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Review

Systems Thinking: A Review and Bibliometric Analysis

Niamat Ullah Ibne Hossain, Vidanelage L. Dayarathna, Morteza Nagahi and Raed Jaradat *

Department of Industrial and Systems Engineering, Mississippi State University, Mississippi State, MS 39762, USA; ni78@msstate.edu (N.U.I.H.); vld66@msstate.edu (V.L.D.); mn852@msstate.edu (M.N.)

* Correspondence: jaradat@ise.msstate.edu

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Abstract: Systems thinking (ST) is an interdisciplinary domain that offers different ways to better understand the behavior and structure of a complex system. Over the past decades, several publications can be identified in academic literature, focusing on different aspects of systems thinking. However, two critical questions are not properly addressed in the extant body of ST literature: (i) How to conduct the content analysis exclusively to derive the prominent statistics (i.e., influential journals, authors, affiliated organizations and countries) pertaining to the domain of ST? (ii) How to get better insights regarding the current and emerging trends that may evolve over time based on the existing body of ST literature? To address these gaps, the aim of this research study is to provide a comprehensive insight into the domain of systems thinking through bibliometric and network analysis. Beginning with over 6000 accumulated publications, the analysis narrowed down to 626 prominent articles with proven influence published over the past three decades. Leveraging rigorous bibliometric tools analysis, this research unveils the influential authors, leading journals and top contributing organizations and countries germane to the domain of systems thinking. In addition, citation, co-citation and page rank analysis used to rank top influential articles in the area of systems thinking. Finally, with the aid of the network analysis, key clusters in the existing literature are identified based on the research areas of systems thinking. The findings of this research will serve as a bluebook for practitioners and scholars to conduct future research within systems thinking context.

Keywords: systems thinking; complex systems; bibliometric analysis; network analysis; systems dynamics

1. Introduction

Organizations tend to restructure their business models due to the rapid growth of technological and economic development. As a result, organizations attempt to find new toolsets and techniques to cope with large-scale complex system problems [1–3]. In addition to the technical characteristics, complex systems are marked by other important characteristics such as ambiguity, emergence, interconnectivity and socio-economical forces such as employee, social and government policies. These characteristics need to be taken into consideration for better management of complex system problem domains [4]. The current traditional systems engineering approaches such as AHP are not purposefully designed to handle large complex system problems, i.e., system of systems [5–12]. To deal with such problems, researchers and scholars have used more holistic approaches through the systems thinking paradigm in conjunction with systems theory and laws. systems thinking is the focus of this research study [5,13–15].

The idea of systems thinking arises around 1960 as a platform to understand the dynamic behavior of complex systems when linear thinking (cause-and-effect thinking) was no longer useful for generating comprehensive solutions [16]. In 1968, Bertalanffy [17]—the father of general system theory—presented a concept of having a general system theory for all systems. He suggested a universal language and

laws that crossed multiple disciplines with universal applicability. Following Bertalanffy's work in systems theory, a trend toward generalized theories in biology, physics, psychology, social science, and other fields has appeared [18–20]. The movement towards systems theory was essential due to: (1) the inability of several mathematical methods, i.e., physics to capture the idea of wholeness (the whole of the system), (2) the need to approach a problem using new ways of thinking that capture general principles for all systems irrespective of its nature, and (3) the failure of mathematical models to solve social-technical problems. The notion of systems thinking dates back to the time of Aristotle, who suggested the concept of holism as a basis for systems thinking. Many studies, perspectives, and works were introduced to describe systems thinking. systems thinking is the cognitive process, which shapes the skills to think in and speak a new holistic language [21]. In his book, Checkland highlighted the idea of wholeness to understand complex problems. Senge [11] stipulated that systems thinking is a theoretical framework that identifies leverage points in a system through the development of knowledge and tools over the past five decades. Flood and Jackson [22] presented a new philosophy, total system intervention (TSI), that follows the principles of critical system thinking to address complex systems problems. Adams and Keating [23] (p. 11) stated that understanding the principles of system theory, "in conjunction with the thought process developed in systems thinking," is an essential and fundamental step toward understanding complex systems.

Systems thinking is applied across different domains, including social sciences, engineering, business and management, computer science and medicine. A survey of systems thinking literature demonstrated the main themes. For example, several studies focused on the general systems thinking paradigm [5,24–29]. Other scholars provided a comprehensive review on different aspects of systems thinking in different fields such as the healthcare sector [30–35], sustainability [36–40], smart cities [41], human resource management [42,43], education [44–50], general practice [51], individual differences and personality [52], lean [53], digital skills [54], gender studies [55], virtual reality [56] and systems engineering/system of systems [6,57,58]. Other studies have attempted to link the concept of systems thinking to cognitive intelligence by using different terminologies such as mental maps, meta-learning, structural thinking, cognitive belief and mindset, which are all embodied in the concept of cognition [59–63].

From the mentioned work along with other research in the literature, we can draw the main gap with respect to the existing body of the literature– there is no single study that conducted a rigorous bibliometric analysis and network analysis on systems thinking. The main contribution of this research study is to provide an advanced and detailed bibliometric and network analysis. The analysis will identify influential institutions, researchers, and emerging areas in systems thinking between 1991 and 2018.

In this research study, a bibliometric analysis is performed to provide detailed quantitative and network analyses for systems thinking literature. Network analysis is "a branch of graph theory which aims at describing quantitative properties of networks of interconnected entities by means of mathematical tools" [64] (p. 2). The technique of network analysis is recognized as a powerful tool that helps in identifying emerging areas of research and clusters that display similar attributes. Bibliometric analysis is different from a traditional literature survey analysis as it compiles a wide range of scientific articles through large databases such as Scopus and Web of Science (WoS). Depending on the discipline or interest of the researcher, this technique provides a microscopic overview of different aspects of relevant scientific articles. Through a bibliometric analysis, researchers can unveil the research patterns, influential authors and publications, leading journals and other vibrant information in a research area. Bibliometric analysis can also play a significant role in identifying research gaps in different research disciplines. In this research study, these two techniques are applied to review the existing body of systems thinking literature. The objective of this research study is summarized as follows:

(i) Identify the influential articles, leading authors, affiliation statistics, top contributing countries, organizations and keywords in the field of *systems thinking* based on the bibliometric analysis within the span of the year 1991–2018;

(ii) Classify the most influential articles, current and emerging research trends pertaining to systems thinking based on network analysis;

(iii) Explore the different clusters in the systems thinking domain. This review analysis will be beneficial to researchers to recognize the prominent topics as well as the existing gap in the extant systems thinking literature.

