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Research article

Can social network analysis contribute to supply chain management? A systematic literature review and bibliometric analysis

Hesham Fouad [a,b,*], Nazaré Rego [c]

[a] Arab Academy for Science, Technology and Maritime Transport, Aswan, Egypt
[b] Escola de Economia e Gestão, Universidade do Minho, Braga, Portugal
[c] NIPE, Escola de Economia e Gestão, Universidade do Minho, Braga, Portugal

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ABSTRACT

Social Network Analysis (SNA) is a modeling technique and analytical approach well-suited for identifying and examining the structural features of supply networks and the patterns of connections between members within the network. This paper aims to present a systematic review and bibliometric analysis by investigating network structural properties and metrics in supply chain management (SCM) research. The approach involved combining a systematic literature review with a bibliometric analysis, forming a two-part methodology to examine 113 articles published between 2008 and 2023 in 62 journals. Our systematic thematic analysis reveals how SCM researchers have applied SNA techniques in terms of the reported node-level and network-level structural metrics, including network configuration description metrics, centrality measures, supply network subgroups, and models of supply network structure and formation. We identify the gaps in the existing body of literature and propose potential directions for future research. By quantitatively analyzing, classifying, and visualizing bibliographic data of previous studies, this paper provides further insights into the application of network structural properties in SCM research. Furthermore, our findings contribute to a deeper understanding of the significance of the supply network's relational structure and configuration. Considering the disruptions to global supply chains caused by the COVID-19 pandemic and the Russo-Ukrainian War, our findings can contribute to a better understanding of strategic supply network design.

1. Introduction

Companies manufacture and distribute products using intricate and worldwide networks. Several factors, such as the number of suppliers, the diversity of technical and functional aspects, and the widespread geographic locations of supply chain members, contribute to the increased complexity of these global networks [1]. Previously, supply chain relationships were conceptualized as occurring among sequential, independent parties, where value is created by transforming raw materials into finished products [2]. As a result, supply chain research has predominantly focused on the dyadic level [3], a restricting perspective that tends to overlook much of the structural configuration and complexity of modern supply chains. There has been a growing recognition of the importance of viewing supply chains as interconnected systems that involve multiple actors and relationships [2,4]. Researchers studying supply

* Corresponding author. Arab Academy for Science, Technology and Maritime Transport, Aswan, Egypt.
E-mail addresses: h.m.fouad@aast.edu (H. Fouad), nazare@eeg.uminho.pt (N. Rego).

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chains are exploring aspects of Supply Chain Management (SCM) that go beyond the usual two-party relationships and adopting a network view of the supply chain [3–5].

Social Network Analysis (SNA) is a modeling technique and analytical method that is appropriate for detecting and examining the structural features of supply networks and the relationship patterns among the individuals or groups involved in those networks [4,6]. SNA helps to understand [7]: 1) the functioning of supply networks, both at individual companies and the entire network levels; 2) the significance of each firm within the network, determined by their respective positions; and 3) the impact of the network's structure on the performance of both individual companies within it and the overall network. Furthermore, it is particularly useful for studying how patterns of inter-firm relationships in a supply network can lead to competitive benefits by controlling the movement of resources and dissemination of knowledge [3]. Taking a network perspective through the techniques of SNA provides a means to conceptualize, visualize, and analyze the complex set of relationships in supply networks [8]. This knowledge provides insights into the potential for information sharing and innovation, the ability to access and control resources and power dynamics, the flexibility and adaptability of various supply chain configurations, and how improvements of linkages between partners could benefit their performance.

Several systematic literature reviews on SNA in SCM have been conducted in the past few years. Some of these reviews have been general and comprehensive [2,4,5,9] while others have focused on specific aspects, such as network structural properties in supply chain sustainability [10], disruptions mitigation in complex supply chain structures [11], or structural analysis for collaborative business ecosystems [12]. While previous reviews have made valuable contributions by identifying key themes and offering insights into the field, our analysis aims to build upon this foundation by providing a more comprehensive and detailed examination.

In this paper, we conducted a rigorous literature review and bibliometric analysis of the available literature by quantitatively analyzing, classifying, and visualizing bibliographic data. This provides further insights into the application of network structural properties in SCM research, which were not fully explored by traditional reviews. Our systematic thematic analysis reveals how SCM researchers have utilized SNA techniques, specifically focusing on reported node-level and network-level structural metrics such as network configuration description metrics, centrality measures, supply network subgroups, and models of supply network structure and formation. The analyses presented in this paper are essential to summarize the contributions of SNA for SCM and encourage academics to expand and complement research in the field. Thus, this study addresses the following research questions concerning SNA in SCM research.

RQ1. What is the current state of SNA in SCM scientific knowledge and how has it evolved?

RQ2. What are the characteristics of this research stream in terms of conceptual, intellectual, and social structure?

RQ3. How have SCM researchers applied SNA techniques?

RQ4. What are the emerging opportunities for future research?

The first research question lays the foundation by examining the overall development and current state of SNA within SCM, which includes identifying early work that served as intellectual roots for subsequent research. Building on this groundwork, RQ2 investigates the characteristics of previous work to identify and cluster the research themes. The first two questions set the stage for our subsequent investigation. RQ3 analyzes and presents examples of SNA application in SCM, highlighting how researchers have applied node-level and network-level structural metrics in their investigations. Finally, RQ4 identifies unexplored areas and potential avenues in applying SNA in SCM future research.

The four research questions collectively provide a comprehensive and structured approach to fulfill our aim. They guide the review and bibliometric analysis to cover the evolution, current state, application, and prospects of SNA in SCM. By answering these research questions, we provide a comprehensive and insightful analysis of SNA in SCM research and contribute to moving the agenda forward by revealing research trends and identifying future pathways for academic debate.

The organization of this paper is as follows. The next section describes the research methodology. Then, the results of bibliometric and thematic analyses are presented and discussed followed by the future research avenues. The final section concludes the study and discusses the limitations.

2. Materials and methods

This study followed a two-pronged methodology that combines a systematic literature review and a quantitative analysis of bibliographic data.

2.1. *Systematic literature review*

By using a process that is both replicable and transparent, a systematic review reduces bias and enhances the scientific foundation of the evidence [13]. With such motivation, this study followed the well-established guidelines for conducting systematic reviews outlined by Tranfield et al. [13]. These guidelines have been widely accepted and utilized in recently published SCM reviews [14–18].

The initial stage involved gathering relevant literature on the topic under investigation. Following Wichmann and Kaufmann [4], a search string was utilized to perform a Boolean search across article titles, abstracts, and keywords: ("supply chain" OR "supply network") AND ("SNA" OR "social network analysis" OR "network analysis") in Clarivate Analytics Web of Science (WoS) Core Collection databases [5]. In December 2023, a search was carried out, resulting in 698 articles. We limited our search to journals that are indexed by either the Social Science Citation Index (SSCI) or the Science Citation Index Expanded (SCIE). After eliminating proceedings, books, and editorial materials, the abstracts of the remaining articles (a total of 530) were evaluated according to the inclusion criteria outlined in Table 1. The research methodology framework is outlined in Table 2, and the flow diagram detailing the number of articles at every stage is provided in Supplementary Materials (A).

Our search strategy was inclusive rather than exclusive. According to Cooper [19], there are more scientific journals where relevant research could be published than what researchers in a particular research field usually look at. Given that the field of SCM is interdisciplinary, no restrictions were placed on journal categories or subjects in the search. The goal was to search across all journals indexed by SSCI or SCIE to avoid the possibility of missing relevant research. Moreover, no subjective limitations were placed on the publication year to ensure the broadest possible time frame. Finally, the selection criteria were limited to publications in English since it has been the primary language used in SCM literature [20]. Table 1 shows the relevant criteria that were used to evaluate and analyze the titles and abstracts. If the research abstract was not detailed enough, the entire text was examined to ensure that only papers that discussed theories or applications of SNA in an inter-organizational or inter-firm setting were considered for inclusion. A final set of 113 papers were included in this review.

