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ScienceDirect

International Journal of Project Management 34 (2016) 1328 – 1346

International Journal of Project Management

www.elsevier.com/locate/ijproman

Similarities and contrasts of complexity, uncertainty, risks, and resilience in supply chains and temporary multi-organization projects

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Received 1 July 2015; received in revised form 15 October 2015; accepted 30 October 2015
Available online 26 November 2015

Abstract

Although complexity, uncertainty, risk, and resilience are concepts of growing interest, there is a lack of structured synthesis of these concepts and their relationships in supply chain management (SCM) and project management (PM) literatures. This paper addresses this gap through novel tertiary and bibliometric analyses. The tertiary research embraces 22 literature reviews and guides the development of the synthesis framework. The bibliometric analysis includes 1,275 papers and complements the tertiary research with study descriptors, a co-citation, and a static and dynamic/longitudinal co-word network analysis. Authors cite each other within the confines of their research area with no cross-fertilization of studies in PM and SCM, despite several commonalities among the areas. Both areas use similar conceptual definitions and there are close resemblances in risk management in SCM and temporary multi-organization (TMOs) projects. Resilience appears as a new topic in SCM but is absent in TMO. A research agenda closes the paper.

Keywords: Research synthesis; Project management; Operations management; Supply chain collaboration; Literature review

1. Introduction

Nowadays, companies tend to compete as supply chains (SCs) and not individually within the boundaries of a single firm. SCs are "networks used to deliver products and services from suppliers of raw materials to end customers through an integrated flow of information, material, and cash" (Blackstone, 2013 p. 171). Supply chain management (SCM) is the integration of key business processes along the SC that add value for customers and other stakeholders (Lambert et al., 1998). SCM embraces large, complex, and multi-faceted temporary projects for collaboration among independently owned firms. Modalities of supply chain collaboration (SCC) projects abound, such as vendor-managed inventories (VMI), continuous replenishment (CR), and collaborative planning, forecast, and replenishment (CPFR) (Hollman et al., 2015; Thomé et al., 2014).

SCC projects are equivalent in project management (PM) literature to temporary multi-organizations (TMOs) or "project organizations that consist of a multidisciplinary composition of participants employed by independent firms", which are often

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http://dx.doi.org/10.1016/j.ijproman.2015.10.012
0263-7863/00/

common in large construction (e.g., Lu and Yan, 2007) and software development projects (Lehtiranta, 2014 p. 640). As an indication of SCC relevance as structured projects, Yao et al. (2013) count more than 300 large-scale CPFR projects in the literature since the inception of the concept in 1998. In SCC projects, collaborative performance systems are established, decisions are synchronized, information is shared, and incentives are aligned among independently owned firms. All these initiatives aim to mitigate risks and to strengthen SC resilience to compete in ever-growing, complex, and uncertain markets.

Complexity, uncertainty, risk, and resilience are concepts of growing interest for academics and practitioners and have been the scope of several recent literature reviews in SCM (e.g., Colicchia and Strozzi, 2012; Fahimnia et al., 2015; Mandal, 2014; Serdarasan, 2013) and PM (e.g., Lehtiranta, 2014). Although there has been a great effort in the literature to address these issues, there is a lack of a structured synthesis of these concepts and their relationships bridging the fields of SCM and PM from an integrated and holistic perspective. This is important because PM literature traditionally treats complexity, uncertainty, and risks from a rather complementary but distinct perspective (e.g., Atkinson et al., 2006; Lehtiranta, 2014; Sanderson, 2012).

PM is a recent academic field, which started in engineering and computing as a technical area, and evolved to embrace management research and business schools (Bredillet, 2010). The SCM concept appeared in the early 1980s in operations management (OM). Since the beginning, SCM searches for mutual benefits of information sharing and coordination of decisions among independently owned companies in the SC (Alfalla-Luque and Medina-Lopez, 2009). As relatively new academic sub-fields, both PM and SCM are still unconsolidated (Bredillet, 2008; Bredillet, 2010; Hohenstein et al., 2015). In PM literature, the germane concepts of risk, complexity, and uncertainty are often associated with crisis management. Risk evolved from the deterministic perspective of "avoidable risks" linked to costs and schedules in individual projects to the complexity and uncertainty of relational risks in TMOs, rooted on collaborative work (e.g., Lehtiranta, 2011). Structural or known uncertainties are avoidable mainly through a reduction of complexity in construction projects (e.g., Giezen, 2012), while unknowable uncertainty brings unpredictability and the need for crisis management (Lehtiranta, 2011). In SCM, since the first definitions, risk has been associated with complexity, uncertainty, and resilience in a manner that resembles the concept of relational risks in TMOs. However, the notion of SC risks is network-related (Jüttner et al., 2003), rather than product-related, as in early PM risk management literature (Bredillet, 2010). Those similarities and contrasts are relevant for researchers and practitioners. As the two fields converge to a commonality of definitions and practices, consistent research streams are more likely to occur, and common best practices of collaborative work among independent firms might emerge. Within this context, this study is an attempt to contribute to close this gap, shredding light on similarities and contrasts between SCM- and PM-related concepts, and offering a research synthesis of complexity, uncertainty, risks, and resilience in SCM and PM. More specifically, this paper addresses two research questions.

R1: What are the analytical categories and relationships among complexity, uncertainty, risk, and resilience in SCM and PM?

R2: What are the directions for future research in SCM and PM related to the complexity, uncertainty, risk, and resilience framework?

Therefore, this paper offers as its main goals a tertiary research and a bibliometric analysis with a co-citation and static and dynamic/longitudinal co-word network analyses from primary studies on the relationships among complexity, uncertainty, risks, and resilience in both SCM and PM. Tertiary researches are reviews of secondary research through systematic literature review (SLR) of primary studies (Glock et al., 2014; Verner et al., 2014). SLR aims to respond to specific research questions in an objective, transparent, and reproducible manner (Denyer and Tranfield, 2009; Tranfield et al., 2003) as opposed to selectively reporting on topics of interest, introducing primary research, or providing scholarly narratives of selected research topics in traditional reviews (Petticrew and Roberts, 2006). Bibliometric analysis and study of co-citation networks are powerful techniques to categorize topical areas, to cluster related research and researchers, and to identify more recent and emerging themes (Fahimnia et al., 2015).

This paper is organized as follows. Section 2 describes the methods and results from the tertiary research and the synthesis framework outlining the relationships among the constructs of complexity, uncertainty, risks and resilience. Section 3 provides the methods of the bibliometric analysis and presents the results by study descriptors, static co-occurrences of keywords and co-citation network, and a post hoc longitudinal analysis of keywords. Section 4 discusses the conceptual similarities and contrasts between the PM and SCM research domains. Conclusions and a research agenda are offered in the paper's last section.

2. Tertiary research

2.1. Methods of tertiary research

The seven-step approach for SLR proposed by Cooper (2010) is adapted for the overview of the literature reviews. In the first step, the objective of the study is delimited and the research questions are specified.

The search and selection of studies comprise the second step and follow the suggestions by Thomé et al. (2012, 2014). The 2010 Combined Journal Guide of the British Association of Business Schools (ABS) was used for the literature search in SCM (Petersen et al., 2011). All journals belonging to grades four and three of the British ABS in the areas of "operations, technology, and management" were selected for the SCM search. The PM field was systematically searched with the addition of four major journals. Consistent with Lehtiranta (2014), the *International Journal of Project Management*, *Project Management Journal*, *Journal of Construction Engineering and Management*, and the *IEEE Transactions on Software Engineering* were chosen because they appeal to a large audience of scholars and are representative of TMOs projects. The search was performed independently in the sites of each of these journals using the main types of literature reviews (e.g., Cooper, 2010; Petticrew and Roberts, 2006; Rousseau et al., 2008; Tranfield et al., 2003) as keywords, separated by the Boolean operator OR. The exact search key was ("research synthesis" OR "systematic review" OR "evidence synthesis" OR "research review" OR "literature review" OR "meta-analysis" OR "meta-synthesis" OR "mixed-method synthesis" OR "narrative reviews" OR "realist synthesis" OR "meta-ethnography" OR "state-of-the-art" OR "rapid review" OR "critical review" OR "expert review" OR "conceptual review"). The search returned 203 reviews. All reviews that were not reporting directly to complexity, uncertainty, risk, and resilience in SCM and in PM were hand-selected for exclusion. Papers using focused literature reviews to introduce primary research were equally excluded, resulting in 15 literature reviews selected. The exclusion criteria guaranteed that only SLR, or the review of primary studies were included in the tertiary research. Both qualitative and quantitative primary studies reviewed in the selected SLR were included in the tertiary review. The search and selection for studies followed the advice of Greenhalgh and Peacock's (2005) to extend the search beyond keywords for inclusiveness, doing "snowball" backward and forward searches. Backward snowball search was performed in the references of the literature reviews retrieved with keywords. Forward searches consisted of applying the keywords to the cited references of selected papers in the Thompsom Reuters™ Web of Science (WoS) database, increasing the total number of selected studies to 22.

In the third and fourth steps, data were gathered using predefined categories for content analysis and evaluated for the quality of secondary studies. As all literature reviews were from top peer-reviewed journals, one can assume that the analysis included only high-quality and reliable reviews. Analysis and interpretation, steps 5 and 6, followed Mayring's (2000) guidelines for content analysis: material collection, descriptive analysis, category selection, and material evaluation. The seventh step is the presentation of results. All modalities of research synthesis suggested by Torraco (2005), but using meta-theory, were applied to the selected papers. They are the taxonomy describing the main content analytical categories, the framework synthesizing the main concepts, and the research agenda presented in the conclusion.

2.2. Results and discussions of the tertiary research

The literature reviews selected for the tertiary research are in Table 1, classified according to the papers' main research scope in complexity and uncertainty, risk, and resilience. Table 1 also includes the number of studies associated to each literature review.

Table 1 highlights that both SCM and PM literatures treat more extensively the concept of risk than complexity, uncertainty, and resilience. This is supported not only by the number of literature reviews, but also by the number of studies considered in each review (primary research). Not surprisingly, tertiary research appears only in risk. Overall, there is a substantial number of primary studies in all concepts. The large majority of studies are located in SCM with a lack of literature reviews in resilience for PM. Table 1 also points to the growing momentum of the subject in both SCM and PM with a large number of literature reviews published in 2014 and 2015.