Review of Existing Literature

Senge [11] (p. 7) suggested that "systems thinking is a conceptual framework, a body of knowledge and tools that been developed over the past seventy years, to make the full patterns clearer, and to help us see how to change them effectively", presented the importance of different perspectives, definitions and taxonomies of systems thinking developed over the years. Figure 1 exhibits the development of influential systems thinking perspectives, methods and tools over time. The intent is not to provide an exhaustive list of scholars' works, but rather to indicate the progress and expansion of the systems thinking domain.

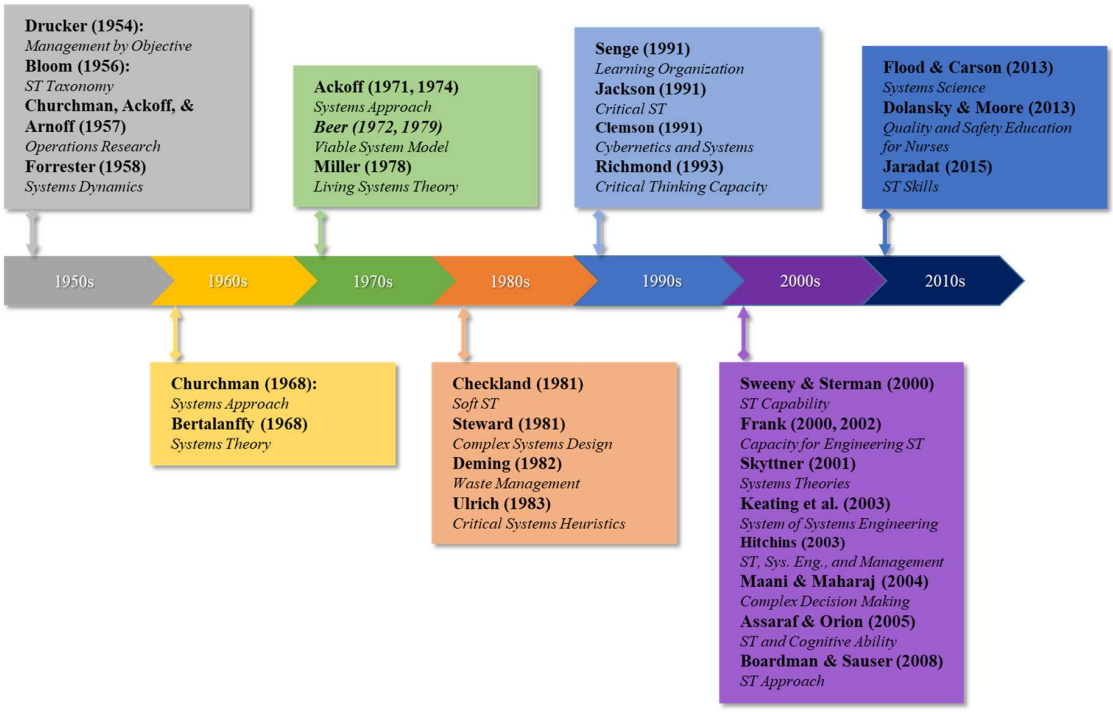


Figure 1. Top impacting systems thinking tools, methods and approaches over time.

It is apparent from Figure 1 that several different systems thinking perspectives, methods, tools and approaches evolved and progressed over the decades. The main themes of most of these influential research works were referred to the complex nature of systems and the introduction of methods and approaches of systems thinking. Table 1 presents some representative approaches, methods and perspectives of systems thinking (this list is not exhaustive).

Table 1. Some representative list of systems thinking tools and approaches.

Researchers	Domain of Study	Application	Description
Drucker (1954) [65]	Management quality and performance	Organizational management by objective	Introduced a systemic approach called "management by objective" to assist organizational managers to enhance their managing quality and performance.
Ackoff (1971, 1974) [66,67]; Ackoff and Emery (1976) [68]	Systems theory	Systems approach	Ackoff clarified that in treating complex system problems, called messes, the focus should be on the whole system and not the parts. He believed all the parts of a complex system are interconnected and interacted with each other; consequently, a holistic point of view needed to answer their corresponding problems.
Checkland (1981) [21]	Organizational management	Real-life management practices	Showed the practical usage of systems science and approaches through the introduction of soft systems thinking/methodology. He considered organizational systems as complex human activity systems instead of the traditional process to create defined output.
Deming (1982) [69]	Management practices	Resource management	Developed a systems thinking approach consisted of 14 principles for the transformation of American style management based on three pillars of human resources, process and results. His purpose was to guide American managers to handle the waste of human resources, materials better and machine-time to achieve better performance in the manufacturing process.
Senge (1990) [11]	Management practice at the organizational level	Organizational management through learning organization	Emphasized on seeing the big picture and the whole systems through three major components of system archetypes, Reinforcing/amplifying feedback, Balancing/stabilizing feedback and delays, to solve complex organizational problems.
Richmond (1993) [70]	Education system	Dynam system	Investigated the impact of systems thinking on the educational process, thinking paradigm and learning tools in the education systems. He introduced three critical thinking capabilities, namely, operational, closed-loop and nonlinear thinking.
Sweeney and Sterman (2000) [15]	Management studies	Understanding of system dynamics concepts	A group of students answered questions relating to stocks and flows (the bathtub/cash flow tasks) and time delays (the manufacturing case) problems. This study identified the lack of systems thinking capability among a group of college students with varying backgrounds.
Frank (2000, 2002) [71,72]	Engineering education curriculum	Engineers' systems thinking	Frank's studies focused on creating a 3-D model to describe the learning environment and a list of topics to be included in a curriculum for constructing a Capability for Engineering systems thinking (CEST). The results showed that engineers that are able to solve complex problems have a higher score in the CEST tool.
Maani and Maharaj (2004) [73]	Management studies	Complex decision making	Used a psychological method, called Verbal Protocol Analysis (VPA) to investigate the thought processes of graduate students in complex decision making. They found relationships between students with certain types of systemic thinking and their complex decision-making performance.
Jaradat (2015) [57]	Complex systems domain	Individual capacity for systems thinking	Developed a systems thinking skills instrument on the basis of seven attributes of complex systems problems to assist individuals in dealing with ill-defined issues. The instrument measures an individual's level of systems skills to deal with complex system problem domains.