2.2. *Bibliometric analysis*

Bibliometrics is a subfield of information science that quantitatively analyzes and classifies bibliographic data by framing representative summaries of the relevant literature. It has the potential to establish a methodical, clear, and repeatable review process using statistical analysis of science, scientists, or scientific activity [21–23]. This study used Bibliometrix [24], an open-source software package that offers a range of tools to conduct thorough quantitative bibliometric analyses. The package is written in R,[1] a highly capable programming language and environment for statistical computing and graphics that has gained immense popularity globally among researchers and data analysts. In addition, our analysis was supplemented by VOSviewer[2] and CiteNetExplorer,[3] software tools for network data visualization.

Bibliographic data contains rich subject descriptions in the form of keywords, subject classification terms, abstracts, authors, document titles, affiliations, etc. WoS databases were used to retrieve bibliographic data for the final set of articles (n = 113). Then, the exported files were loaded into the Bibliometrix R-package and converted into a bibliographic data frame [24]. The main bibliographic indicators determined were a summary of the key features of the bibliometric data, the most productive researchers, the most cited articles, keywords that appeared most frequently, the most cited references, the most cited authors, and author-level metrics that assess the productivity and citation impact of individual publications.

Several methods have been developed to generate research networks using various units of analysis [25]. This study involved conducting co-word analysis, co-author analysis, co-citation analysis, and bibliographic coupling. Co-word analysis reveals the conceptual structure of a research field by using word occurrence frequency in a set of documents. It produces semantic maps of the field using a similarity measure that facilitates the understanding of the cognitive structure [24,26].

We performed co-authorship analysis to analyze the social structure and research collaboration networks [27,28]. The most prevalent form of analysis in bibliometrics is citation analysis. It uses citation counts to measure the similarity between documents, authors, or journals and can be divided into bibliographic coupling [29] and co-citation analysis [30]. The former helps identify relationships among research groups, whereas the latter detects shifts in paradigms and schools of thought in each research field. Both techniques are employed to analyze the intellectual structure of a scientific research domain [25].

3. Results and discussion

3.1. *Overview of the dataset*

In this review, 113 articles that were published from 2008 to 2023 in 62 different journals were examined (as of December 2023). Detailed information about the reviewed articles is shown in Table 3.

The growth of scientific output within a particular field of research is an important measure of progress and potential directions for the future. Fig. 1 shows the annual distribution of published articles over time and the mean total citations per article. The compound annual publication growth rate is 6.30% with the highest number of publications in 2023 (n = 15), followed by 2020 and 2019 (n = 14). Approximately 38% of the articles in this review are from the last three years, suggesting that SCM scholars have taken a strong interest in SNA in recent years.

One measure frequently used to assess publication impact or influence is the average number of citations per year, shown in Fig. 2. For each year from 2008 to 2023, this metric was calculated by dividing the mean total citations per article by the citable years. What stands out in Fig. 2 are the three remarkable peaks in 2009, 2011, and 2015, with average citations per year of approximately 21.5, 12, and 21, respectively. The highest peak, in 2009, was the result of two highly cited articles. The first is "On social network analysis in a supply chain context" by Borgatti and Li [3], a key paper that outlined explanatory mechanisms invoked by network theorists to relate key social network concepts to outcomes of interest. This paper was also the highest ranked in terms of local citations (i.e., the number of articles that cite it in the 113 papers in the dataset) (n = 52), and global citations (n = 415). The second paper is "Supply chain

1 https://www.r-project.org.
2 https://www.vosviewer.com.
3 https://www.citnetexplorer.nl.

Table 1
Inclusion criteria.

Inclusion criterion	Rationale
Publication type: journal articles indexed by SSCI or SCIE	To obtain high-quality, peer-reviewed literature published by leading journals.
Publication year: any	To provide the most extensive time frame possible.
Language: English	The language most widely used by SCM researchers.
Relevance: SNA in SCM	The analysis aims to provide a comprehensive overview and investigate SNA in the context of SCM research. The inclusion criteria for papers were limited to those that covered theories or applications of SNA in the context of multiple organizations or firms. Articles focusing on SNA in different technical settings were excluded (e.g., engineering articles focusing on power supply networks or water supply systems, carbon emission networks, biological, epidemiological networks, or research networks).

Table 2
Research methodology framework.

Stage	Objective(s)	Method(s)	Software
Defining scope	Establish focus and delimitation	Research questions formulation: RQ1-RQ4	N/A
Literature search	Retrieve relevant literature	Search terms development	N/A
Refinement of search results	Segment, evaluate, and select relevant literature	Development of inclusion criteria	N/A
Bibliometric analysis	Quantitatively analyzes, classifies, and visualizes bibliographic data	Descriptive and network analyses	Bibliometrix R VOS Viewer CiteNetExplorer
Literature themes analysis	To reveal how SCM researchers applied SNA techniques	Development of a data extraction template organized by descriptive and thematic categories	N/A

Table 3
Dataset main information.

Description	Results
Timespan	2008: 2023
Journals	62
Articles	113
Average years from publication	5.42
Average citations per article	40.68
Average citations per year per article	4.93
References	6216
Keywords	
Keywords Plus	367
Author's Keywords	398
Authors	
Number of authors	332
Authors of single-authored articles	7
Authors of multi-authored articles	325
Authors Collaboration	
Single-authored articles	7
Articles per Author	0.34
Authors per Article	2.94
Collaboration Index	3.07

process integration: a theoretical framework" by Chen et al. [31] who proposed social network analysis as a relevant theoretical framework for studying supply chain process integration and its relationship to capability development.

3.2. Top researchers and collaboration networks

Our sample involved 332 unique authors, the majority of whom (325, 98% of the authors) published 106 multi-authored articles, around 93.8% of the total publications (n = 113). Co-authorship is considered one of the extensively documented forms of scientific collaboration [32]. The collaboration index is a metric used to determine how many authors contribute to a joint paper. It is obtained by dividing the number of co-authors by the number of multi-authored articles. In this study, the collaboration index is approximately three, which means that research teams in this field consist of three researchers on average. One alternative method for evaluating an author's productivity is to examine their output with both the number of publications they have produced and the number of times their work has been cited over time, as shown in Fig. 3. Each line represents an author's timeline, the bubble size represents the number of published articles, and the intensity of the bubble color is proportional to the total citations per year. Choi TY and Mula J have the

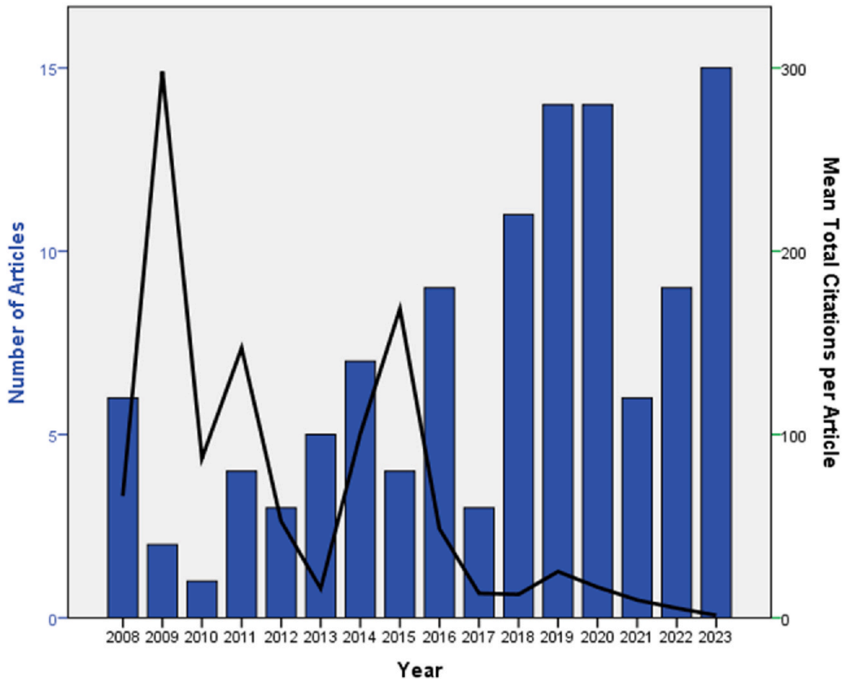


Fig. 1. Evolution of the number of articles and average number of citations per article.