The next subsections discuss each concept and present a synthesis framework.

2.2.1. Complexity and uncertainty

Serdarasan (2013) reviews complexity drivers in SCM and classifies them according to type in static (or structural: number of SC components and interactions), dynamic (operational: related to

Table 1
Selected literature reviews with their respective number of studies.

Concepts	Supply chain management		Project management	
	Literature reviews	No. of studies	Literature reviews	No. of studies
Complexity and uncertainty	Simangunsong et al. (2012) **	38	Geraldi et al. (2011)	25
	Serdarasan (2013)	107	Svejvig and Andersen (2015)	74
Risks	Tang (2006) **	225	Zhang (2011)	171
	Rao and Goldsby's (2009)	55	Lehtiranta (2014)	105
	Tang and Musa (2011)	138	Taroun (2015)	68
	Colicchia and Strozzi (2012)	55		
	Ghadge et al. (2012)	120		
	Jaberidoost et al. (2013)	9		
	Kache and Seuring (2014) *	11		
	Rangel et al. (forthcoming) **	16		
	Fahimnia et al. (2015) ***	1,128		
	Heckmann et al. (2015) **	162		
	Ho et al. (2015)	224		
Resilience	Bhamra et al. (2011)	74		
	Mandal (2014)	57		
	Hohenstein et al. (2015)	67		
	Tukamuhabwa et al. (2015) **	109		

* Tertiary research/refers to number of literature reviews.
** Total number of references as the exact number of studies reviewed was not stated.
*** Bibliometric review.

the uncertainty of time and randomness), and decision-making (associated with the volume and nature of the information required to make a decision). Complexity types are cross-referenced with complexity origin and the categories are not mutually exclusive. Complexity origins are internal (generated by decisions and internal factors like processes and products), supply/demand interface (generated by material and information flows with suppliers, customers, and service-providers), and external/environmental (e.g., market trends and regulations).

Svejvig and Andersen (2015) place complexity and uncertainty at the center of the rethinking project management (RPM) stream of research. They refer to Geraldi et al.'s (2011) taxonomy of complexity and uncertainty in projects that are consistent with Serdarasan's (2013) classification of complexity drivers in SC. Their typology is the basis for the complexity and uncertainty dimension of the synthesis framework presented in Subsection 2.2.4.

For Geraldi et al. (2011), complexity is something perceived by the manager. Geraldi et al. (2011) define five dimensions of the complexity of projects, which evolved in time as indicated in the parentheses: structural complexity (1996), uncertainty (1997–1999), dynamic (2002–2004), pace (2005–2006), and socio-political (2007–2008). Examples of structural complexities are size, variety, and interdependency, which is consistent with Serdarasan's (2013) taxonomy of SC static complexity. The dimensions of uncertainty comprise novelty of projects, experience of teams, and availability of information. Dynamic complexity expresses variability, dynamism, and change. Pace refers to the urgency and criticality of time goals and is often associated with new product development literature. These five dimensions are not mutually exclusive and they interact, which "challenges the multiple exclusive clause of typology" (Geraldi et al., 2011 p. 983). For Geraldi et al. (2011) in PM, as well as for Serdarasan (2013) in SC, uncertainty is one among several dimensions of complexity. Accordingly, complexity and uncertainty are grouped in the same dimension in Table 1 and in the synthesis framework (Subsection 2.2.4).

Simangunsong et al. (2012) state that uncertainty and risks are often quoted interchangeably in the SCM literature, with some authors (e.g., Jüttner et al., 2003) questioning the relevance of the terminological discussion. For Simangunsong et al. (2012), the main reason for maintaining the distinction between uncertainty and risks rests on the ground that the consequences and management of risks gear to counteract negative effects, while uncertainty might result in positive consequences as well (e.g., demand uncertainty might lead to increased sales). In both PM and SCM, uncertainty can be considered a driver and an antecedent of risk. In large construction projects, known uncertainties brings the need to refocus on relational risks rather than on performance risks and unforeseen uncertainties drive efforts towards risk mitigation through crisis management (Lehtiranta, 2011). In SCM uncertainty is often linked to complexity. Known uncertainties triggers risk mitigation strategies, while unknown uncertainties drive efforts towards resilience (Jüttner et al., 2003). Therefore, uncertainty might precede risks and bring either negative or positive consequences. It can become a risk or an opportunity. Jüttner et al. (2003) rank uncertainty as a predecessor or risk source. Accordingly, complexity and uncertainty lead to risk in the synthesis framework presented later in the subsection.

2.2.2. Risk

The concept of vulnerability is often confused with the concept of risk (Heckmann et al., 2015). Vulnerability is rather viewed here as the "propensity, susceptibility and exposure" to risk (Wagner and Bode, 2006). In this latter sense, vulnerability leads to the exposure to risk and risk mitigation leads to resilience (Heckmann et al., 2015).

Risk is a multidimensional construct with different definitions and measurement depending on the field of research. The term appears in a variety of fields. For instance, in finance, risk is the fluctuation around the value of an expected return and comprises both gains and losses. In decision theory, risk is based on the availability of probability distributions. In the area of health, safety, environment, and reliability engineering, risk is the product of the probability and harm of an event (Heckmann et al., 2015).

In SC, risk is simply any "variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective value" (Jüttner et al., 2003 p. 200). Ho et al. (2015), p. 5) define SC risk as "the likelihood and impact of unexpected macro- and/or micro-level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities". Rao and Goldsby (2009) define SC risks as the combination of the range and impact of the consequence of risks with the probabilities of occurrence of the risk.

In PM, risk in construction projects is the variance of cost or duration estimation and is evaluated by the combination of the probability of occurrence with the impact of the consequences of risks (Taroun, 2015). This definition is similar to Rao and Goldsby's (2009) definition of SC risks. The commonality of this definition of risk as a probability in both SCM and PM can be traced back to the prominence of the notion of risks in mathematics since the 17th century, linked with the measurement of uncertainty in gambling and it is encountered in different research domains (Heckmann et al., 2015).

Ghadge et al. (2012) identified through word mining a large diversity of typologies in SC risk management. They suggested a classification of SC risks following Jüttner et al. (2003) in organizational, network, and environmental (man-made and natural disasters). This classification is the basis for the risk dimension in the synthesis framework proposed next.

Colicchia and Strozzi (2012) acknowledge that there is a large diversity of SC risk typologies, but they quote the influential typology of Tang (2006) in supply management, demand management, product management, and information management risks. SC risks related to demand, product, and information were largely underrepresented in Kache and Seuring's (2014) tertiary research in SCC and risk management. Colicchia and Strozzi (2012) retrace the evolution of the concept. The early papers in SC risks appeared in the mid-1990s and they were concerned with the focal company and not with the network. The notion of uncertainty as harm and as a potential benefit appears clearly in the early papers in SC risks. After the World Trade Centre events of September 11th, 2001, concerns with SC disruptions emerged in SCM literature, adding natural disasters, terrorism, and political instability to the list of disruption risks. Risk avoidance becomes proactive in the second half of the first decade of this century and concerns the SC network nodes and arcs, going beyond the boundaries of the single company. Kache and Seuring (2014) adopt the typology of risks proposed by Tang (2006) as well. The typologies of risk proposed by Jüttner et al. (2003) and Tang (2006) complement each other and they are combined in the synthesis framework.

Zhang (2011) discerns about two schools of thoughts on risk: risk as an objective construct and risk as a subjective perception. Risk management and mitigation strategies differ depending on the stance of project risks being objective or perceived.

Lehtiranta (2014) reviews TMO risks in the PM literature in the 2000–2012 period focusing on multi-firms, with emphasis in construction and software development projects. She defines risk from the stance of perceived risks. Consistent with Zhang (2011), she stresses that the perception of risks defines the approaches taken for risk management. The TMO approach to risk is closer to the SCM approach to risk than it is to classic risk analysis in PM literature (e.g., the PMBOK; Project Management Institute, 2009). Similarities are mainly due to the management of internal and external risks in a network of independent firms, common to both TMOs and SCM. The early studies in PM risks related risks to uncertainty with a sense of harm from negative consequences of uncertainty and they did not relate risk to both threats and opportunities, contrary to the early perception of risks in SCM literature (Colicchia and Strozzi, 2012). Out of 74 papers reviewed by Lehtiranta (2014) in construction projects, only eight reported risks as opportunities, against three out of 20 in software development projects and three out of 11 in other project types. PM literature in TMO projects has in common with SCM literature a concentration of early studies in the individual firm and not in the network (Colicchia and Strozzi, 2012; Lehtiranta, 2014).

Jaberidoost et al. (2013) focus on the risk mitigation strategies in the pharmaceutical industry. They classify risks in the categories of "supply and suppliers, organization and strategy, financial, logistic, political, market and regulatory issues".

Rangel et al. (forthcoming) propose the five SC risk management (SCRM) steps of identification, assessment, management, monitoring, and organizational and personal learning, including technological transfer. They review 16 classifications of SC risks and propose a summary classification relating 14 types of SC risks to the SC processes as described in the SCOR model (plan, source, make, delivery, and return).

Fahimnia et al. (2015) classify quantitative models for SCRM in eight clusters, directly related to uncertainty as a risk source. These are the uncertainties linked to supply, demand, network design, tactical and operational planning, forecasting, inventory, sustainability, purchasing, and sourcing.

The notion of risk in SC is closely associated with risk mitigation strategies or initiatives geared at risk management, as indicated in the synthesis framework. Ho et al. (2015) p. 6) define SCRM as "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". Therefore, risk management can lead to resilience, as depicted in the synthesis framework and discussed next.

2.2.3. Resilience

Both SCM and PM research streams seem to treat resilience as risk mitigation, as reported in the literature reviews. Bhamra et al. (2011) review the concept in organization theory, strategy, and OM in the context of small and medium enterprises (SMEs). Examples of fields where the term *resilience* is used include ecology, metallurgy, individual and organizational psychology, SCM, strategic management, and safety engineering. The term has a straightforward and homogeneous meaning across these fields: "the capability and ability of an element to return to a stable state after a disruption" (Bhamra et al., 2011). The topics covered by the concept of resilience in the papers reviewed by Bhamra et al. (2011) were classified in behaviour and dynamics capabilities, strategy, and performance in decreasing order of relevance. There are three elements of resilience: readiness and preparedness, response and adaption, and recovery or adjustment (Bhamra et al., 2011). The authors equally stress that resilience is a relatively new concept that emanated from ecology and it is rarely treated in isolation of its germane concepts of risk and uncertainty.