In the literature, different scholars attempted to demonstrate the mutual inclusiveness of "systems thinking" and other related terms such as big-picture thinking [74–77], holistic thinking [78–81], multidimensional thinking [82–85] and systemic thinking [86–89]. A thorough review of the literature shows that researchers focused on the identification of systemic approaches to deal with complex system problems. For instance, in their book, Anderson and Johnson [90] illustrated that all systems thinking related terminologies focus on the big picture of a system to support more effective solutions.

Arnold and Wade [24] took an effort to propose a complete definition of systems thinking where the concept of traditional systems thinking can collaboratively engage with other general practices in future organizational systems., i.e., integrate various perspectives, work within a system that has vague boundary or scope, explore various operational contexts, recognize relationships and dependencies of the system capture complex system behavior, and reliably forecast the impact of change to the system. Mononen [91] acknowledged that the use of systems thinking in different domains, such as art and science and technology, showed how these domains have similar characteristics in terms of common practice. By providing the emerging areas of systems thinking, we believe that the methodology and the bibliometric analysis conducted in this research paper will present 'a point of reflection' to improve practice in the systems thinking domain.

The remainder of the research paper is structured as follows: Section 2 introduces the research methodology and initial data statistics including data refinement process; Section 3 presents bibliometric analysis; Section 4 introduces detailed network analysis with PageRank analysis and co-citation analysis;

Section 5 provides a discussion including the managerial implications and future research directions. Finally, Section 6 ends the paper with concluding results and limitations.

2. Research Methodology and Data Statistics

In this research paper, a structured literature review is conducted through an iterative sequence by defining relevant keywords, searching the literature and conducting the analyses [92]. In order to conduct a literature review, Rowley and Slack [93] mentioned five steps structured methodology, including scanning the different resources, making relevant notes, designing mind maps to organize the literature review, writing the literature review, and finally, building the bibliography. In this research paper, we follow the same five steps process proposed by Rowley and Slack [93] to identify the most prominent works, then ascertain the topical areas of research and the outlook of the future research possibilities in the domain. With the large volume of sources used and the difficulty of navigating and managing the collection of relevant literature, the five-step methodology is suitable since it provides a step-by-step systematic approach starting from research initialization to bibliography development to research gap identification. The research methodology steps are summarized below and the overview of the methodology is illustrated in Figure 2.

1. Search and collect data from Scopus database using the selected keywords: (1) big picture thinking, (2) hierarchical thinking, (3) holistic thinking, (4) multidimensional thinking, (5) systemic thinking, (6) systems thinking (7) systems thinking and design thinking and (8) systems thinking and systems dynamics. These keywords were extracted using *grounded theory* methodology with the help of NVIVO 12 software [94]. Then, the selected articles, based on the aforementioned keywords, were saved in research information systems (RIS) format. As a result, 6577 related articles in RIS format were saved.
2. Remove duplicates using endnote. Consequently, a total of 5985 articles were retained;
3. Select scientific articles that appeared only in peer-reviewed journals. Hence, 3884 articles were chosen;
4. Sort the scientific articles journal-wise and year-wise to have a detailed bibliography;
5. Finally, identify the research gap and the following analyses are conducted to address the gap:

    - Analyze the processed data for meaningful bibliometric results using Bib Excel software.
    - Analyze the processed data for network analysis using Gephi software.

2.1. The Selection of Keywords (Criteria and Justification)

Within systems thinking literature, there are different ideas, words and topics used frequently that may be recognized as keywords. These keywords cover the aspect of systems thinking and its derivative terms and serve as a baseline of the data collection process. These keywords include; (1) big picture thinking, (2) hierarchical thinking, (3) holistic thinking, (4) multidimensional thinking, (5) systemic thinking, (6) systems thinking (7) systems thinking and design thinking and (8) systems thinking and systems dynamics. These keywords were derived based on the highest frequency of coding from the literature using grounded theory methodology [94]. *Grounded Theory* methodology was conducted using the help of Nvivo 12 (QSR International) software that aided in collecting, analyzing and synthesizing the qualitative data. To the best of our ability, we found that these keywords captured the concept of systems thinking. For example, big-picture thinking resonates as a preference to systems thinking.

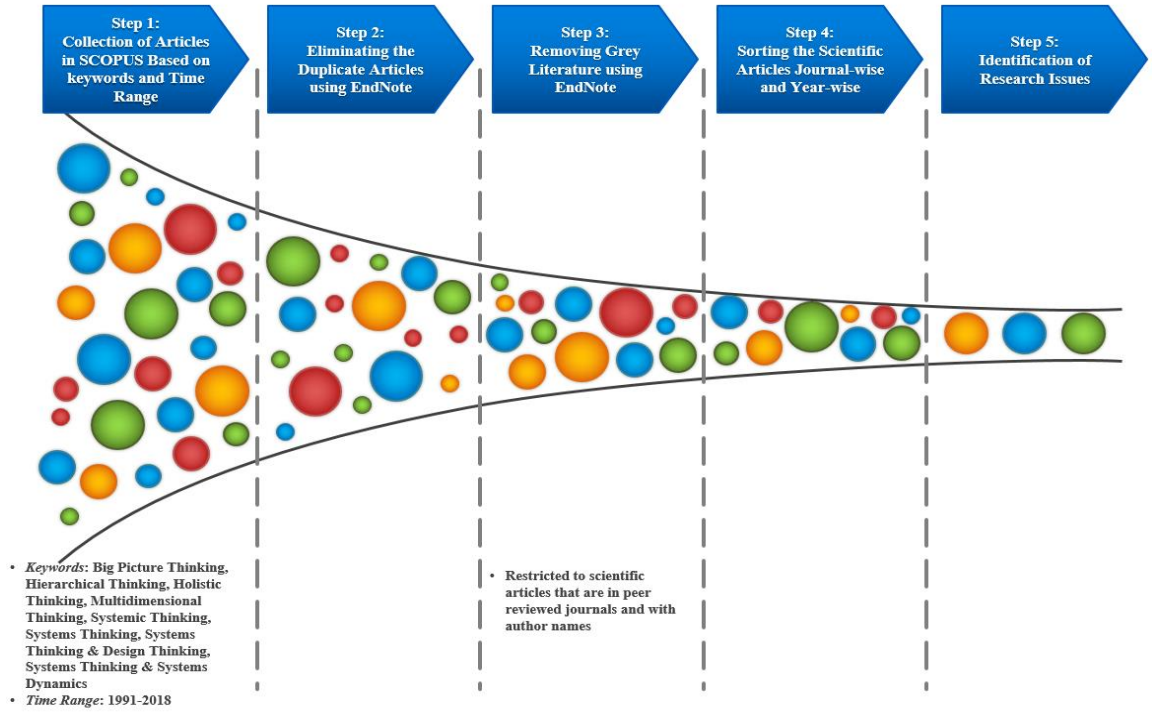


Figure 2. Research methodology steps.