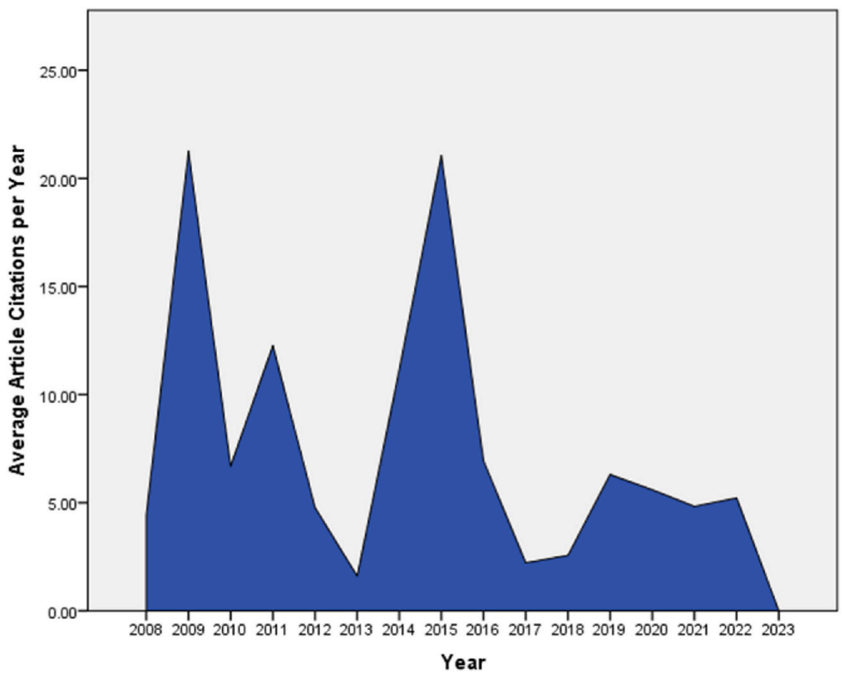


Fig. 2. Evolution of the average number of citations per article and citable year.

longest publication timeline of over 10 years with the first paper published in 2008 and 2011 respectively, while Bellamy MA authored 3 articles in 2014 with a total of 423 global citations.

3.3. Keywords and citation analysis

A co-citation map (Fig. 4) was created using VOSviewer software. The map was produced by analyzing the frequency with which

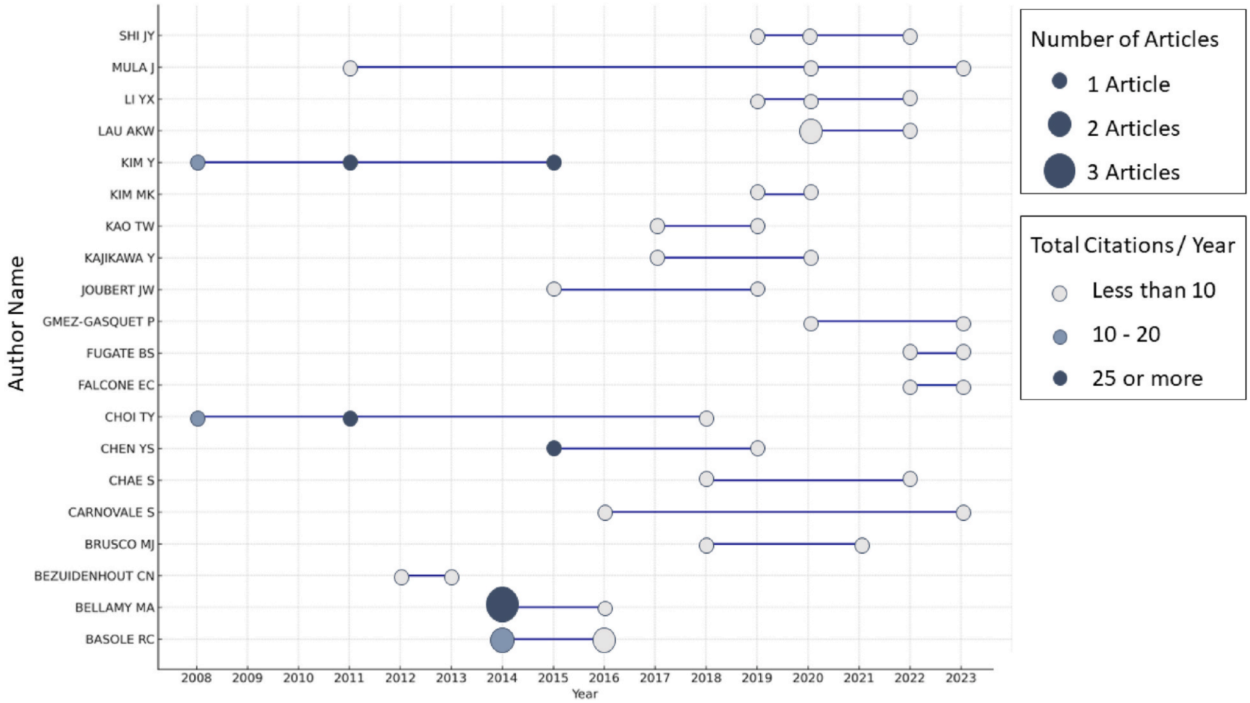


Fig. 3. Top 20 authors' production over the time.

two references were cited jointly in a research paper to establish their interrelatedness: a threshold of five citations was set to be included in the map, which resulted in 103 references. A strong co-citation relationship between articles means they are more similar, which suggests that articles within a cluster are probably related to the same topic [33]. References were grouped into three clusters (signaled using different colors). References within a cluster are densely connected and there are relatively few links connecting vertices of different clusters. The JSON file is provided in the Supplementary Materials to facilitate an interactive exploration of the network through the web-based version of VOSviewer.

Fig. 5 displays the citation relations between the top 40 references in terms of number of citations, thus indicating how publications built on each other. In this graph, publications are located close to each other if they are closely connected in the citation network. The early work is highlighted in blue color. The earliest top-cited publication in our dataset is Granovetter [34] on weak-ties theory, which suggests that distant, infrequent, and arm's length relationships generate new information and diversity from external resources that trigger innovation and opportunities for network members. Later, work by Granovetter [35] advanced the concept of embeddedness (i.e., the extent to which an organization is involved in the network of interrelations) by explaining how social structure influences the economic behavior of actors. Along the same lines, Coleman [36] introduced the concept of social capital, arguing that tangible and intangible resources are embedded within, available through, and derived from social interactions and connections with others. More recently, the seminal work of Burt [37] on social capital advanced the concept of structural holes. The main argument is that much of the competitive behavior and its results can be explained by the ability to access structural holes, which are viewed as opportunities for entrepreneurship in gaining information and obtaining power benefits. Concerning the centrality concept, Freeman's early work on centrality measures uncovered intuitions and conceptions that have been used to capture the idea of structural centrality in social networks [38,39]. Uzzi [40,41] focused on developing a systematic understanding of the concept of embeddedness and developed a formulation that explains the impact of embeddedness and network configuration on economic behavior. Lastly, the work of Wasserman and Faust [42], also one of the most cited earlier works, was one of the initial standard texts discussing the SNA method and its applications. Together, these fundamental publications can be regarded as the intellectual roots of SNA in the SCM field.