Mandal (2014) and Heckmann et al. (2015) credit the resurgence of research in resilience to Cranfield's (2003) SC resilience report. Based on Cranfield's report, SC resilience is defined as the ability to return to its original or move to a new, more desirable state after being disturbed (Heckmann et al., 2015).

Tukamuhabwa et al. (2015) stress that the main strategies put forward in the literature to increase SC resilience are increasing flexibility, creating redundancy (spare capacity and inventory to cope with disruptions, such as spare stocks, multiple suppliers and extra facilities), forming collaborative SC relationships, and improving SC agility. Hohenstein et al. (2015) distinguish four phases in building SC resilience: readiness, response, recovery, which are consistent with Ponomarov and Holcomb (2009) and with Bhamra et al. (2011), and growth.

2.2.4. Synthesis framework

Fig. 1 presents a framework synthesizing the results and emphasizing the interactions and the logical chain from complexity and uncertainty to resilience, mediated by risk factors (or sources) and risk management. The intention of this synthesis framework is to be a guide further research on the interactions among concepts.

Colicchia and Strozzi (2012) clearly relate complexity to uncertainty, risk, and risk mitigation (or resilience) in SC in a historiographic analysis of citations network. Kache and Seuring (2014) reinforce this logical path from complexity to uncertainty, risk, and resilience in SC. Lehtiranta (2014) equally stresses that

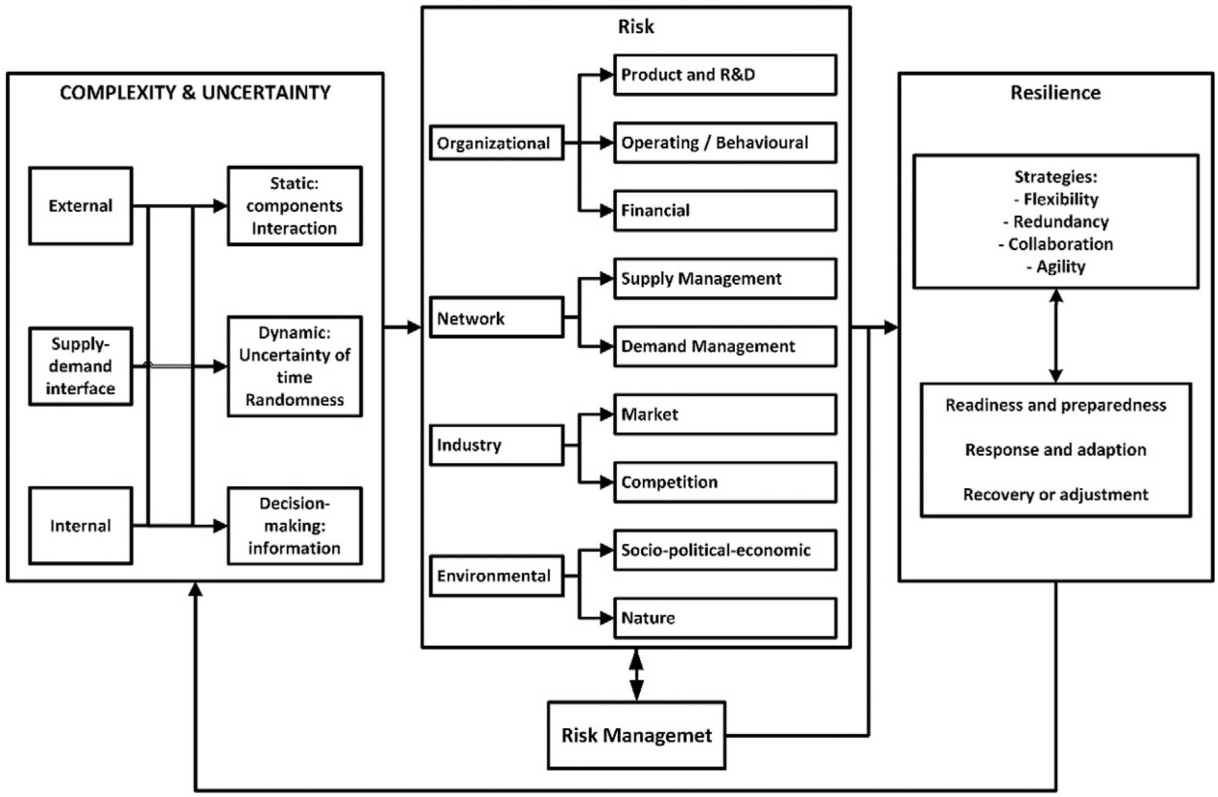


Fig. 1. Complexity and uncertainty, risks, and resilience: a synthesis framework for SCM and PM.

project complexity links to the perception of uncertainty; uncertainty is related to the perception of risks and mitigation strategies in a continuum consistent with the SCM literature. According to Fig. 1, complexity includes uncertainty, as highlighted in Geraldi et al. (2011) for PM and in Serdarasan (2013)) for SCM, and drives towards risk factors (or risk sources), which is consistent with Simangunsong et al. (2012)). The typology of risk sources is pivotal for the framework and is grounded on previous typologies proposed by Jüttner et al. (2003), Tang (2006), Rao and Goldsby (2009), and Ghadge et al. (2012).

The complexity and uncertainty dimension of the framework follows Serdarasan (2013); classifying complexity drivers according to type in static, dynamic, and decision making. These complexity types are cross-referenced with complexity origins, which can be internal, supply–demand interface, and external. This typology is in accordance with the literature in SCM and PM (e.g., Geraldi et al., 2011; Svejvig and Andersen, 2015).

The risk dimension of the framework is based on previous literature and comprises organizational, network, industry, and environmental risks. Organizational risk sources include product- and production-related uncertainties, such as liability risks with existing products and risks associated with the development and launching of new products (R&D). Operating and behavioural risks are those associated with labour unrest, strikes, shortage of raw material, IT and manufacturing technology risks, and self-interested lead employee behaviour. Financial risks at the organizational level comprise bad debts and long cash conversion cycles, among others. Network risks are those linked with supply disruption risks and those related to demand factors, such as outbound logistics, seasonality, new product development (NPD), and product life cycle threats. Blurring boundaries between buyers and suppliers or unclear divide lines of responsibilities in TMOs lead to the exposure to the risk of lack of ownership in the network. Inertia and chaotic joint actions exacerbate network risks and might lead to bullwhip effects of fluctuating orders in SC. Industry-specific risks are those affecting the quantities and timing of acquisition of inputs for production, but can also affect the market downstream due to unanticipated changes in demand patterns and preferences. Competition-related risks are new entrants and technological novelty in new products or newly introduced production processes. Environmental risks is classified into man-made, socio-political changes (including acts of war and terrorism) and governmental regulatory actions (e.g., fiscal policies, trade restrictions), and natural disasters that can cause ruptures and disruptions in project development and SC functioning.

Projects and SC strengthen their ability to face risk sources through risk management. The double-sided arrow linking risk sources to risk management indicates the permanent interaction between risks and risk mitigation strategies. Risk management is a driver to build resilience. Tukamuhabwa et al. (2015) summarize 24 resilience strategies in the four main categories depicted in the resilience dimension of the synthesis framework: flexibility, redundancy, collaboration, and agility. However, the authors caution that these main strategic areas to increase resilience are intertwined, with synergies and trade-offs among them that deserve to be further researched, as one strategy may be in detriment of others (e.g., dual sourcing increases redundancy but might decrease collaboration). Resilience strategies lead to a constant state of preparedness and readiness to respond to unforeseen events, an extended ability to respond and adapt to a changing environment and to recover and adjust, returning to the state before the event or to a new and strengthened state (Ponomarov and Holcomb, 2009; Bhamra et al., 2011; Hohenstein et al., 2015).

Finally, resilience loops back to complexity, as strengthened resilience might often lead to networks that are more complex (Colicchia and Strozzi, 2012).

3. Bibliometric analysis

3.1. Methods of bibliometric analysis

Cooper's (2010) seven-step approach used for the tertiary review was also adapted to conduct the bibliometric analysis to chart the conceptual domain of complexity, uncertainty, risk, and resilience in primary research. To avoid redundancies, this subsection reports only the main differences in the application of Cooper's steps to the bibliometric analysis when compared to its application to the tertiary research described in Subsection 2.1. The core collection of WoS was searched with the following keywords in titles, abstracts and keywords of the records: ("project* complex*" OR "supply chain* complex*" OR "project* uncertain*" OR "supply chain* uncertain*" OR "project* risk*" OR "supply chain* risk*" OR "project resilien*" OR "supply chain* resilien*"). Results were further refined by limiting document types to papers and reviews and by selecting English language material only. There was no restriction regarding publication years. The indexed databases included were SCI-EXPANDED, SSCI, A&HCI, CPCI-S, and CPCI-SSH. The search resulted in a network of 1,275 papers from 577 journals, with 3,526 occurrences of authors and 39,330 cited references spanning over 67 years (1949–2015).

Next, the main descriptors (year, journals, authors, research areas and organizations) were extracted from the database and analysed with Histcite (http://interest.science.thomsonreuters.com/forms/HistCite). BibExcel (Persson et al., 2009) was used to prepare analytical matrices for the analysis of occurrence/co-occurrence of keywords, citations, co-citations, and geographical files. There are several software to conduct network analysis of literature reviews (Cobo et al., 2011). BibExcel was selected for the co-citation and static co-word analysis due to its flexibility to retrieve different bibliographic databases and its ability to prepare data for different network analysis packages. Network analysis was done with Pajek (De Nooy et al., 2005) (http://mrvar.fdv.uni-lj.si/pajek).

The frequencies of keywords' occurrences and citations, as well as co-occurrences of citations in the network were used to assist in mapping the main themes. The number of citations between a pair of papers (nodes) indicates the degree of connectivity in the network, with the cited papers being the edges. The frequency of citations a paper receives indicates the influence of these papers/authors in a given network. Both local and global citations are analysed. Local citations refer to the number of citations within the selected network of 1,275 papers. Global citations are the total number of citations received in the whole WoS database. The citation map is a visualization of nodes consisting of journal papers and a set of edges comprised by the references cited in these papers. A paper "C" is co-cited if papers "A" and "B" cite paper "C". The existence of a co-citation network is an indication of subject relatedness (Hjørland, 2013). It is likely that papers citing each other would be treating similar subjects. Furthermore, clusters of papers within a given co-citation network would be related to similar sub-themes or conceptual domains within the network. Persson's party clustering heuristic was used to create thematic clusters within the co-citation network (Persson, 1994). The Appendix 1 shows the algorithm with examples of applications.