2.2. Initial Results

Scopus is one of the largest databases of peer-reviewed articles [95]. By providing over 20,000 peer-reviewed journals within the science, technology, medicine, social sciences, arts and humanities, Scopus is the best database candidate to use for this research study. When compared to other databases such as Web-of-Science (WoS) and Pubmed, Scopus is more comprehensive and provides a greater selection of articles focused on *systems thinking*, where some of them may be relatively new, but influential. Web-of-Science (WoS) database was a second choice to use, but it mainly includes ISI indexed journals, which is limited to only 12,000 titles. The keywords include *big-picture thinking*, *hierarchical thinking*, *holistic thinking*, *multidimensional thinking*, *systemic thinking*, *systems thinking*, *"systems thinking and design thinking"*, *and "systems thinking and systems dynamics"* were searched in the field of "title, abstract, keywords" of the collection of articles belong to Scopus database. The search resulted in 6577 related articles for the standalone and different pairings of the selected keywords. Table 2 shows the breakdown of the search result. These results were saved in research information systems (RIS) format to retain the necessary information related to the article (title, authors' names, abstract and keywords).

Table 2. Initial search results.

Search Keywords	Search Result (# of Publications)
big picture thinking	31
hierarchical thinking	59
holistic thinking	316
multidimensional thinking	19
systemic thinking	547
systems thinking	5123
systems thinking AND design thinking	56
systems thinking AND systems dynamics	426
Total	6577

2.3. The Refinement of Initial Results

When the same article appears more than once using different combinations of selected keywords, it is considered as a duplicate article. For the refinement purpose, the duplicated copy of any article is removed. After removing the duplicated articles, a total of 5985 articles were retained. To further reduce the pool of articles, we narrowed it down to scientific articles that only appeared in peer-reviewed journals and therefore 3884 published articles for the time span from 1991 to 2018 were retained. A breakdown of the search results, based on the keywords, is summarized in Table 3. An endnote bibliography software was utilized to refine the RIS files and then the resulting data were stored for further analysis.

Table 3. Refined search results.

Search Keywords	Search Results (No of Papers)
big picture thinking	23
hierarchical thinking	34
holistic thinking	231
multidimensional thinking	10
systemic thinking	382
systems thinking	2928
systems thinking AND design thinking	23
systems thinking AND systems dynamics	253
Total	3884

2.4. Initial Data Statistics

To ensure an effective analysis in terms of frame of reference, we further filtered the pool of the articles to keep those articles that appeared in the top 15 journals in the Scopus database in terms of the number of accumulated publications for the period of 1991–2018. This refinement resulted in 626 articles in the top 15 journals, as shown in Table 4.

Table 4. Journal-wise publication breakdown.

Name of the Journal	Systems Research and Behavioral Science	Systemic Practice and Action Research	Systems Practice	Kybernetes	Journal of the Operational Research Society	European Journal of Operational Research	System Dynamics Review	Sustainability Switzerland	Journal of Cleaner Production	Learning Organization	Systems Engineering	Safety Science	Civil Engineering and Environmental Systems	Ecology and Society	Accident Analysis and Prevention	Total Publication per Year
1991			10													**10**
1992			10		1	3										**14**
1993			9		1		3									**13**
1994			6				9									**15**
1995			5		4											**9**
1996	2		9		3											**14**
1997	8		6		1		1			1						**17**
1998	2	6			2						2					**12**
1999	4	6			1	1	2			1	1					**16**
2000	6	10			3		1		1		1					**22**
2001	6	12			1	1							1			**21**
2002	1	4		1	1		2		1	1						**11**
2003	7	3			2											**12**
2004	2	3		3			2			8	1					**19**
2005	4	3		2			2				1			1		**13**
2006	4	2		4	2				1	1	1					**15**
2007	6	4		5	3	1	1		1	6	1					**28**
2008	12	3			1	2			2		1					**21**
2009	12	3		2	1	1				1	1					**21**
2010	10	5			1	1	1		1	1	2	1	6	1		**30**
2011	6	3			2		2				1	2		1		**17**
2012	9	7		1	1	1	1			1	1	1		1	2	**26**
2013	9	2		1	1	2	1	1	1	1	1		3	1		**24**
2014	8	10		13	1	1					1	1		2	5	**42**
2015	9	9		1		2		1	3		2	4	3	4	2	**40**
2016	14	11				2		4	3	1		3	1		3	**42**
2017	5	8				1		7	5	1	2	2	2	2	1	**36**
2018	11	7		4		10	1	15	6	1	3	3		3	2	**66**
Total Publication per Journal	**157**	**121**	**55**	**37**	**33**	**29**	**29**	**28**	**25**	**25**	**23**	**17**	**16**	**16**	**15**	**626**

To elaborate, as previously discussed, this research study considered all research articles pertaining systems thinking published from 1991 to 2018 that contain the selected keywords (big-picture thinking, hierarchical thinking, holistic thinking, multidimensional thinking, systemic thinking, systems thinking, "systems thinking and design thinking", and "systems thinking and systems dynamics"). After following all the steps mentioned in the methodology, due to the space limitation, Table 4 presents only the top 15 journals that appeared in the Scopus database based on the highest number of articles appeared in the field of systems thinking within the year of 1991–2018.

Figure 3 presents the annual publication frequency from 1991 to 2018. As shown in Figure 3, the number of systems thinking publications in the top 15 journals has increased exponentially over the years. One major interpretation of the significant increase rate is that practitioners, academia and industry have recognized the necessity of using systems thinking as a new way of thinking to deal with modern enterprise systems. Another interpretation is that systems thinking as a domain is not saturated yet, and there is plenty of progress and improvement that can take place. The geometric trend of Figure 3 also reveals an interesting fact that the total number of publications from 2013–2018 is slightly more than the total number of publications from 1991–2012. This growth clearly indicates that systems thinking has been receiving more attention in recent years, and the full-spectrum maturation of this domain is underway.