3.4. Key publications, keywords analysis, and bibliographic coupling

To identify publications with high impact, articles were ranked based on total citations (Table 4), and normalized citations (i.e., the proportion of a particular article's citations compared to the average number of citations received by all articles in the sample published in the same year), a measure based on the idea that publications that were released a long time ago have had more opportunities to gather citations than those that have been recently published (Table 5).

WoS Clarivate Analytics database uses a method that creates words or phrases commonly found in the titles of an article's references but not in its title (the keywords Plus). KeyWords Plus capture the document content with greater depth and variety [43]. In Fig. 6, we have visually depicted the frequency of occurrence for the top 50 out of the 367 KeyWords Plus included in our sample. The

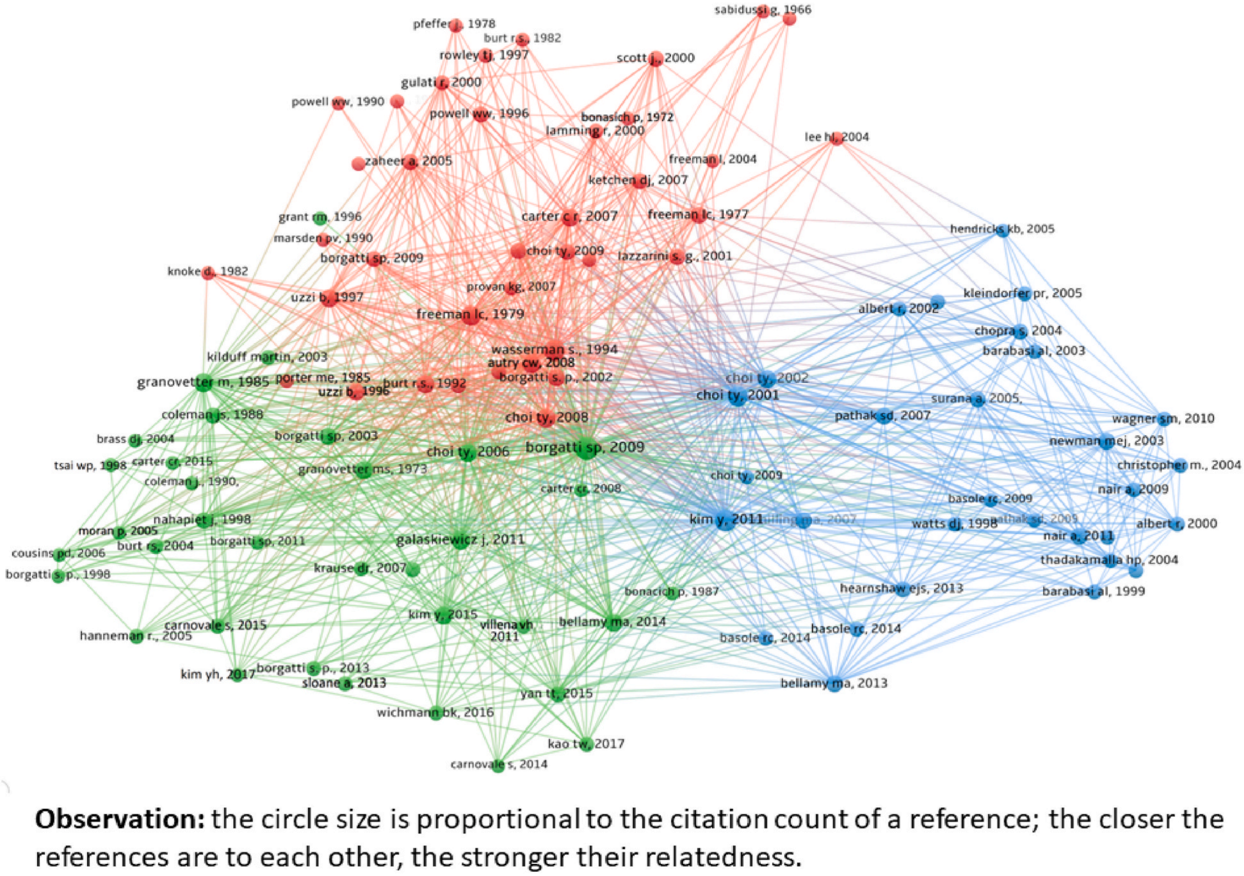


Fig. 4. Co-citation network of the top 103 references.

figure emphasizes the key features of both SNA and SCM. It shows that SNA has been extensively utilized to examine various aspects of supply chain management, including operational, financial and innovation performance, resilience, complexity, and cooperation. Looking at the abstracts, the word "network" is the most frequent in article abstracts (486 occurrences), indicating the increasing shift to viewing supply chains as complex networks.

The construction of co-occurrence networks, networks of terms frequently appearing together in articles, was facilitated by both keywords and KeyWords Plus. Analyzing these networks makes it possible to determine the research topics addressed within a particular field [44]. A Thesaurus file was generated to combine synonyms (e.g., "SNA" and "social network analysis") using VOSviewer. Fig. 7 shows the co-occurrence network for the 35 terms that appeared together five times or more. The data used to generate Fig. 7 is provided in Supplementary Materials (B).

VOSviewer clustering algorithm suggested assigning terms into four clusters; however, the network is highly interrelated with a relatively considerable number of links (n = 346). The terms indicate the main themes of supply chain research that have been investigated from a network analysis perspective: supply chain risk, innovation, complexity, resilience, etc.

Furthermore, VOSviewer was utilized to conduct a bibliographic coupling analysis. This analysis involved categorizing the articles in the dataset according to shared references to assess their level of similarity. Fig. 8 depicts the outcome of this analysis, which divided the articles into four highly interconnected clusters (Red n = 33, Green n = 30, Blue n = 28, Yellow n = 22) with a significant number of links (n = 3267). A minimum cluster size of 20 articles was set to form these clusters. The list of articles in each cluster is provided in Supplementary Materials (C).

The full text of all articles in the four clusters was examined to determine the main themes. The primary focus of the articles in the largest cluster (Red) was to utilize concepts and metrics from SNA to study various aspects of supply chain collaboration, integration, and knowledge exchange. Some of the articles in Cluster 2 (Green) and Cluster 3 (Blue) investigated how structural features of supply networks are related to risk, resilience, and disruption and how network characteristics can affect companies' operational and productive efficiency. On the other hand, the articles in Cluster 4 (Yellow) primarily dealt with topics related to the structural properties of supply networks and their relationship to innovation, process integration, and financial performance.