Co-word analysis was enriched further with a post hoc longitudinal analysis of co-occurrence of users and WoS keywords showing the evolution of main themes. The SciMAT software (Cobo et al., 2012a) was used to build thematic clusters and to show Callon's thematic strategic diagrams (Callon et al., 1991; Cobo et al., 2012b). The strategic diagrams are based on the co-occurrence of keywords measured by the similarity index $e_{ij} = c_{ij}^2/c_i c_j$, where e_{ij} is the equivalence index, c_{ij} is the number of documents in which two keywords i and j co-occur, c_i and c_j are the number of documents in which each one occurs (Cobo et al., 2011). Appendix 2 shows the "simple center algorithm" used to build thematic clusters using similarity measures in SciMAT. The strategic diagram is a tool to visualize two measures of co-occurrence of clusters: Callon's centrality and Callon's density (Callon et al., 1991; Cobo et al., 2011; Cobo et al., 2012b). Centrality measures the degree of interaction of a network with other networks. It is calculated as $c = 10\sum e_{kh}$, where k is a keyword belonging to the theme and h a keyword belonging to other themes. Density measures the internal strength of the network, and is equal to $d = 100(\sum e_{ij}/w)$, where i and j are keywords belonging to the theme and w is the total number of keywords in the theme. The results presented here are based on density and centrality of the h-index of the keywords. The h-index is simply defined as the number of papers with citation number $\leq h$ (Hirsch, 2005). Callon's strategic diagram and the meaning of themes located in each quadrant of the diagram are depicted in Fig. 2.

Density

Developed but peripheral areas	Central and developed areas – motor themes	
Peripheral and underdeveloped areas (boundaries) – Usually new or disappearing themes	Central but less developed areas. Important but transversal and generic.	Centrality

Fig. 2. Callon et al. (1991) four quadrants of the strategic diagram.

3.2. Results and discussions of the bibliometric and network analysis

The findings of the bibliometric analysis described next enrich the content analysis and the research agenda. The bibliometric data attest the diversity and vigour of research in this area and complements the tertiary research in important ways. First, it allows the quantification of the structure of the research fields of SCM and PM through a co-citation network analysis. Second, this makes it possible to visualize the research fronts of SCM and PM as separate networks of authors citing each other in isolation (e.g., one research front does not refer to the other, even if they are treating similar concepts). Third, it eases the identification of the main themes discussed by the lead authors in the different research streams through the analysis of the co-occurrence of words in titles, keywords, and abstracts of selected papers. Fourth, it eases the identification of the evolution of themes through a longitudinal post hoc analysis of the interaction among keywords.

This subsection analyses the main descriptors first, followed by the keywords and co-citation network analysis, and closes with an analysis of the thematic evolution of the field.

3.2.1. Study descriptors

The first indexed publication in WoS appears in 1949, in a mathematics research paper authored by Eckmann (1949) about polyhedron projections in complex numbers theory. Since then, publications have appeared in other WoS research areas. Currently, engineering, business and economics, operations research and management science, and computer sciences are the prevailing research domains in which the constructs are being defined and applied, as depicted in Table 2. This finding confirms the multidisciplinary nature of the field.

The number of publications per year for the first five WoS research areas since year 2000 is in Fig. 3. There is a constant trend upward in all the main research areas, which corroborates the increase observed in the first part of this article along the tertiary analysis (see Subsection 2.2). After 2012, one can notice a plateau for engineering and a faster increase in the number of publications in the business and economics research area than in the other areas.

Table 2
Number of publications by ten main WoS research areas.

WoS research areas	Publications
Engineering	416
Business and economics	369
Operations research and management science	203
Computer science	190
Mathematics	133
Environmental sciences and ecology	76
Construction and building technology	67
Information science and library science	38
Meteorology and atmospheric sciences	34
Transportation	33
Total	1,559

Note: a paper can appear in more than one research area.

Table 3 depicts the five authors with the larger number of publications by WoS research area and number of publications. Marle worked mainly in risks in information systems and software development, publishing often in co-authorship with Vidal. Keil focuses in large engineering projects complexity and risk management. Wagner publishes in SC complexity, vulnerability, risks, and resilience. Chan writes on vulnerabilities, risk assessment, and risk management in large construction projects in China. Not surprisingly, these most prolific authors are from the diverse fields of SCM and large projects (generally TMOs) in software development and construction. These research areas (column 2 of Table 3) are representative of the diversity involved in the analysis, reinforcing the multidisciplinary perspective of the subject.

Table 4 reports the twenty main journals by number of publications, local citation, and global citation scores, ranked by the number of publications. Among the five first ranked in number of publications, the *International Journal of Project Management* and the *Journal of Construction Engineering and Management-ASCE* have much larger yearly global citations than local citations scores, which shows that they have a broader audience globally, reaching beyond the confines of the selected network of papers. Three journals appear among the five most influential in both local and global citations: the *International Journal of Production Economics*, the *International Journal of Production Research*, and the *Journal of Business Logistics*.

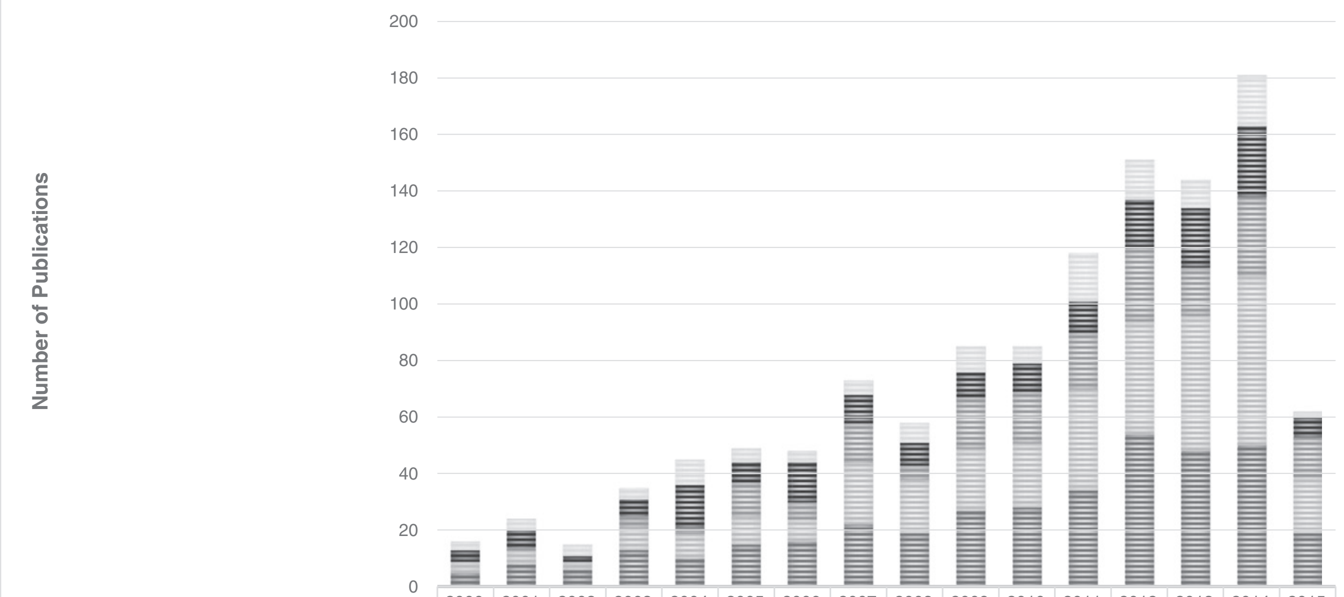
The distribution of publications by organization and by country is shown in Table 5. Among the top ten organizations, two are located in Asia (Hong Kong and Singapore), two are in Europe (France and UK), one in Canada, and the remaining are in the USA.

The distribution of authors by country is shown in Table 6. The large majority of authors is located in Europe (especially UK), USA, and China. Author's occurrence is measured by the number of times he/she authored or co-authored a paper in the network. The occurrence of authors from continents other than Europe and North America is not negligible and attest to the vitality of the research field worldwide.

3.2.2. Keywords and co-citation network

The number or times a paper is cited is used here as an indication of its influence among scholars. Keywords appearing in titles, user's keywords, and abstracts will guide the search for identifying the most frequently cited words and themes. The co-citation network closes this subsection and is geared at identifying influential researchers and prevalent themes in both SCM and PM areas.

Table 7 depicts the total number of citations for the top five papers, ranked by global citations in the upper panel and by local citations in the bottom, as well as the ratio of local citations at the end of the period to the number of local citations at the beginning and after publication. Papers that are more influential closer to the publication date than later will have ratios below one. The higher the ratio, the higher the growing influence of the paper in the network of citations as time passes, showing an enduring influence in the field. Citation counts are



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Mathematics	3	4	4	4	9	5	4	5	7	9	6	17	14	10	18	2
Computer Science	4	6	2	6	15	7	14	10	8	9	10	11	17	21	25	7
Operations Research & Management Science		1		4	2	12	6	14	5	18	18	20	26	17	28	14
Business & Economics	4	5	3	8	9	10	8	22	19	22	23	36	40	48	60	20
Engineering	5	8	6	13	10	15	16	22	19	27	28	34	54	48	50	19

Fig. 3. Number of publications per year and research areas.

provided as standard reports from Histcite software. Local citation shows the count of citations from the papers included in the co-citation network, excluding the author's self-citation. Thus, the local citation analysis shows the number of times a paper is cited within the network of selected papers. Global citation shows the count of citations in the whole WoS. Hence, global citation analysis shows the total number of citations, including other disciplines and research areas.

As seen in Table 7, both Chopra and Sodhi (2004) and Tang (2006) appear among the five top-ranked papers for local and global citations, indicating that they appeal to a large audience going beyond the network. Both are in the area of SC. Two papers highly ranked on the global score have no impact in the network, which is not surprising as they come from the fields of finance (Graham and Harvey, 2001) and medicine (Kessler et al., 2007). The same applies to Griffin and Hauser's (1996) paper, which focuses closely on NPD despite being in the OM research area. All SC top-ranked papers in local citations have an enduring and growing influence on the field, with LCS ratios well above the unity.