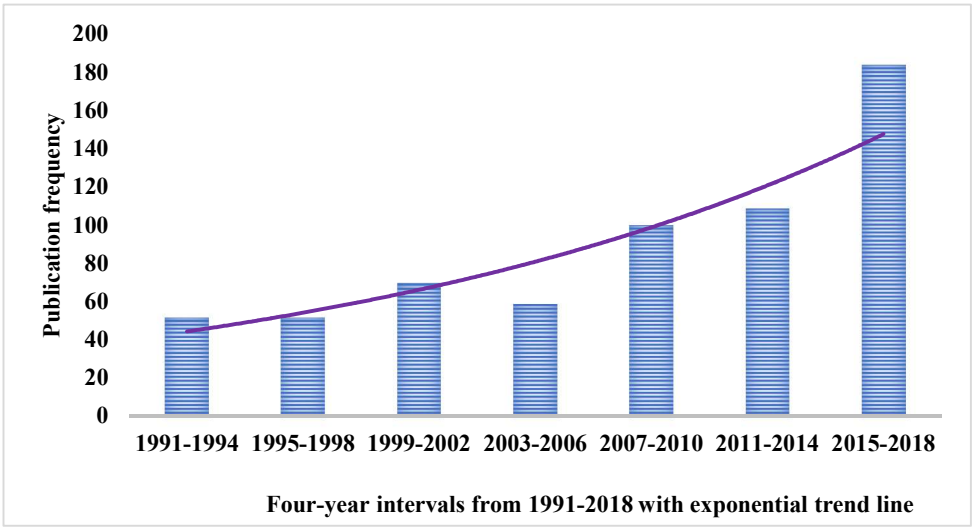


Figure 3. Publication frequency during 1991–2018. (n = 626).

2.5. Data Analysis

The data analysis was performed in two steps: *bibliometric analysis* and *network analysis*, and these analyses are explained in Sections 4 and 5. The Bibliometric analysis is composed of analytical methods that review a large number of articles in order to demonstrate a comprehensive overview of a specific research field [96]. The bibliometric analysis also provides information pertaining to the influential/leading studies, authors, countries, institutions, journals and universities for that specific research field. For our study, by using the Bibliometric analysis, we can identify the research patterns of systems thinking domain and avail the information germane to the most influential studies, researchers, affiliations, institutions and countries in the extant systems thinking literature.

BibExcel software was used to perform the Bibliometric analysis. The rationale behind the selection of BibExcel is (1) to provide additional statistical information related to the author' names, affiliation and the keywords, (2) to provide flexibility and capacity to navigate and manage the large volume of data from various databases including Scopus, (3) has greater functional compatibility when paired with Scopus and (4) the ability to structure extensive dataset as an input for different network analysis tools such as Gephi, pajek and VOSviewer [97]. Other software such as HistCite and Persih

are also popular; however, HistCite is only compatible with data imported from WoS, while Perish is compatible with Google Scholar and Microsoft Academic Research [98]. However, none of these software packages was able to generate data for further analysis.

Upon completion of the data collection using BibExcel, the next step is to perform the network analysis. The network analysis was performed using Gephi—-A software that has the capability of handling large datasets such as the dataset of this research and can produce a collection of powerful visualization options. These two main features were the reasons of using Gephi over other available software such as VOSviewer [99] and Pajek [100]. Table 5 summarized the different analyses used in this research study.

Table 5. Overview of the analysis.

Types of Analysis	Approach	Key Outcome
Bibliometric	Content Analysis	- Influential journals - Influential authors - Affiliation statistics - Top contributing countries - Top contributing organizations - Top keyword statistics
Network	- Citation analysis - Page rank analysis - Co-citation analysis	- Influential articles - Prestigious articles - Current and emerging research trends and clusters

3. Bibliometric Analysis

The dataset imported from Scopus output is entered into BibExcel using RIS format. This particular analysis includes the authors' name and title, journal name, publication year, keywords, authors' affiliations and references. During the analysis, we stored the RIS file with several different formats to produce different file types. For a better understanding of the process and applications of BibExcel, readers may refer to Paloviita [101] and Persson et al. [97]. The following subsections will present the statistics on authors' affiliation, influence and the keywords obtained from the BibExcel analysis.

3.1. Author Influence

To run the author's influence analysis using BibExcel, the author's field was extracted from the RIS data file, and the frequency appearance of all authors was listed to analyze the authors' influence on the systems thinking domain in terms of the number of publications. Table 6 shows the top 15 contributing authors and their respective number (frequency) of publications in the span of 1991 to 2018. The data shows that Midgley has published most with 28 articles, followed by Salmon, who published 26 articles. In other words, Midgley and Salmon together published almost 9% of articles in the area of systems thinking and related topics in the top 20 journals from 1991 to 2018. Another key finding indicates that more than 30% of publications in the area of systems thinking and related topics have been published by the top 15 authors in the top 20 journals from 1991 to 2018. This is an indicator of their significant contributions to the body of systems thinking knowledge.

Table 6. Top fifteen contributing authors.

Author Name	No of Publications
Midgley, G.	28
Salmon, P.M.	26
Mulej, M.	15
Lenné, M.G.	14
Bosch, O.J.H.	13
Goode, N.	13
Fuenmayor, R.	12
Nguyen, N.C.	12
Frank, M.	11
Jackson, M.C.	10
Stanton, N.A.	10
Best, A.	9
Flood, R.L.	9
Read, G. M.	9
Metcalfe, M.	8

3.2. Affiliation Statistics

We followed the same approach, BibExcel, to find the authors' affiliation from the RIS file. Each corresponding affiliated location was analyzed further. Based on the coordinates obtained from *latlong.com*, the graphical location of all the organizations was developed using ArcGIS, as displayed in Figure 4. The dispersion of all of these shapes, including circles and polygons, suggests that there is a global interest in systems thinking. The size of each shape is proportional to the extent each organization contributes to the domain of systems thinking. It is apparent from Figure 4 that a greater contribution comes from United Kingdom, United States and Australia regions, whereas United States, United Kingdom and Australia are leading the chart depicted by a blue polygon. Table 7 shows the top 20 countries in the domain of systems thinking.