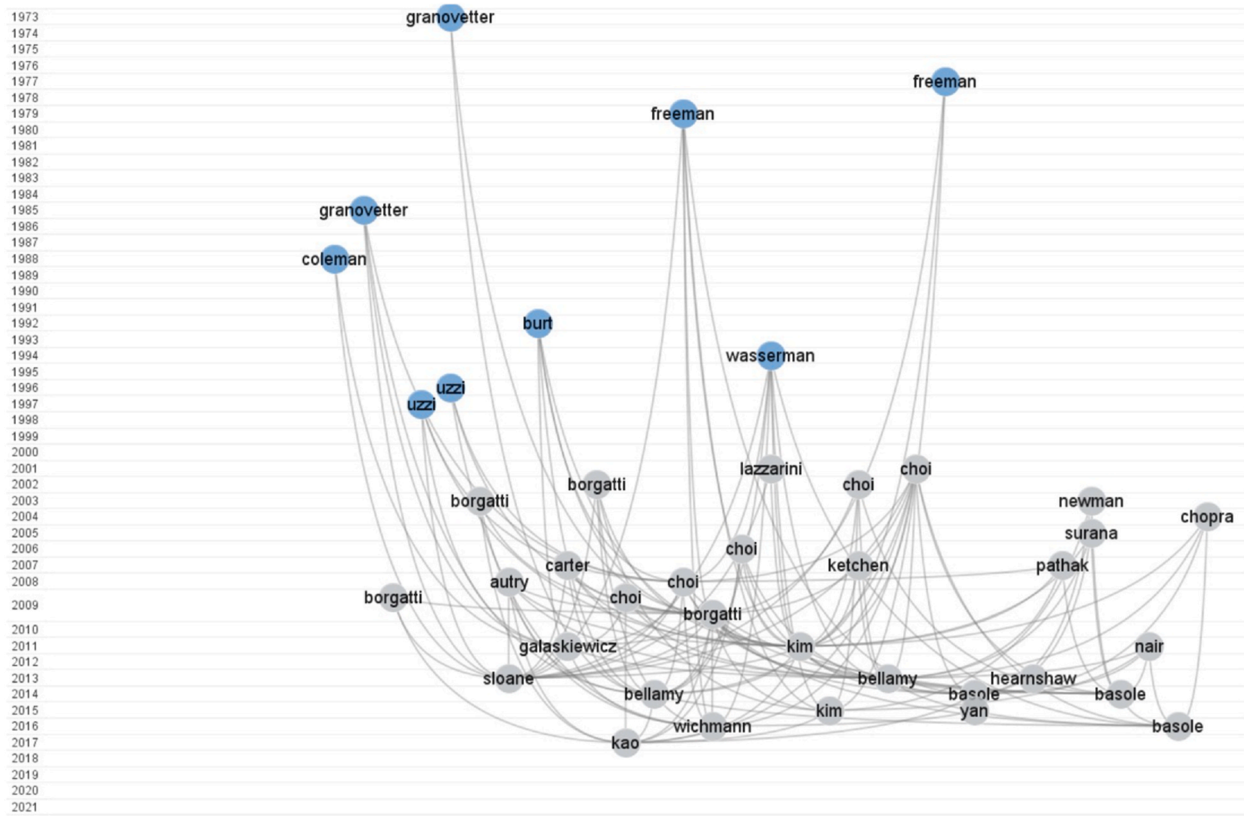


Fig. 5. Citation network of the 40 most frequently cited publications.

Table 4
Top 15 articles based on the total number of citations.

Rank	Author	Title	Year	Total Citations
1	BORGATTI SP	On Social Network Analysis in A Supply Chain Context	2009	415
2	KIM Y*	Structural Investigation of Supply Networks: A Social Network Analysis Approach	2011	413
3	KIM Y*	Supply Network Disruption and Resilience: A Network Structural Perspective	2015	355
4	CHAE B	Insights From Hashtag #Supplychain and Twitter Analytics: Considering Twitter and Twitter Data for Supply Chain Practice and Research	2015	286
5	BELLAMY MA*	The Influence of Supply Network Structure on Firm Innovation	2014	264
6	VARSEI M	Framing Sustainability Performance of Supply Chains with Multidimensional Indicators	2014	205
7	CHOI TY*	Structural Embeddedness and Supplier Management: A Network Perspective	2008	198
8	CHEN HZ	Supply Chain Process Integration: A Theoretical Framework	2009	181
9	LI CZ*	Schedule Risks in Prefabrication Housing Production in Hong Kong: A Social Network Analysis	2016	172
10	ASHTON W*	Understanding The Organization of Industrial Ecosystems - A Social Network Approach	2008	152
11	LUO LZ*	Stakeholder-Associated Supply Chain Risks and Their Interactions in A Prefabricated Building Project in Hong Kong	2019	136
12	GALASKIEWICZ J	Studying Supply Chains from A Social Network Perspective	2011	118
13	VAN DEN BRINK S*	Identifying Supply Risks by Mapping the Cobalt Supply Chain	2020	114
14	BASOLE RC	Supply Network Structure, Visibility, And Risk Diffusion: A Computational Approach	2014	114
15	LUTHE T	Network Governance and Regional Resilience to Climate Change: Empirical Evidence from Mountain Tourism Communities in The Swiss Gotthard Region	2012	105

Observation: Articles marked by an asterisk are included in the top 15 articles based on normalized citations.

3.5. Network structural properties in SCM research

To reveal how SCM researchers have applied SNA techniques in their investigations, we identified the reported node-level and network-level structural metrics in our dataset [10].

Supply networks description. There are various ways to characterize networks that can assist in determining their size, level of

Table 5
Top 15 articles based on normalized citations.

Rank	Author	Title	Year	Normalized Citations
1	VAN DEN BRINK S*	Identifying Supply Risks by Mapping the Cobalt Supply Chain	2020	6.8
2	LUO LZ*	Stakeholder-Associated Supply Chain Risks and Their Interactions in A Prefabricated Building Project in Hong Kong	2019	5.4
3	JANKOVIC-ZUGIC A	Servitization 4.0 As A Trigger for Sustainable Business: Evidence from Automotive Digital Supply Chain	2023	5.3
4	MARQUES L	Towards Social Network Metrics for Supply Network Circularity	2023	5.3
5	LI CZ*	Schedule Risks in Prefabrication Housing Production in Hong Kong: A Social Network Analysis	2016	3.5
6	CHOI TY*	Structural Embeddedness and Supplier Management: A Network Perspective	2008	3.0
7	FALCONE EC	Supply Chain Plasticity During a Global Disruption: Effects of CEO And Supply Chain Networks on Operational Repurposing	2022	2.9
8	BRINKLEY C	The Small World of The Alternative Food Network	2018	2.8
9	KIM Y*	Structural Investigation of Supply Networks: A Social Network Analysis Approach	2011	2.8
10	BELLAMY MA*	The Influence of Supply Network Structure on Firm Innovation	2014	2.6
11	SHAO BBM	A Data-Analytics Approach to Identifying Hidden Critical Suppliers in Supply Networks: Development of Nexus Supplier Index	2018	2.5
12	KAZEMIAN I	A Multi-Attribute Supply Chain Network Resilience Assessment Framework Based On SNA-Inspired Indicators	2022	2.5
13	ASHTON W*	Understanding The Organization of Industrial Ecosystems - A Social Network Approach	2008	2.3
14	SLOANE A	The Emergence of Supply Network Ecosystems: A Social Network Analysis Perspective	2013	2.1
15	KIM Y*	Supply Network Disruption and Resilience: A Network Structural Perspective	2015	2.1

Observation: Articles marked by an asterisk are included in the top 15 articles based on total citations.

Fig. 6. Word cloud based on Keywords Plus.

connectivity, number of groups, density, level of clustering among network members, and compactness [45].