Table 3
Main authors by number of publications.

Authors	WoS research areas	No. of papers
Marle, F.	Management; operations research and management science	11
Keil, M.	Management; operations research and management science	11
Wagner, S.M.	Management; operations research and management science	9
Vidal, L.A.	Computer science, hardware and architecture; computer science, software engineering	8
Chan, A.P.C.	Mathematics, applied; mathematics	7

The frequency of occurrence of words in the papers provides a first reading of the themes in a given area. Table 8 is a list of the most popular words appearing in titles, user keywords and abstracts of all 1,275 selected papers.

It is no surprise to see a high frequency of occurrence of the search keywords of complexity, uncertainty, risk, project, and supply chain. The fact that risk is the most frequent word in all panels of Table 8, and resilience only appears as an emergent theme at the bottom of the list of user's keywords, is adherent to the findings of the tertiary research. The words construction, software, information, and systems appear frequently as well, which is not a surprise either, as these words are associated with TMO projects (construction) or with both TMO projects and SC (software and information systems). Words related to research methods also appear frequently, such as data, approach, model, method, study, assessment, fuzzy, framework, case, and simulation. One should mention the high frequency of words China and climate change as well, most likely reflecting the importance of China worldwide and the regained interest in the environment in both fields. Briefly, the most cited words relate to the substantive research areas and methods, but they also reveal a concern with management, costs, performance, and research methods.

Table 4
Main Journals by number of publications, local and global citation scores.

No.	Journal	No. of papers	TLCS/y	TGCS/y
1	International Journal of Project Management	43	9.54	63.10
2	Journal of Construction Engineering and Management-ASCE	37	4.17	44.30
3	International Journal of Production Economics	32	32.27	133.90
4	International Journal of Production Research	32	16.33	55.09
5	Supply Chain Management—An International Journal	23	16.30	44.92
6	International Journal of Physical Distribution and Logistics Management	20	12.80	38.27
7	IEEE Transactions on Engineering Management	19	5.62	38.30
8	Project Management Journal	15	2.46	15.50
9	Journal of Management in Engineering	14	1.53	14.34
10	Technovation	14	1.94	27.98
11	Journal of Business Logistics	13	19.29	45.69
12	International Journal of Logistics Management	11	10.69	31.24
13	Computers and Industrial Engineering	10	2.49	9.74
14	Decision Sciences	10	10.28	36.14
15	International Journal of Operations and Production Management	10	4.36	23.80
16	Journal of the Operational Research Society	10	2.75	9.72
17	Production and Operations Management	10	5.92	16.65
18	European Journal of Operational Research	9	5.84	46.86
19	Expert Systems with Applications	9	2.81	25.62
20	International Journal of Logistics-Research and Applications	9	1.63	3.78

Note: TLCS/y: total local citation score per year; TGCS/y: total general citation score per year.

Co-citation network clustering is a method to explore thematic areas further, as described in Subsection 3.1. In the network, there were 54,188 pairs of co-citations among the

Table 5
Twenty main research organizations by country and number of publications.

Organization	Country	No. of papers
Hong Kong Polytech University	Hong Kong	22
Georgia State University	USA	16
University of Nebraska	USA	14
National University of Singapore	Singapore	13
École Centrale de Paris	France	12
Iowa State University	USA	12
University of Washington	USA	11
University of Tennessee	USA	11
Arizona State University	USA	11
Texas A&M University	USA	10
Cranfield University	UK	10
MIT	USA	10
Michigan State University	USA	10
University of North Texas	USA	9
North Carolina State University	USA	9
Northeastern University	USA	9
University of Southern California	USA	9
Duke University	USA	9
University of Toronto	Canada	9
University of Colorado	USA	9

Table 6
Unduplicated number of authors per country.

Countries	Authors	Countries	Authors	Countries	Authors
Europe					
UK	165	Poland	12	Hungary	2
Germany	75	Belgium	12	Belarus	1
France	66	Greece	11	Croatia	1
Italy	46	Austria	11	Bulgaria	1
Spain	44	Romania	9	Bosnia and Hercegovina	1
Switzerland	42	Ireland	8	Ukraine	1
Netherlands	35	Portugal	7	Latvia	1
Sweden	27	Serbia	5	Slovakia	1
Finland	24	Cyprus	3	Estonia	1
Norway	18	Slovenia	3	Czech Republic	1
Denmark	13	Lithuania	2		
Total					649
North America		South America			
USA	443	Brazil	9	Colombia	1
Canada	62	Mexico	4	Venezuela	1
		Chile	3		
Total	505				18
Asia and Middle East					
China	121	Iran	18	Qatar	2
Taiwan	47	Israel	11	Lebanon	2
India	31	Russia	9	Egypt	2
South Korea	28	Saudi Arabia	6	Pakistan	1
Singapore	23	Indonesia	4	Iraq	1
Turkey	22	Malaysia	4		
Japan	21	United Arab Emirates	3		
Total					356
Oceania					
Australia	43	New Zealand	7		
Total					50
Africa					
South Africa	5	Zimbabwe	1	Mali	1
Tunisia	2	Algeria	1	Morocco	1
Nigeria	2				
Total					13
Grand total					1,591

39,330 cited references. The top 30 most cited papers in local citations were selected for co-citation analysis. The selection of top-ranked papers make the analysis less cumbersome and also avoid clobbering the network with low-ranked papers with few citations, those that are expected to be less influential in the field (de Nooy et al., 2005; Janssen et al., 2006; Persson et al., 2009). The manual choice of a cut point is somewhat arbitrary and subjective, but it resulted in stable networks after experimenting with some other cut points around the value of 30. This choice balances the desire to represent several points in the graph with the need of having less cumbersome graphs and identifiable nodes (Janssen et al., 2006). The selection resulted in 299 co-citation pairs. The application of Persson's (1994) party clustering algorithm to the co-citation pairs resulted in two dissociated clusters, depicted in Table 9 and Fig. 4. Cluster 1 regroups the most influential papers in the SCM field. Cluster 2 regroups the most influential papers in the area of PM. Table 9 provides a panel for each cluster listing their respective lead papers, providing a description of their themes and the number of their links in the network. One may notice the

Table 7
Top five papers ranked by local and global citation.

Authors	Local *	Global	LCS(e/b)	Discipline
Ranked by global citation				
Graham and Harvey (2001)	3	651	0	Finance
Griffin and Hauser (1996)	2	420	0	OM/NPD
Tang (2006)	84	365	13.33	SC
Kessler et al. (2007)	0	314	0	Mental health
Chopra and Sodhi (2004)	74	278	29.00	SC
Ranked by local citation				
Tang (2006)	84	365	13.33	SC
Chopra and Sodhi (2004)	74	278	29.00	SC
Craighead et al. (2007)	56	184	8.75	SC
Schmidt et al. (2001)	48	230	5.00	PM
Manuj and Mentzer (2008)	39	105	7.00	SC

OM, operations management; LCS (e/b), ratio of local citations at the end/beginning of a period; NPD, new product development.
* Excludes self-citation.

absence of interfaces in the thematic areas between both clusters, having Cluster 1 as a direct focus on SC issues and Cluster 2 on PM topics, especially in large software development and construction projects.

Fig. 4 depicts the two clusters well apart from each other, with no cross-fertilization between SCM and PM fields. They resort to different analytical traditions and do not cite the same authors, although both areas treat the same basic concepts, with several commonalities stressed throughout this article.

3.2.3. Thematic evolution: 1949–2015

The longitudinal analysis of users and WoS keywords shows a growing number of keywords in the successive periods, as depicted in Fig. 5.

The number of keywords is inside the circles for each period in Fig. 5, with the outgoing and incoming arrows indicating, respectively, the number of keywords leaving and arriving at a given period. Numbers in parentheses are the proportion of keywords that went from one period to another. Total number of keywords went from 393 in the 1949–1999 period to 3,424 keywords in the 2010–September 2015 period, showing a growing diversity of themes.

Fig. 6 shows the main themes for each period. The thickness of the lines is proportional to the strength of the links among themes from one period to another. The solid line means that the theme keeps the same name in the next period or the theme in the following period incorporates a theme with another name from the preceding period. For instance, management in 2005–2009 merges with performance in 2010–2015 through a solid line because it is a keyword belonging to performance. A dotted line means that the themes share elements (sub-themes) that are not the name of the themes. For instance, some elements of management in 2005–2009 are associated with risk management, project management, and systems in 2010–2015 resulting in a dotted line linking the clusters in the two periods as management is not a keyword of risk management, project management, or systems. The size of the circles is proportional to the *h*-index of each theme and shows the impact of the theme

Table 8
Most frequently cited words.

Words	Frequency	Words	Frequency
I. In Titles			
Risk *	562	Uncertainty *	83
Project *	421	Construction	75
Supply *	253	Product	49
Chain *	232	Study	67
Management	190	Performance	55
Model	152	Information	48
Analysis	114	Software	48
Approach	97	Fuzzy	46
Development	87	Case	45
Assessment	86	Complexity *	45
II. In user keywords			
Risk management *	144	Project risk *	27
Supply chain management *	86	Complexity *	26
Project management *	83	Simulation	25
Supply chain risk management *	62	Supply chain *	22
Risk *	46	Monte Carlo simulation	18
Risk assessment *	38	Supply chain resilience *	18
Uncertainty *	37	Climate change	17
Supply chain risk *	36	Project complexity *	17
Project risk management *	33	China	13
Risk analysis *	29	Resilience *	12
III. In Abstracts			
Risk *	3,959	Process	609
Project *	3,385	System	557
Supply *	1,702	Factors	522
Management	1,509	Data	460
Chain *	1,350	Information	442
Model	1,296	Cost	441
Complexity *	864	Performance	421
Uncertainty *	834	Assessment	401
Method	812	Construction	348
Approach	660	Framework	331

* Search-keyword related (see Subsection 2.2).

in terms of citations received. The names of the themes are extracted from the densest theme in the cluster.