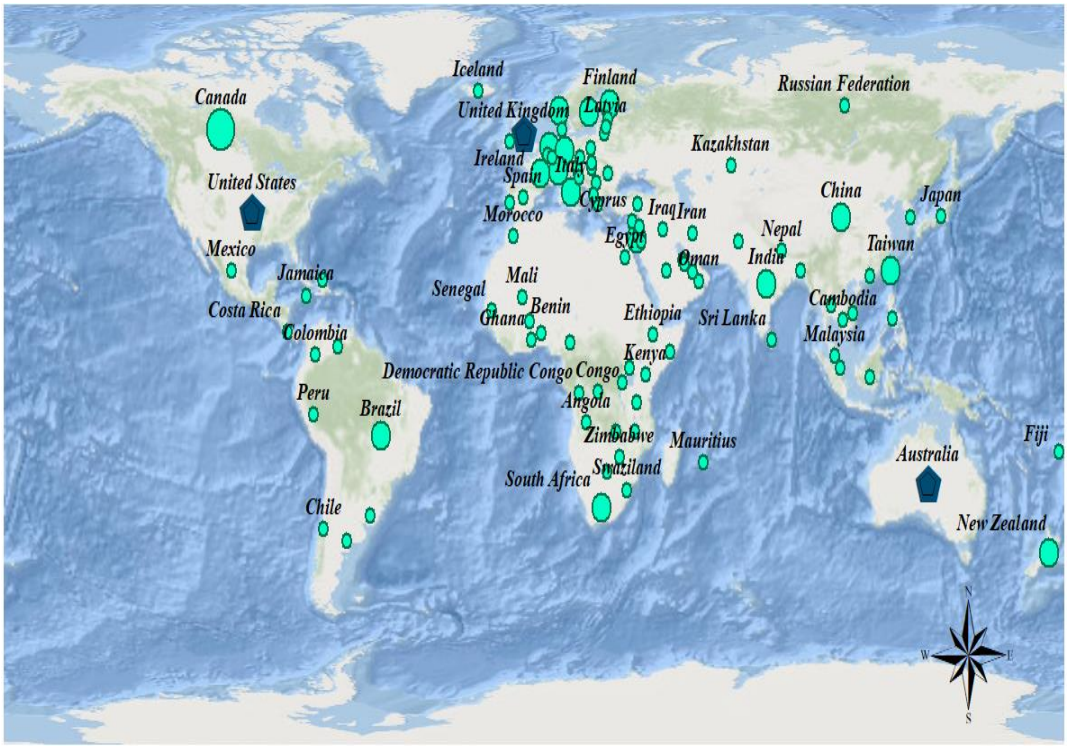


Figure 4. Geographical locations of contributing countries.

Table 7. Top fifteen contributing countries.

Country	Publication Frequency
United States	888
United Kingdom	556
Australia	347
Canada	136
Sweden	111
China	92
New Zealand	80
Netherlands	79
Germany	78
Italy	71
South Africa	71
India	55
Israel	51
Finland	47
Brazil	46

Table 7 indicates that there is a significant difference between native English language countries with the rest of the world with regard to the contribution of the systems thinking body of knowledge. Table 8 presents the top-performing organizations in terms of the number of publications. The comparison between Tables 6 and 8 shows that Midgley and Salmon belong to the University of Hull and University of Sunshine Coast. This indicates that the contribution of one or two researchers is sufficient to make a place for his organization in the top-performing chart [102]. It is also apparent from Table 7 that about 13% of systems thinking publications and related topics from 1991 to 2018 in the top 20 Scopus indexed journals have been performed by the University of Hull, which clearly indicates the essential contribution of this university to the domain of systems thinking. The top 10 organizations/universities contributed more than 56% of publications from 1991 to 2018 is shown in Table 8.

Table 8. Top ten contributing organizations.

Organization/Affiliation	No of Publications
University of Hull	81
University of Queensland	55
University of the Sunshine Coast	34
Monash University	31
Open University	29
Michigan State University	27
Victoria University of Wellington	25
Massachusetts Institute of Technology	25
University of Waterloo	23
The University of Adelaide	22

3.3. Keyword Statistics

A similar analysis was performed to determine what words/phrases appeared in the article's keywords most frequently, as shown in Table 9.

Table 9. Top 20 keywords.

Keywords	Frequency	Keywords	Frequency
systems thinking	1053	Complexity	125
Human/Humans	445/363	System Analysis	120
System Theory	315	Learning	118
Sustainability	191	System Dynamics	116
Sustainable Development	177	Critical systems thinking	114
Decision Making	173	Thinking	113
Systems Analysis	173	Methodology	108
Organization and Management	152	Leadership	101
Education	136	System Thinking	90
Systems Theory	127	Procedures	89

3.4. Subject Category Statistics

The application of systems thinking in each domain is illustrated by the bar chart shown in Figure 5. It is apparent from Figure 5 that systems thinking has the widest application in the business, management, and accounting field followed by computer science and decision science. The length of each bar represents the number of publications that appeared within 1991–2018. The total percentage value of the bar chart is above 100 percent since, in some cases, the same publication may belong to different domains.

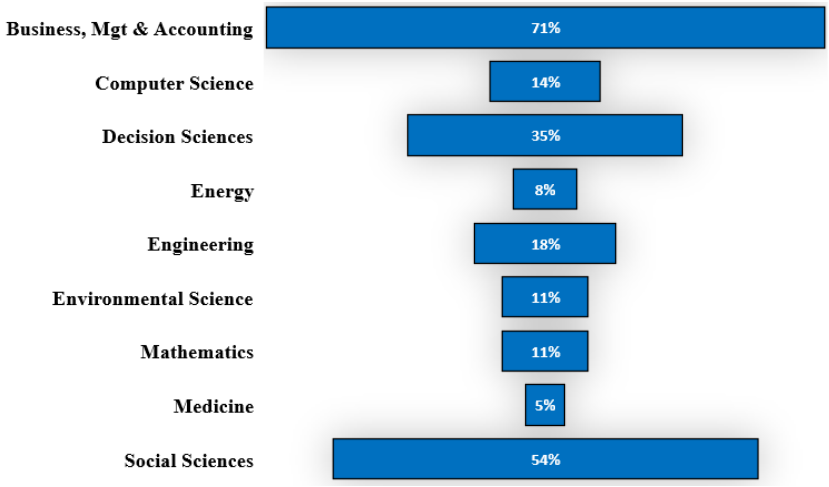


Figure 5. Subject-wise systems thinking publications (in%).

4. Network Analysis

Now that the required data are available, Gephi software was chosen to perform the network analysis over different available tools due to the user-friendly platform, better visual aids, advanced filtering techniques and compatibility with different data formats. The other options to choose from have some forms of inconvenience. As an example, HistCite graph maker exclusively works on WoS data outputs, while Pajek is limited to ".Net" format files and VOSviewer has a very limited array of toolboxes for network analysis.