Network size (i.e., the number of nodes in a network) is one of the fundamental attributes of a network. In a supply chain context, network size can be used as an indicator of the level of supply chain complexity [7,46]. Although large networks are characterized by higher efficiency and innovation capacity [47], they are more complex to manage because they require further coordination and information sharing. In addition, the increased level of complexity can have significant implications for risk diffusion, resilience capabilities, adaptive capacity, and performance after disruptions [46–48].

The interconnectedness of a network is measured by network density, which is the ratio of the observed relationships to the highest possible number of relationships between members of the network. Researchers have offered competing arguments about the relationship between network density and aspects of SCM. While higher density is conceptually linked to increased level of complexity [7,49] and more challenges in managing risk [50,51], denser networks facilitate knowledge sharing [10,52], allow for higher chances for collaboration [53,54], increase the level of trust between members [47], and lead to greater degrees of bargaining power in buyer-supplier relationships [55]. On the other hand, lower network density supports innovative capacity while limiting the homogenization of ideas and perception [47], unlike higher density networks in which frequent interactions may lead to redundancy of information and knowledge [10,46].

Building on graph theoretical concepts that consider the paths between a set of nodes, several metrics have been used in supply chain contexts. A path refers to the steps needed to move from node A to node B within a network. The length of a path is the distance

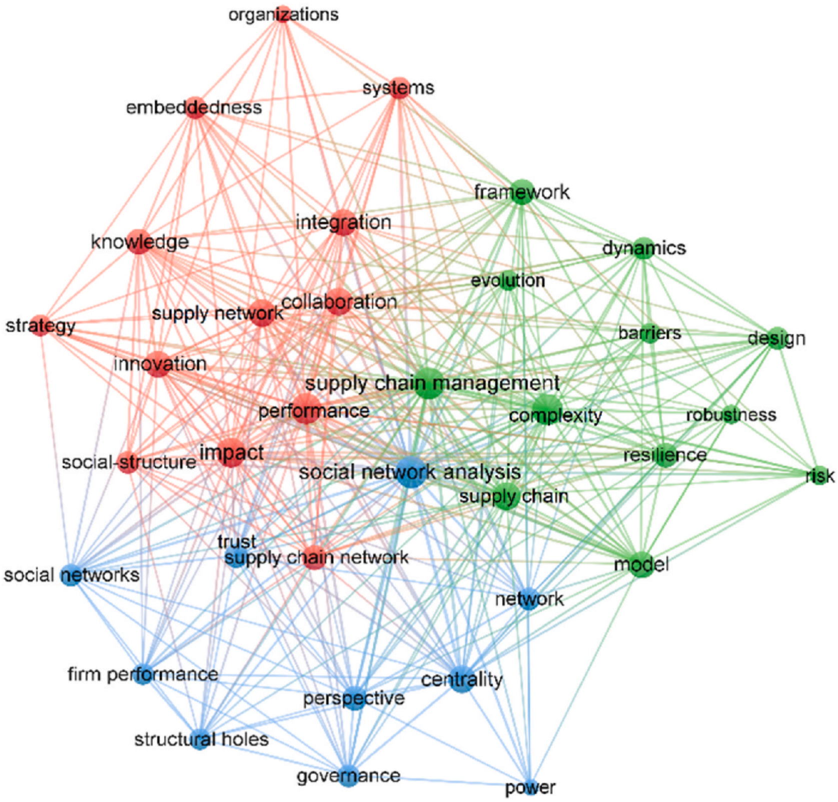
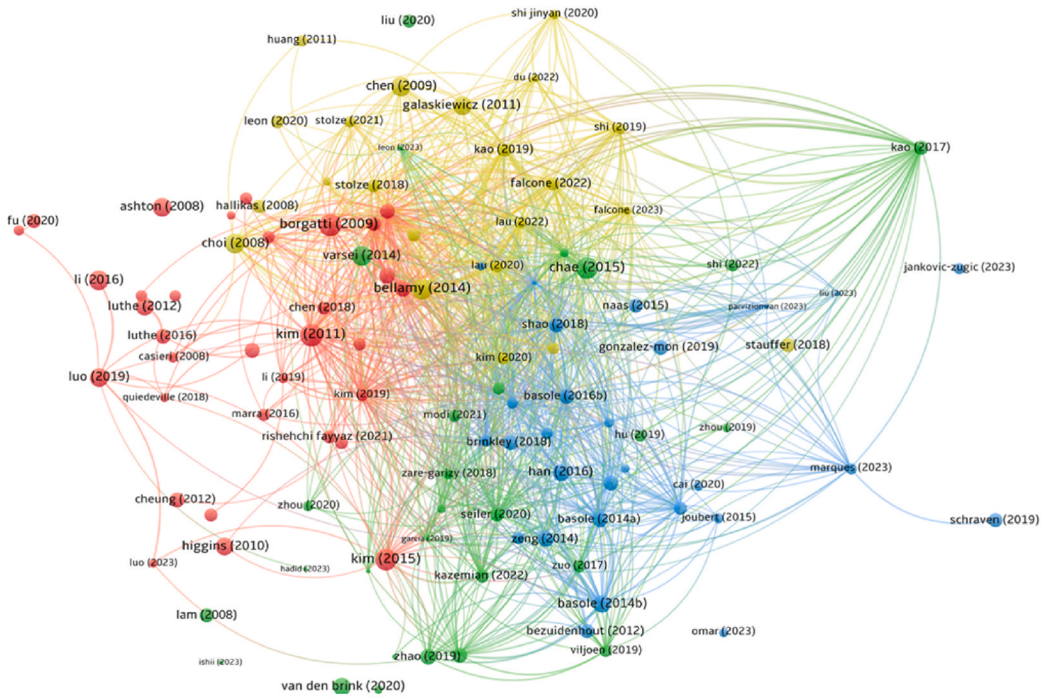


Fig. 7. Co-occurrence network for most frequent terms.



Observation: Larger nodes indicate a higher citation count, while closely positioned articles indicate more shared references

Fig. 8. Bibliographic coupling map.

between two nodes in the network, while the Average Path Length (APL) is the mean value of these distances for all node pairs. The longest of the shortest paths between any two nodes is termed the diameter [42,45]. APL and diameter are among the main aspects of supply chain design [46]. In a supply chain context, shorter APL facilitates faster and more efficient information sharing between supply chain members and enables timely reaction to sudden changes [47]. In addition, APL and network diameter have been incorporated in several models that evaluate supply chain resilience and structural robustness against risk propagation [46,48,51,56–58].

The presence of clustering is one of the fundamental characteristics of networks [45]. Clustering measures the extent to which network members tend to be grouped [46]. The clustering coefficient can explain the average probability of actors being a part of a collaborative group [53], and it has been utilized to assess the degree to which companies tend to form sub-networks with network partners [59]. A higher clustering coefficient may be associated with increased quantity and velocity of information dissemination and facilitated inclusion of members for collective action [47,53,60]. High levels of clustering enable the formation of resilient supply chain governance structures because the rapid dissemination of information and centralized direction of group efforts increase the ability to react fast to short-term shocks [46,47,51]. During the COVID-19 pandemic, there was an observed rise in the clustering coefficient. From the initial reported case in October 2019 to the conclusion of the Wuhan lockdown relief in April 2020, the clustering coefficient values consistently remained high among Chinese companies [50]. Moreover, members of the same cluster are likely to have a higher innovative capacity as a result of their ability to capitalize on collective knowledge, the ease with which they can observe comparable firms within the network, the effect of the scale of agglomeration, the higher social interaction and collaboration intensity [58,59], and the possibility of belonging to the same cluster of early adopters [61]. These factors give highly-clustered companies competitive advantages over their isolated competitors [59].

