertaining to the forth industrial revolution (e.g. nanomaterials).

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	Keywords		
Year	"industry 4.0"	"fourth industrial revolution"	"industry 4.0" + "fourth industrial revolution"
2009	24	21	0
2010	46	18	1 (wrong indexation, 2015)
2011	52	15	0
2012	52	33	1
2013	123	49	15
2014	488	140	63
2015	1440	305	172
2016	3410	1380	575
2017 (13/05/2017)	*1260*	*609*	*203*
No time restriction	*7430*	*2690*	*1070*
Variation between 2016 and 2014	***599%***	***886%***	***813%***

Table 1 . Keyword analysis of Industry 4.0 in Google Scholar (2009 – 2016).

	Keywords		
Year	"industry 4.0" + "fourth industrial revolution"	"industry 4.0" + "fourth industrial revolution" + "supply chain"	"industry 4.0" + "fourth industrial revolution" + "supply chain" + mobile
2009	0	0	0
2010	1 (wrong indexation, 2015)	1 (wrong indexation, 2015)	0
2011	0	0	0
2012	1	0	0
2013	15	8	4
2014	63	22	8
2015	172	66	34
2016	575	215	111
2017 (13/05/2017)	*203*	80	*53*

Table 2 . Keyword analysis of Industry 4.0, supply chain, and mobile in Google Scholar (non null simultaneous results for the three keywords combination occurred in the period 2009 – 2016).

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	Keywords					
Year	cloud + "supply chain"	RFID + "supply chain"	cloud + "supply chain" + RFID	"iot" + "internet of things" + "supply chain"	"iot" + "internet of things" + "supply chain" + cloud	"supply chain" + tablet + smartphone
2009	1360	4220	149	71	11	48
2010	2020	4480	285	170	42	132
2011	3330	4610	516	324	107	404
2012	4340	4700	670	443	156	906
2013	5500	4980	916	556	274	1310
2014	6710	4970	1300	809	484	1580
2015	7870	4760	1260	1380	902	1940
2016	7520	4100	1440	2430	1710	2050
2017 (13/05/2017)	*2140*	*1270*	*476*	*789*	*529*	*526*
No time restriction	*35900*	*48100*	*7250*	*7320*	*4390*	*9600*
Variation between 2016 and 2014	***12%***	***-18%***	***11%***	***200%***	***253%***	***30%***

Table 3 . Keyword analysis of mSCM topics in Google Scholar (2009 – 2016).

Note: Our analysis take into consideration that Google Scholar results vary over time. For example, when we searched the database with the term “fourth industrial revolution” restricting the year 2015, we obtained 263 matches in August 2016 and 305 in May 2017 (16% more). We contrasted the results obtained in the different moments of our research to confirm literature trends and identify the research gaps.