Gephi is one of the best open-source software packages that uses a 3D render engine to establish depictions of large networks in real time [103]. Gephi offers animated network visualization to the experts and general audience in terms of analysis clarity and exploration. The highly versatile and multi-task architecture of Gephi provides insightful visualization of network data. It allows convenient and broad access to network data and helps in spatializing, filtering, navigating, personalizing and clustering the complex dataset [104]. In order to visualize and map the network using Gephi, it is necessary to introduce a database that includes published papers and the corresponding

citations [105,106]. In this research paper, we illustrate the published papers as nodes and the citations as arcs or edges between the nodes. The bibliographic data obtained from the Scopus is in a RIS format and cannot be run directly into Gephi; thus, this dataset was converted into a ".NET" file using BibExcel software. This format contains different information fields that were fed into Gephi for network analysis.

4.1. Citation Analysis

Citation analysis provides a citation frequency of any particular document. The amount of citations in a scientific journal implies its significance in that field of research [107]. It is noted that the most frequently cited articles in the scientific field have more impact when compared to articles that have fewer citations [105,106,108,109]. The citation analysis is a reliable approach to check the influential author, journal or work on a particular research area [110]. However, this analysis was receiving some criticism, still considered the most commonly used technique of literature analysis [111–113]. Table 10 demonstrates the top ten influential works published between 1991 and 2018.

Table 10. Top 10 Publication Based on Number of Citation.

Authors	Title of Publication	Cited by
Sterman (1994) [114]	Learning in and about complex systems	524
Bazilian et al. (2011) [115]	Considering the energy, water and food nexus: Towards an integrated modeling approach	374
Sterman (2002) [116]	All models are wrong: Reflections on becoming a systems scientist	370
Forrester (1994) [117]	System dynamics, systems thinking and soft OR	337
Wilensky & Resnick (1999) [118]	Thinking in levels: A dynamic systems approach to making sense of the world	304
Holmberg (2000) [119]	A systems perspective on supply chain measurements	290
Rubenstein-Montano et al. (2001) [120]	A systems thinking framework for knowledge management	281
Sweeney and Sterman (2000) [15]	Bathtub dynamics: Initial results of systems thinking inventory	274
Richmond (1993) [70]	systems thinking: critical thinking skills for the 1990s and beyond	262
Kay et al. (1999) [121]	An ecosystem approach for sustainability: Addressing the challenge of complexity	260

It is apparent from Table 10 that J.D. Sterman's article is the most cited work based on the Scopus database. Moreover, in his work, Sterman demonstrated the efficacy and extensibility of systems thinking approach to enhance learning about complex dynamic systems. This indicates that his work is used as a point of reference in the systems thinking literature. The other authors, listed in Table 10, have similar notable works in the literature.

4.2. PageRank Analysis

Citation analysis may lead to bias as, in many cases, some authors tend to cite their own work frequently—-a contemporary criticism of this analysis. Therefore, total citations count does not always indicate a higher scientific value nor the popularity of an article. In order to compensate this criticism, PageRank (PR) is used as a convenient choice. PageRank is an evaluation algorithm developed by Brin and page [122] to prioritize web pages when keywords are inputted in the Google search engine. PageRank measures the scientific value of an article and its popularity simultaneously. PageRank assigns a probability distribution for each article considering the number of available articles for the analysis; thus, the sum of all PR scores is equal to one.

Assume that article A is cited by papers B_1, B_2, ...,B_n, where study B_i has citations $C(B_i)$. Parameter d denotes the damping factor, representing the fraction of random walks that continue to propagate with the citation. The value of parameter d is set between 0 and 1 and then we defined $C(T_i)$ as the number of times study T_i has cited other papers. Thus, for study A, the PageRank $PR(A)$ in a network of N papers is calculated using the following formula:

$$PR(A) = \frac{(1-d)}{N} + \frac{PR(B_1)}{C(TB_1)} + \frac{PR(B_2)}{C(B_1)} + \ldots + \frac{PR(B_n)}{C(B_n)} \quad (1)$$

As the PageRank analysis develops a probability distribution over the articles, the sum of the page score of all papers would be equal to one. It should be noted that if there any condition arises

where $C(B_i) = 0$, then $PR(B_i)$ should be divided by the number of papers instead of $C(B_i)$. The value of d is fixed at 0.85 [122]; however, $d = 0.5$ is a more appropriate choice for PageRank analysis in citation networks, as stated by Chen et al. [123].

Table 11 presents the top 10 publications based on PageRank analysis. As shown in Table 11, the PageRank analysis is different from the citation analysis (number of citations) approach in terms of influential authors' work. For example, using the PageRank analysis, Sweeney & Sterman's article is ranked 2nd, while Richmond's article is considered the most influential work in the systems thinking literature. Rubenstein-Montano et al. work ranked 10th in the PageRank analysis instead of 7th in the number of citations analysis approach (Table 10). This indicates that different analysis approaches can lead to different outputs, as highly cited study may not necessarily be a prestigious study. Since the citation analysis cannot provide an accurate representation of the prestige of a study, PageRank analysis is a better choice to obtain an idea of the worth and significance of a study in terms of prestige and popularity index.

Table 11. Top 15 Publication Based on PageRank.

Authors	PageRank
Richmond (1993) [70]	0.01246
Sweeney & Sterman (2000) [15]	0.01150
Forrester (1994) [117]	0.01092
Sterman (1994) [115]	0.00735
Wilensky & Resnick (1999) [118]	0.00486
Sterman (2002) [116]	0.00473
Bazilian et al. (2011) [114]	0.00301
Holmberg (2000) [119]	0.00276
Kay et al. (1999) [121]	0.00250
Rubenstein-Montano et al. (2001) [120]	0.00008

4.3. Co-Citation Analysis

Co-citation analysis explores the relationship between authors, topics, journals and keywords [124,125]. Co-citation analysis is performed based on the graph theory to explore the data structure behind the publications. Publications are considered to be co-cited if they appear together in the reference lists of other documents. The co-citation analysis reveals the prominent research clusters in a certain research area and manifests how the research clusters evolve over time based on the frequency of the publications.

To perform a co-citation analysis, the ".NET" file, obtained earlier from BibExcel, is used and performed using Gephi. A fully random map with no distinct pattern was generated through Gephi. To provide a more organized map, different algorithms, built-in Gephi, are used to shape the pattern of the map. In this research paper, we applied the Force Atlas layout algorithm because of its simplicity and the vast array of parameters that can be manually controlled, such as strength, speed, gravity, node and size [104]. The resulting network analysis is composed of nodes and edges that repulse and attract each other. For instance, the nodes that are a strongly connected move towards the center of the layout, whereas the nodes that repulse each other move towards the periphery. The more connections a node has closer to the center it gets, the fewer linkages it has the further to the edge it will be positioned. Figure 6 shows the Force Atlas layout of 626 nodes.