Centrality measures in supply networks. When studying networks, it is crucial to examine their structural patterns and how they impact the members within the network [5]. In addition to simple network descriptions, network analysis offers numerous techniques to examine, evaluate, and explore the positions of individual nodes and connections [45]. In a supply chain context, researchers have utilized various measures of centrality to assess prominent network members. The position of a focal firm within a network can be measured in various ways, including the number of direct links to other firms (degree centrality), the average distance between the focal firm and all other firms in the network (closeness centrality), the degree to which the primary company connects other firms that would otherwise not be connected (betweenness centrality), and the degree of connectedness to well-connected nodes (eigenvector centrality) [5]. Our research involved examining which centrality measures were utilized in each article within our data collection. As shown in Table 6, degree centrality is the most widely used measure, followed by betweenness centrality, closeness centrality, and eigenvector centrality. These results are in line with other studies [4,11,62]. Supplementary Materials (D) and (E) contain a categorized compilation of articles that utilize these metrics and their focus on various themes in SC research.

Supply network subgroups. Some social networks consist of relatively densely connected subgroups, and SNA offers a wide range of techniques to identify and examine meaningful sub-structures contained in broader networks [45]. Cohesive subgroups can be described as sets of network members connected through frequent, strong, and direct relations [42]. In the context of SCM, researchers have utilized the concept of cohesion to study the extent of collaboration and interaction quality [52,54]. Another area of application was to examine the effective knowledge transfer and information flows that facilitate the diffusion and implementation of environmentally responsible business practices [63,64].

According to Han, Caldwell, and Ghadge [2], the level of cohesiveness is a suitable measure to assess the level of connectedness among network members that may indicate strong common relationships in the management of contemporary fragmented and dispersed organizations. Also, network cohesion has been used to measure the level of supply network structure complexity and its implications in terms of supply chain risk management [65,66].

SNA techniques have also been applied in SCM for community detection. Network scientists have developed several subgroup identification methods and techniques to categorize groups according to how connections are formed between various groups. The degree of structure within a network, known as modularity, is a significant attribute employed in numerous community detection algorithms [45]. Modularity is a chance-corrected statistic defined as the difference between the actual number of connections within a particular group and the number of connections that would be expected to occur by chance if connections were distributed randomly [67]. In supply chain context, modularity has been utilized in several ways. Examples include the integration of a modularity metric to understand collaboration network structure and information sharing across supply chains [68,69], to forecast the credit risk of participants who are collaborating in a financial network [70], to assess the level of differentiation in the structure of a network's stability [71], and to characterize supply chain resilience in terms of innovative capacity and adaptive capacity [47,51,53].

Supply network structure and formation models. The utilization of mathematical or computational models that enable analysts to go beyond simple descriptions and to develop and test hypotheses on network structure, formation, and dynamics has been a central feature of modern SNA [45,72].

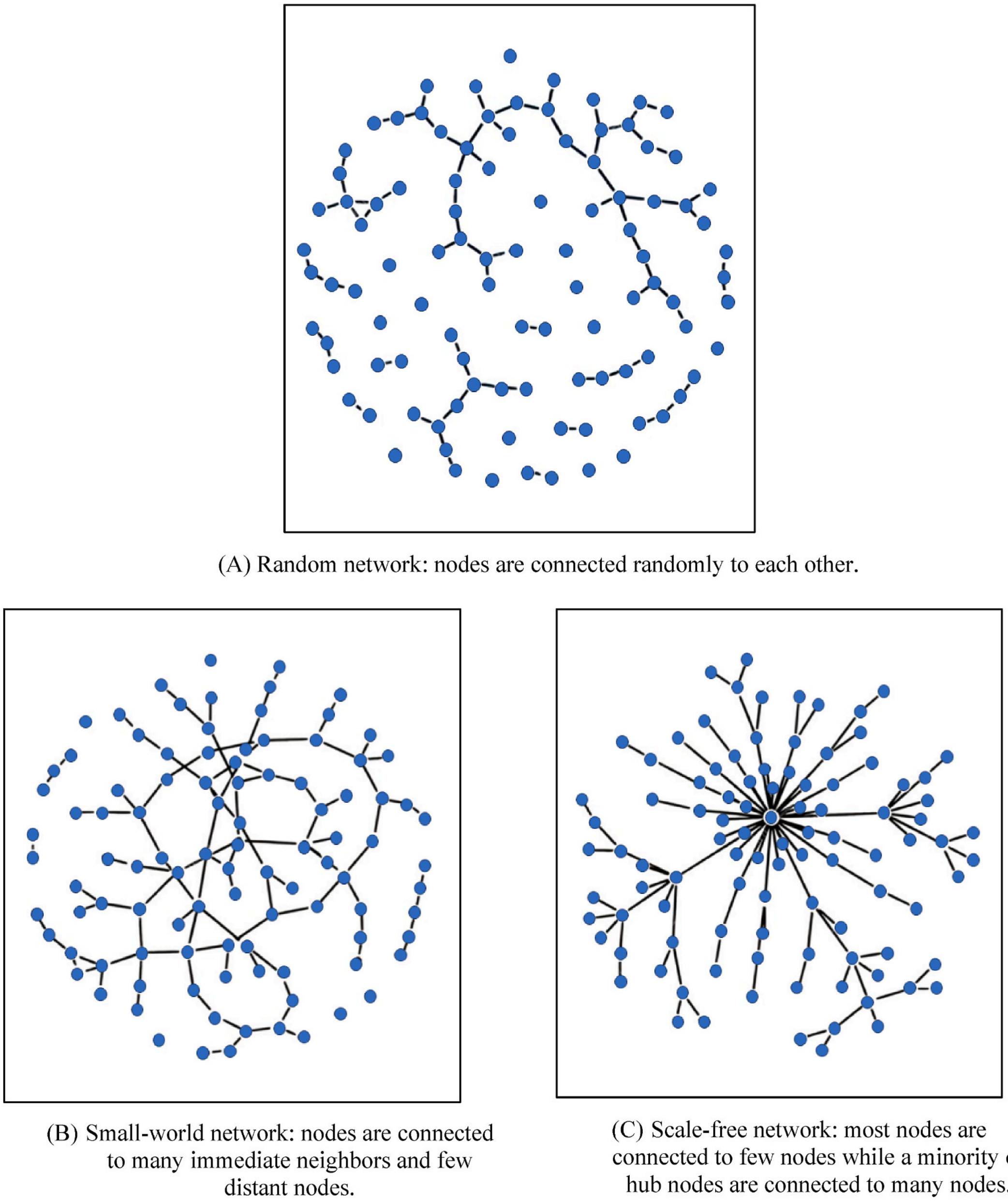
The random graph model, one of the first mathematical models used to study network structure, characterizes a network as G (n,m). In this model, a random graph G is generated with n vertices and m random links. Small-world and scale-free models are common network models that provide insights into fundamental features of networks, serve as a standard or reference point for real-world networks, and act as building blocks for network simulations [45]. In a small-world model, networks are characterized by high clustering and small APL between nodes. The process begins by creating a circular structure consisting of n nodes, where each node is connected only to its closest neighboring nodes, thus forming a lattice pattern. Then, a few links are eliminated from one end and reconnected to a different random node in the network using a probability denoted as Pn [45,73]. On the other hand, scale-free networks are defined by the presence of hub nodes that exhibit a high degree of connectivity and heavy-tailed degree distributions that bear resemblance to a power-law degree distribution, a feature resulting from the preferential attachment formation process [45,

Table 6
Distribution of centrality measures in the reviewed articles.