Systems and project management appear early in the co-word analysis (1949–1999) and are carried to the 2000–2004 period, joining the project management cluster. Cost-effectiveness and criticality appear as isolates in 1949–1999, and do not appear in the next period. Management appears as an influential theme in 2000–2004 and its influence is strengthened in 2005–2009 when it is also linked with risk management and design. Communication (2000–2004) merges into the themes of management and design in 2005–2009. The three themes of management, risk management, and design (2005–2009) merge with performance, strategy, risk management, project management, and systems, which appear as the actual themes for the period 2010–2015. It is worth noting that the themes of risk management gain dominance in 2005–2009 and performance seems to be the dominant theme in 2010–2015. Performance forms a cluster in association with the keywords of management, model, uncertainty, supply chain management, supply chain risk management, framework, perspective, and disruptions. Risk management includes supply

Table 9
Lead papers and themes in each cluster.

	Themes	No. of links
Cluster 1		
Chopra and Sodhi (2004)	Classification of SC risk categories in disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity. Devise risk mitigation strategies	6
Kleindorfer and Saad (2005)	Propose a conceptual framework for the joint management of risk assessment and risk mitigation for disruption risk management in SC. Classify risk sources in operational contingencies, natural hazards, terrorism, and political instability	6
Tang (2006)	Reviews quantitative approaches to mitigate SC risks through supply management, demand management, product management, and information management	5
Jüttner et al. (2003)	Sets an agenda for future research in SCRM. Makes a clear separation of risk sources (environmental, network, organisational), risk consequences (industry-specific), and mitigating strategies (avoidance, control, cooperation, and flexibility)	4
Harland et al. (2003)	Review definitions and types of SC risks and propose a tool for empirical assessment and management	3
Craighead et al. (2007)	Address the issue of the severity of SC disruption and relate it to the density, complexity, and node criticality of the network, as well as the mitigation capabilities of recovering and warning	2
Norrman and Jansson (2004)	Describe SCRM at Ericsson after a SC disruption due to a fire at a sub-supplier and how risks were mitigated	2
Christopher and Peck (2004)	Describe Cranfield University research on SC resilience. Define SC resilience and classify risks in internal to the firm (process, control), external to the firm but internal to the SC (demand, supply) and external to the network (environmental)	2
Jüttner (2005)	Defines the "philosophy, principles and processes" of SCRM from a practitioner perspective. Categorizes risks as demand, supply, process, and control	1
Cluster 2		
Barki et al. (1993)	Software development risk management to prevent time and cost overruns, and unmet user requirements	4
Schmidt et al. (2001)	Delphi survey to produce a rank-order list of risk factors for software development from panels of experts from Hong Kong, Finland, and USA	2
Boehm et al. (2003)	Defines software risk management as a discipline whose objectives are to identify, address, and eliminate risk items before they become either threats to successful software operation or major sources of rework	1
Keil et al. (1998)	Propose a framework to mitigate risks in software development in four categories of mitigation: (i) customer mandate, (ii) scope and requirements of projects, (iii) environment, and (iv) execution	1
Mcfarlan (1981)	Addresses questions to assess risk and to build a risk profile to choose management tools for projects of differing risk types. Classifies software project risks according to (i) project size, (ii) experience with technology, and (iii) project structure	1
Baccarini (1996)	Defines project complexity, with reference to construction projects. Project complexity is viewed from the angle of differentiation and interdependency in both organizational and technological dimensions	1

chain resilience, flexibility, networks, China, enterprise, perspectives, systematic literature reviews, and ERP. Strategy includes the sub-themes of supply-chain risks, disruption risks, mitigation, firm performance, operations, governance, environmental uncertainty, and competitive advantage. Project management's cluster comprises risk, complexity, product development, construction, organizations, optimization, communication, and projects. Two new clusters emerge in this last period: demand (associated with the keywords of coordination, inventory management and random-yield) and decisions (forming a cluster with the keywords of capacity, inventory and supply chain). One may notice that, not surprisingly, the search keywords are present in the themes and sub-themes.

The strategic diagrams for the four periods are shown in Fig. 7. The size of the circles is proportional to the *h*-index and indicates the impact of the theme in the field, measured by the consistency of the citations received.

The keyword systems has a high centrality in 1949–1999. Project management appears as a central but yet unconsolidated theme in the first period (see Fig. 2). It remained on the same lower right quadrant of low density and high centrality in 2000–2004. It merged with risk management as seen in Fig. 6 in 2005–2009 and reappeared in 2010–2015, moving left to a less central and lower density position. This trajectory might partly be a reflection of the appearance of new themes related to SCM and to the evolution of project management towards the integration of complexity, uncertainty and risk management. Looking at the right upper corner of the diagrams, we locate the dominant themes of each period, those with high centrality and high density: management (2000–2004), risk management and management (2005–2009), performance and strategy (2010–2015). Themes with high centrality and low density are important for the research field, but are yet to be further developed. They evolved from project management (1949–1999) to communication and project management (2000–2004) to systems and risk management (2010–2015).

4. Similarities and contrasts

There are striking similarities and important differences remaining in the way both fields treat the concepts of complexity, uncertainty, risk, and resilience. Table 10 summarizes the main similarities and contrasts.

PM and SCM fields evolved recently from operations research, computing, engineering, and management and are largely unconsolidated research fields, which partly reflects the diversity of theories and definitions in both fields (Alfalla-Luque and Medina-Lopez, 2009; Bredillet, 2008; Bredillet, 2010; Hohenstein et al., 2015). As a result, both present inconsistent definitions of phases, elements, measurement, and assessment

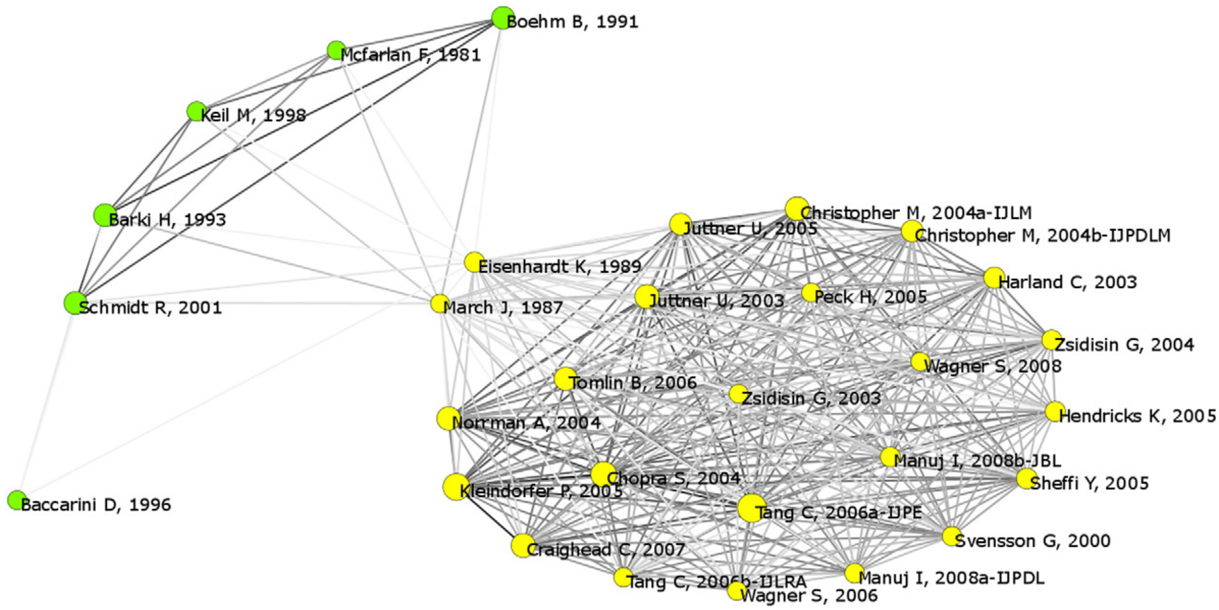


Fig. 4. Co-citation network.

tools (Bredillet, 2008; Bredillet, 2010; Hohenstein et al., 2015; Lehtiranta, 2011).

Despite the recent efforts to incorporate complexity thinking in PM (Bredillet, 2010; Lehtiranta, 2011), the field is mainly concerned with individual firms, while the scope of SCM evolved quickly from the focal firm's perspective to a network view. Drivers, origins, and dimensions of complexity are treated in a similar manner in PM and in SCM (e.g., Geraldi et al., 2011; Serdarasan, 2013). Uncertainty appears as a dimension of complexity (a driver or antecedent of risk) in both fields (Jüttner et al., 2003; Lehtiranta, 2011). In SCM, uncertainty can bear positive and negative results (Simangunsong et al., 2012), while it is mainly viewed as a source of harm in PM literature (Lehtiranta, 2014).

The concept of risk has important similarities in both areas. It is defined as being objective and subjective (Jüttner et al., 2003; Lehtiranta, 2014; Zhang, 2011), results from the probability and impact of harm (Rao and Goldsby, 2009; Taroun, 2015), and reflects the variance of possible SC outcomes (Jüttner et al., 2003) or of projects' costs and schedules (Taroun, 2015). Both fields also converge in incorporating complexity (and uncertainty) thinking in risk management. However, while unknown uncertainty drives towards resilience in SC, it tends to evolve to crisis management in TMOs. PM predominantly define risks from inside-out, looking at the firm's internal relations and into performance risks before looking at relational risks in the network (Lehtiranta, 2011). SCM seems to be more prone to look at risks from the network perspective before looking inside the firm, looking at risks from an outside-in perspective, in Lehtiranta's (2011) terms. This might be partly understood due to the origin of the concept of risk, which was product-related in PM (Bredillet, 2010) and network-related in SCM (Jüttner et al., 2003).

Resilience appears as a new theme for SCM and is absent from most research in PM, or is treated as "crisis management" in TMO projects. Both the concepts of resilience and "crisis management" are related to unforeseen events. Those similarities and contrasts shape the research agenda outlined in the conclusion of this paper.