Main theme	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality
Risk, resilience, or disruption	21	18	10	3
Innovation, financial, or operational efficiency	22	16	7	9
Collaboration, integration, or knowledge sharing	12	8	8	2
Sustainability, SC design, complexity, or dynamics	19	10	5	5
Total (% of sample)	74 (65%)	52 (46%)	30 (27%)	19 (17%)

74,75]. Fig. 9 depicts a visual representation of these models.

It has been argued that real-world supply chains resemble these network topologies, i.e., random, small-world, or scale-free networks [76,77]. Several SCM scholars have explicitly factored the topological characteristics of different network models. For example,



(A) Random network: nodes are connected randomly to each other.

(B) Small-world network: nodes are connected to many immediate neighbors and few distant nodes.

(C) Scale-free network: most nodes are connected to few nodes while a minority of hub nodes are connected to many nodes.

Fig. 9. A visual representation of random, small-world, and scale-free networks [87].

researchers have argued that focal firms in supply networks with small-world characteristics (i.e., highly clustered with short average path length) benefit from faster spreading of information [74] and efficient transfer of resources along the network, resulting in higher levels of responsiveness [60,78]. On the other hand, scale-free networks are comprised of hubs and an uneven, heavy-tailed distribution of degrees [79], i.e., most nodes in a network have connections to only a limited number of other nodes whereas a minority of nodes have connections to a large number of other nodes. In this situation, a few firms hold the most power and control in the supply network while leaving the remaining organizations with little influence [9,80]. Researchers have also considered the different network topologies (i.e., random, small-world, and scale-free) to evaluate how each type of network performs in terms of supply network resilience [53,60,78] and robustness to failures [48,56,74,78,81].

Lastly, network science has offered highly sophisticated models for statistical network modeling, such as Exponential Random Graph Models (ERGMs), a highly effective and adaptable modeling technique widely used for constructing and evaluating statistical models of networks. An ERGM is a true generative statistical model that generates network structure and characteristics, allowing for the formulation and examination of inferential hypotheses. ERGMs utilize information about the distinct components of a network (i.e., actors) and local structural properties to predict attributes of the entire network (e.g., diameter, degree distribution, etc.) [45]. Few studies have applied these models in the context of supply chain management. Stauffer et al. [82] applied an ERGM to statistically test the impact of mega disaster response on supply network asset flows. Meisel et al. [69] applied an ERGM to assess the structure of information sharing and identify the elements influencing collaborative relationships.

Potential avenues for future research. Our results show that the current research primarily focuses on network metrics that describe network structural characteristics such as degree, betweenness, or closeness centrality. Although useful, these metrics offer a limited view since they are primarily focused on individual node characteristics. In contrast, advanced statistical network modeling, such as ERGMs, has the potential to explore complex network dynamics [45]. More specifically, ERGMs do not only consider nodal or network attributes but also capture and represent higher-order dependencies within a network [82,83]. For example, in a supply chain network, the relationship between two suppliers is not independent of their relationships with a mutual manufacturer. In the logistics services triad, which includes a supplier, a logistics service provider, and a customer, the logistics service provider has the power to affect the dynamics between the supplier and customer (the central dyad). This is done by selectively sharing information with one of these key actors while withholding it from the other [84]. Therefore, future research could employ ERGMs to capture triadic relational performance and dependencies, allowing researchers to model more complex interactions and interdependencies within a supply chain.

Moreover, SCM researchers could benefit from the high flexibility of ERGMs that allows the inclusion of various parameters to represent different hypotheses about network formation and provides the possibility of tailoring ERGMs to specific research questions. For example, a recent study [69] used three parametric forms of the ERGM to reveal the information-sharing structure in a supply network. The model provides different lenses to understand the complex interplay of factors that shape the collaboration network structure [69]. Leveraging on the high flexibility and analytical capabilities of ERGMs, future research could investigate network dynamics and interactions in similar contexts. Nevertheless, despite the described advantages, ERGMs present some challenges since they demand substantial computational resources and are contingent on the presence and precision of network data, particularly for extensive networks [85].

Another area for future research could be comparing network structures across industries to gain insights into their effectiveness in different contexts. Organizations in highly regulated industries often operate within a network structure heavily influenced by regulatory requirements. Often, such contexts create rigid networks with a strong emphasis on compliance, safety, and quality control [86]. Examples include companies operating in the food and beverage, pharmaceuticals, and healthcare sectors. The interactions in these supply chains extend beyond traditional business actors and include non-business actors such as regulatory bodies, advocacy groups, and other stakeholders. In addition, different network structures can be more (or less) favorable depending on the industry. For example, pharmaceutical supply chains may prioritize a structure that allows for higher stability and reliability over flexibility, reflecting the critical nature of pharmaceutical products and the industry's emphasis on patient safety and adherence to stringent regulations [86]. In contrast, the apparel industry is characterized by more adaptable networks oriented towards rapid response and innovation. These networks need to constantly evolve to keep pace with changing consumer tastes and trends. Future research could explore contrasting network structures across industries to explore their distinct characteristics and identify their unique challenges and opportunities.

4. Conclusions

As supply networks become more complex, there is a growing demand for new scientific principles, approaches to collecting data, and methods of analysis that can effectively examine complex systems and behavior [45]. This paper presents a methodical, transparent, and replicable review of 113 articles on Social Network Analysis within the context of Supply Chain Management. This thorough bibliometric examination offers various insights to guide and encourage further research in the field. It does so by presenting a concise overview of the current literature in the area and emphasizing the potential of Social Network Analysis to make additional contributions to Supply Chain Management.

Our findings show that there has been a growing interest in the utilization of Social Network Analysis in Supply Chain Management research. The consistent growth in scientific output reflects the increasing relevance and application of Social Network Analysis in the field. Given the significant concentration of articles in recent years, the field is gaining momentum. We also observed highly fragmented authorship patterns, a wide range of publication outlets, and an interdisciplinary interest. The origins of the field were traced through citation analysis of early work, and key publications that served as intellectual roots for subsequent studies were identified. Our analysis further categorizes the literature into clusters, revealing the distinct research areas and the relationship between network structures and various aspects of Supply Chain Management. This classification provides a structured overview of the field, allowing for a more targeted approach to future studies.

Another key outcome of this study is the detailed description of how Supply Chain Management researchers applied Social Network Analysis techniques, from basic network description to more advanced statistical network modeling. Our findings identify various metrics used by supply chain researchers, such as network size, density, path lengths, clustering, and centrality measures. These metrics provide valuable insights into supply networks' complexity, efficiency, and robustness. Notably, applying these metrics during events like the COVID-19 pandemic highlights the practical relevance and adaptability of SNA in real-world scenarios. It is worth noting that the majority of the reviewed publications were limited to network visualization and description, with very few studies attempting to build and test statistical models of supply networks, such as Exponential Random Graph Models, possibly because these advanced models have only been developed in the past couple of decades [45].

Future research would benefit from the high flexibility of advanced statistical network modeling, allowing the exploration of various hypotheses about higher-order network dynamics and dependencies. Another potential area of research is comparing network structures across different industries to understand their effectiveness and unique challenges in different contexts. There are two limitations to this research. First, while a bibliometric analysis offers an objective and systematic evaluation of the literature, its scope is limited by the choice of keywords. To minimize sampling bias, we reviewed past reviews and selected keywords that were sufficiently general to guarantee that no relevant publications were omitted from our dataset. Secondly, our exploration may have been constrained by selecting articles only from the Web of Science database, which may have overlooked relevant publications not covered in the database. Nevertheless, it is believed that the overall rigorousness of the review and bibliometric analysis offers a comprehensive map of the field.

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Data included in article/supp. Material/referenced in the article.

CRediT authorship contribution statement

Hesham Fouad: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Nazaré Rego:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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Appendix A. Supplementary data

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