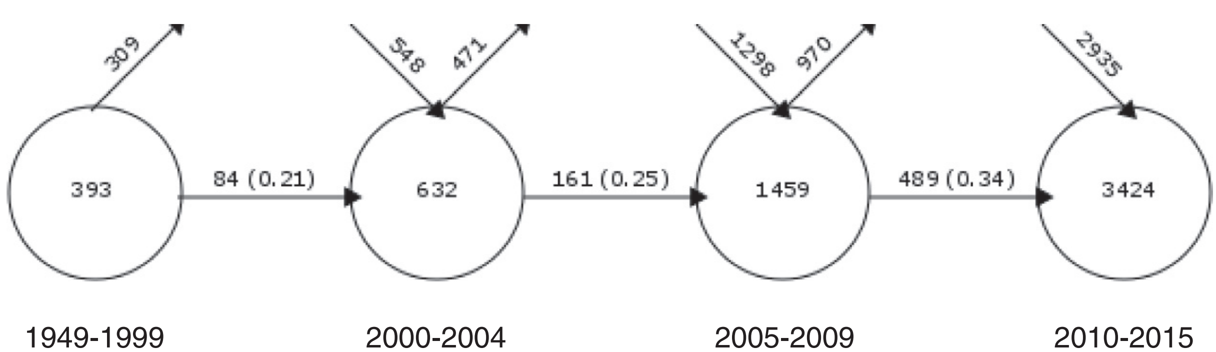


Fig. 5. Overlaping map of stability of keywords between periods.

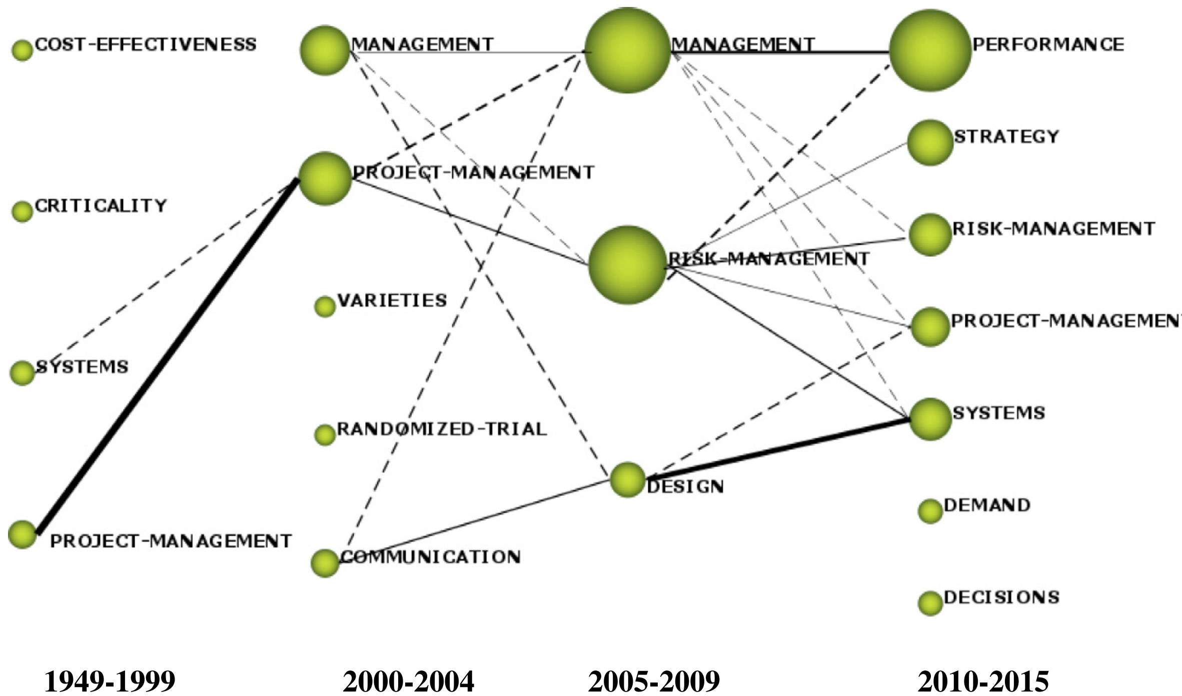


Fig. 6. Complexity, uncertainty, risk and resilience: thematic evolution.

5. Conclusion and research agenda

This paper is an attempt to contribute to elicit the concepts of complexity, uncertainty, risk, and resilience and their interactions in both PM and SCM. It offers a novel approach to the theme by conducting structured, transparent, and reproducible tertiary research analysis of literature reviews and bibliometric network of co-citation and co-word (static and longitudinal) analysis of primary studies. Findings from both research approaches do not contradict each other. This point reinforces the robustness of the research method adopted and highlights the importance of combining these different approaches to corroborate and complement the research synthesis.

The tertiary research reveals a growing number of publications in all four of the concepts analysed in this paper and attests the multidisciplinary nature of the field. This is corroborated by the bibliometric analysis that additionally shows a faster increase in the number of publications in business and economics among all research areas, with a plateauing effect for engineering, after 2012. In the static analysis of co-words, construction appears in relation to PM, while the words software, information, and systems seem to bridge PM and SCM, which reinforces the commonalities among TMO and SCM.

Findings from both tertiary and bibliometric analyses indicate that PM and SCM appear to treat the concept of risk more extensively than the germane concepts of complexity and uncertainty. On the one hand, the tertiary research shows a paucity of literature reviews in complexity, uncertainty, and resilience in both disciplines when compared with risk. Moreover, there is a lack of literature reviews in resilience in PM. On the other hand, the static analysis of co-words corroborates this finding among the primary researches as well. Resilience only appears as an emergent theme, situated at the bottom of the list of most frequent user's keywords. In the longitudinal analysis of co-words, risk appears as a theme in 2005–2009 and in 2010–2015. It also appears more often as a sub-theme in the thematic clusters then the other three concepts of complexity, uncertainty and resilience. Systematic literature reviews appear as a sub-theme of the risk management cluster in 2010–2015. This is coherent with the tertiary research findings, as 12 out of the 22 literature reviews retrieved in both PM and SCM were about risk and were published between 2011 and 2015. In addition, the bibliometric analysis provides the evolution of themes, showing management as a core theme in 2000–2004, with high centrality and high density, while risk management appears as a core theme in 2005–2009 and performance and strategy in 2010–2015.

Looking into PM and SCM, this paper makes four main contributions. The novel association of tertiary research and bibliometric analysis of primary data to bridge the fields is a first significant contribution, as already quoted. To the best of our knowledge, this is the first paper that blends these two research approaches, namely, tertiary research and bibliometric analysis of co-occurrence of citations and of static and longitudinal co-words network analysis. Second, the paper offers a synthesis framework for both SCM and PM originated in a tertiary research displaying the relationships and interactions among the concepts of complexity, uncertainty, risks, and resilience in both fields. Third, commonalities among concepts in SCM and in large projects as TMOs are worth emphasizing. Both fields emerged in the last quarter of the last century. They are new and unconsolidated. Both lack tools for empirical tests of theories and management schemes. Uncertainty is a driver and antecedent of risk, with positive and negative consequences,

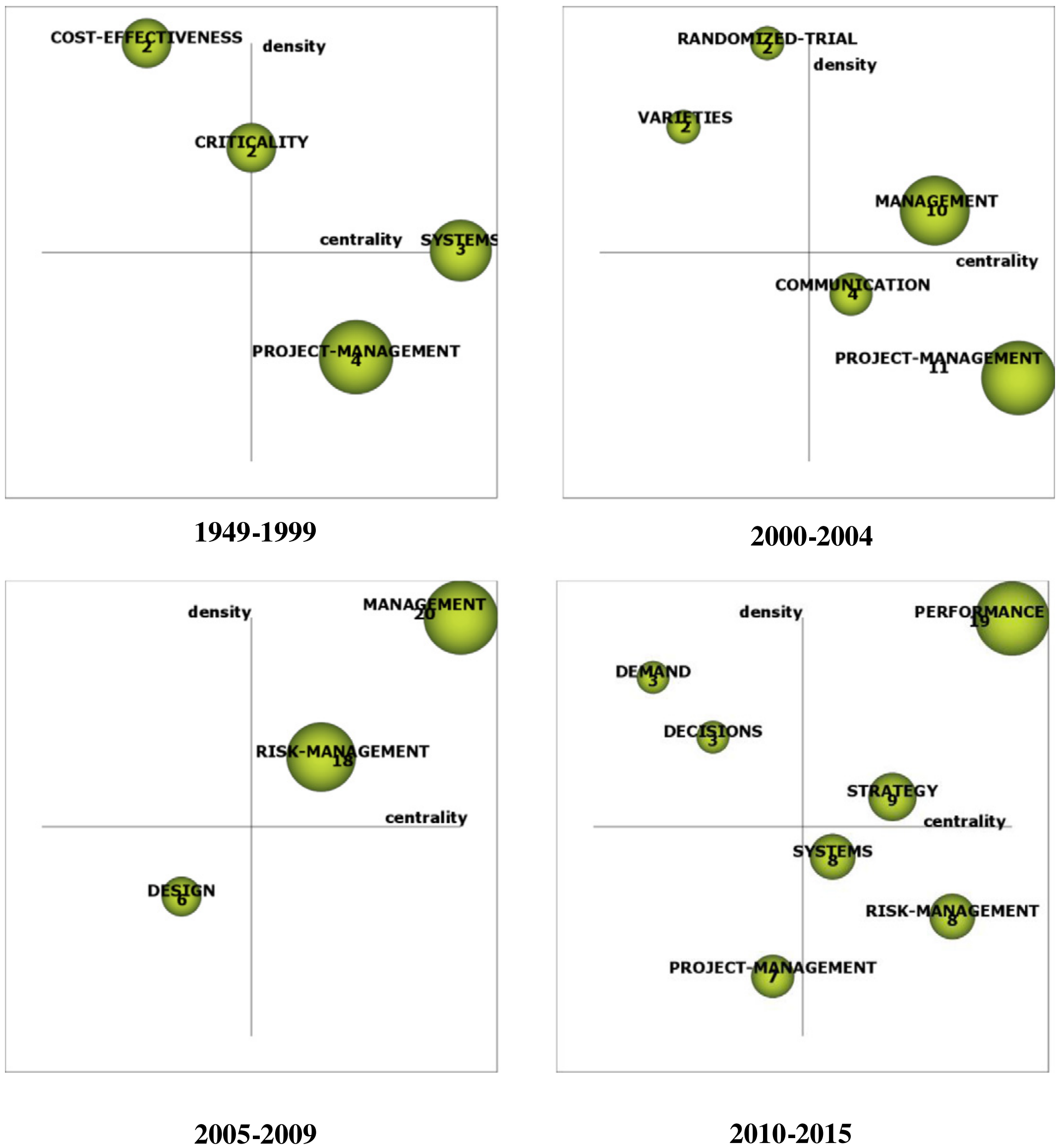


Fig. 7. Strategic diagrams based on *h*-index per period.

although PM refers mainly to the latter. The basic concept of risk emanated from the mathematics as the by-product of the probability of occurrence and the severity of the risk is common to both areas. TMOs and SCM view risk as internal and external to the focal firm, contrary to the prevalent view of risk as internality in single-firm projects. The relationships among concepts follow the same logic: uncertainty is a dimension of complexity, complexity links to the perception of uncertainty, uncertainty relates to the perception of risks and mitigation strategies in a continuum that is common to both PM and SCM literature. Resilience is an emergent issue for both. Resilience in SCM and "crisis management" in PM are the consequence of unknown uncertainties. The fourth contribution is the evidence from the analysis of the occurrence of document co-citations that there are two unrelated clusters of authors not quoting each other beyond the realm of their own field of expertise. These two clusters emerged: authors quoting PM literature do not cite SC authors, and vice versa. Although this result is not entirely surprising due to the specificity of the two areas, there might be some lost opportunities for cross-fertilization among research areas as they show several commonalities.

There are important ways to strengthen and enrich this study. The authors of this study propose a research agenda in seven topics. First, the analytical categories of complexity, risk, and resilience could be researched further using word-mining techniques of content analysis and co-word network analysis. Second, the lack of coverage of the concept of resilience in both SCM and PM literatures deserves more attention by scholars and is an opportunity to aid project and SC management, as resilience mitigates risk. Third, despite similarities in concepts, the research streams of both SC and PM seem to advance in parallel with little cross-fertilization among the fields. They could benefit from further investigation of commonalities and

Table 10
Similarities and contrasts between SCM and PM.

Dimensions	Supply chain management	Project management
Start time of academic research	Early 1980s for SCM and early 2000 for resilience	Early 1990s for PM and early 2000 for complexity and "crisis management" in TMOs
Theoretical basis	Unconsolidated: operations research, management and business fields. Divergent concepts from theory building (Alfalla-Luque and Medina-Lopez, 2009, Hohenstein et al., 2015)	Unconsolidated: operations research, engineering, computing, management and business fields. Incompatible and incomplete theories and perspectives Bredillet (2010)
Scope	Start with individual firms and expand to the network (Colicchia and Strozzi, 2012)	Still mainly focused in individual firms (Lehtiranta, 2014)
Definition of phases and elements	Inconsistent	Inconsistent
Measurement and assessment	Incipient and inconsistent. Lack of empirical tests. Lack of tools (Hohenstein et al., 2015)	Inconsistent (e.g., Bredillet's (2008) "nine schools" of PM research). Lack of tools for relational risk management (Lehtiranta, 2011)
	Currently network-related (Colicchia and Strozzi, 2012)	Individual firm related, evolving to a network view in TMOs (Lehtiranta, 2011)
	Drivers: static, dynamic and decision-making (Serdarasan, 2013)	Dimensions: structural, uncertainty, dynamic, pace, and socio-political. (Geraldi et al., 2011)
Complexity	Origins: internal, supply–demand interface, external/environmental (Serdarasan, 2013)	
	A dimension of complexity (Serdarasan, 2013)	A dimension of complexity (Geraldi et al., 2011)
	A driver and an antecedent of risks (Jüttner et al., 2003)	A driver and an antecedent of risks (Perminova et al., 2008; Lehtiranta, 2011)
Uncertainty	Unknown uncertainty drives towards resilience (Heckmann et al., 2015)	Unknown uncertainty drives towards crisis management (Lehtiranta, 2011)
	Has negative and positive consequences (Simangunsong et al., 2012)	Has mainly negative consequences to be counteracted by risk management (Lehtiranta, 2014)
	Early definitions are network-related (Jüttner et al., 2003).	Early definitions are product-related (Bredillet, 2010).
	Variation in the distribution of possible SC outcomes (Jüttner et al., 2003).	Variance of costs and durations (Taroun, 2015).
Risks	Probability–impact risk model is common (Rao and Goldsby, 2009)	Probability–impact risk model prevails (Taroun, 2015)
	Based on its "subjective value" (Jüttner et al., 2003)	Can be objective or perceived (Lehtiranta, 2014; Zhang, 2011)
Risks	Outside-in: risk is relational, focused on the collaboration and coordination of decisions in the supply chain (Alfalla-Luque and Medina-López, 2009)	Inside-out: risk is rather related to performance and aspects that are interior to the company. Complexity thinking is evolving to relational risk concepts (Lehtiranta, 2011)
	Have both positive and negative consequences (Colicchia and Strozzi, 2012)	Positive consequences rarely included (Lehtiranta, 2014)
	Based on unforeseen events, i.e. "unknown uncertainty" (Hohenstein et al., 2015)	Treated as "crisis management" related to complexity and unforeseen events (Lehtiranta, 2011)
Resilience	Phases: readiness, response, recovery (Ponomarov and Holcomb, 2009), and growth (Hohenstein et al., 2015)	
	Might result from risk mitigation and risk management (Bhamra et al., 2011)	

differences in concepts between the two research streams. Tracing the parallel lines could assist in identifying where to bridge gaps. This line of inquiry will contribute to further clarifying the complementarities among the fields and to draw lessons for both research and practice. Fourth, the qualitative and quantitative content analysis should be pursued further to shed light on the most used concepts, their contexts of application, and their interactions. Fifth, empirical studies, such as surveys, case research, or bibliographic reviews of specific themes in the confluence of TMOs and SCM can use the proposed synthesis framework as a guide. Sixth, acknowledging that both fields started analysing the concepts within the confines of the individual firm, additional efforts should be engaged to extend research to the network and to several tiers within a given network. Seventh, the impact factors (*h*-index) of themes and sub-themes offered by the bibliometric analysis can aid in the selection of papers to be retrieved for a qualitative content analysis of the evolution of thematic clusters.

Acknowledgements

The authors are very grateful to the reviewers and guest editors for their comments and constructive feedback. This work was supported by CNPq, CAPES and Alexander-von-Humboldt Foundation research agencies.

Appendix 1. Persson's party clustering heuristics (adapted from Persson, 1994)

Document identification string used the last name and first initial of first author, coupled with publication year, volume number, first page of the article and journal name, as follows: Chopra S., 2004, V46, P53, MIT Sloan Manage Rev.

The core of the intellectual basis was identified by decrementing the number of co-citations required to enter the cluster, as exemplified in Table A1.

For example, Chopra and Kleindorfer entered cluster 1 at 6 co-citations, Tang entered at 5, Juttner at 4, and so on. Another cluster emerged in parallel at four co-citations incorporating the PM research front (Barki in Table A1). From the publication year, one can notice that PM cluster emerged earlier than SCM cluster (1981 and 2003, respectively). Single link clustering was allowed due to the relatively small number of co-citations.

The method starts with the creation of a citing–cited matrix with citing documents in columns and cited documents in rows. Cell values are one (1) if a given article cites a given document and zero (0) otherwise. Bibliographic coupling, or the number of shared references from two articles is obtained by the scalar product of the column. The number of co-citations between two cited documents is given by the scalar product of their respective rows. However, the number of co-citations is a rough measure of association. The number of citations received by an article and the length of the citation list influence co-citation strength. In Persson (1994), for example, if A cites B five times and A cites C five times, they do not have the same weight if B is cited twice as much as C. Conversely, one might assume that citations from short citation lists are more significant than are those from longer citation lists. To circumvent the problem, Persson (1994) suggests normalizing the citation matrix with a measure of association provided by fractional counts of co-citations, as follows.

$$NCC_{ij} = \frac{4\left(\sum_{d=1}^{n} \frac{CC_{ijd}}{L_d}\right)}{C_i + C_j} \tag{1}$$

where NCC_{ij} = normalized co-citation between i and j units; CC_{ijd} is the co-citation in document d (0 or 1); L_d = number of cited units in reference list of document d; C_i is the citation frequency of cited document i; C_j is the citation frequency of cited document j. The constant 4 multiplies the numerator to force the normalized co-citation index to vary from zero (no co-citation) to one (e.g., when a co-citation between two units appears in a reference list, which only contains two units).

The following clustering routine is applied:

- All co-citation links are sorted in descending order of co-citation links. At the same integer value, links are sorted by the normalized co-citation strength.
- The clustering starts with the most strongly related pair (Chopra and Kleindorfer in the example in Table A1). A cluster is formed if the next pair links to the first pair and the third author joins the first cluster (Tang in the example in Table A1). It requires at least three authors to form a cluster. If a link is not related to the clustered authors, it is "put aside" and waits for new clusters to form. This is what happened with Barki in the example in Table A1. The procedure continues until all links joins a given cluster and no isolated link is left.

Table A1
Co-citation threshold in descending order by clusters.

Cluster 1	No. of links	Cluster 2	No. of links
Chopra, S., 2004	6	Barki, H., 1993	4
Kleindorfer, P., 2005	6	Schmidt, R., 2001	2
Tang, C., 2006	5	Boehm, B., 1991	1
Juttner, U., 2003	4	Keil, M., 1998	1
Harland, C., 2003	3	Mcfarlan, F., 1981	1
Craighead, C., 2007	2	Baccarini, D., 1996	1
Norrman, A., 2004	2		
Christopher, M., 2004	2		
Juttner, U., 2005	1		

Appendix 2. Simple centers algorithm for clustering co-occurrence of words (based on Cobo et al., 2011, p. 150)

Pass 1 creates internal networks and pass 2 generates external links among networks.

1. Select parameters: MINe_{ij} (minimum number of co-occurrences between keywords i and j for inclusion); $MAX_{pass\ 1}$ (maximum number of pass 1 links); MAX_{tot} (maximum number of total links from pass 1 and pass 2)
2. Start pass 1
3. Begin pass 1 network from the highest e_{ij} from all possible keywords
4. From that link, add all possible subsequent links until no additional links are possible due to MINe_{ij} or $MAX_{pass\ 1}$ or MAX_{tot}. Remove all keywords included in the link from the list of available keywords for pass 1
5. Repeat steps 3 and 4 until no additional keyword pairs meet MINe_{ij}
6. Start pass 2
7. Return all keywords to the list of available keywords
8. Take the first pass 1 network
9. Generate all links between the current network and pass 1 nodes meeting the MINe_{ij} criteria in descending order of e_{ij} value. Stop when no keyword pairs meet the MINe_{ij} criteria. Do not remove keywords from the available list
10. Select the next pass 1 network and repeat step 9

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