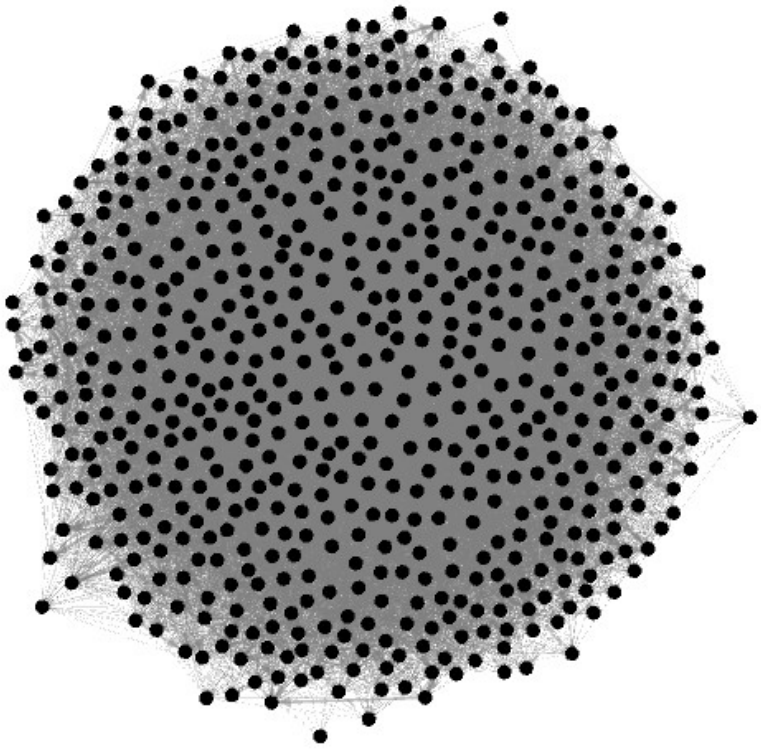


Figure 6. Network analysis using the force atlas layout of 626 nodes.

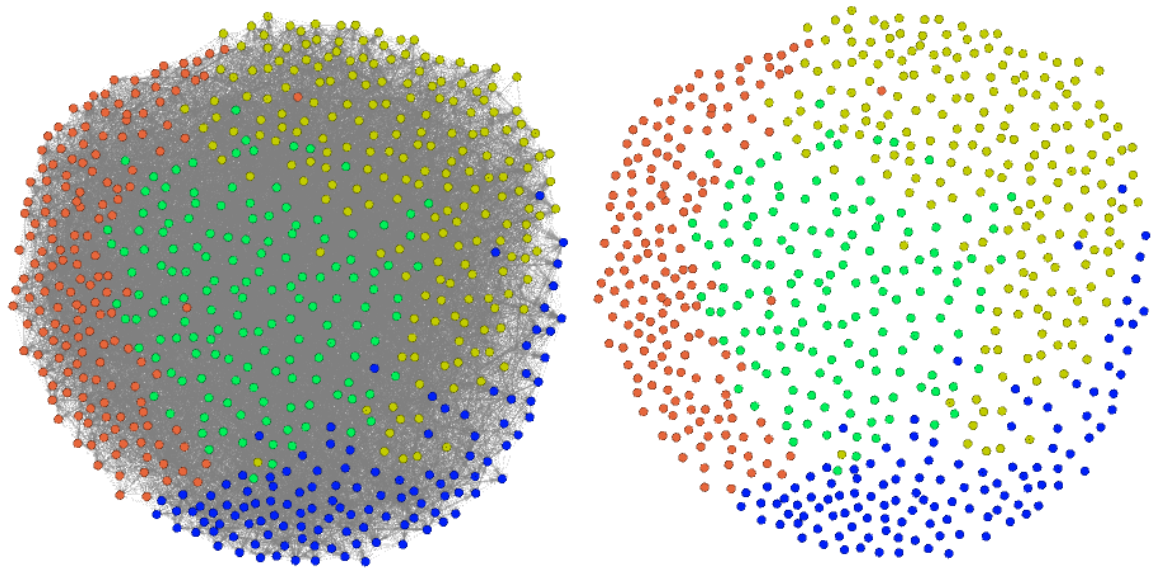
Data Clustering

Data clustering is a classification tool that enables the grouping of article sets [105,106,126]. To distinguish between different research concentrations and scopes in the domain of systems thinking from 1991 to 2018, a data clustering technique was performed. Moreover, the nodes in the developed network analysis, as shown in Figure 5, were further clustered based on a Louvain algorithm developed by Blondel et al. [127]. For data clustering, the Louvain algorithm evaluates the density of the links within communities (clusters) against the links across communities (clusters). In an arrangement, the nodes can be grouped into clusters that represent different articles and the edges that link the nodes are an indicator to distinguish between clusters [126,128,129]. The modularity index of a cluster illustrates the density of the links across clusters and within clusters and ranges from −1 to +1. Blondel et al. [127] developed a formula to calculate the modularity index:

$$Q = \frac{1}{2m}\sum_{ij}[A_{ij} - \frac{k_i k_j}{2m}]\delta\left(c_i, c_j\right) \quad (2)$$

where A_{ij} represents the weight of the edge between nodes i and j, k_i is the sum of the weights of the edges attached to node i ($k_i = \sum_j A_{ij}$), c_i is the community to which vertex i is assigned, $\delta(u, v)$ is equal to 1 if $u = v$ and 0 otherwise and finally $m = (1/2)\sum_{ij} A_{ij}$.

Applying the Louvain algorithm on 626 nodes resulted in four main clusters with a modularity index of 0.18. The modularity index shows how strong is the interrelationship among identified clusters, as shown in Figure 7a,b. In our case, the modularity index of 0.18 indicates the strong linkage among nodes within each cluster and across clusters.



(**a**) (**b**)

Figure 7. Structure of four clusters (**a**) with arcs and (**b**) without arcs.

As Hjørland [130] mentioned, the frequently co-cited articles in each cluster are likely to have similar research areas and scope. As a result, a precise analysis of top articles within each cluster would help to provide a holistic view of the research area of that specific cluster. The top-ten articles within each of the four clusters were identified (see Table 12). The detailed interpretation of each research area within each cluster is discussed next.

Table 12. Top 10 articles of each cluster: co-citation PageRank measure.

Cluster One	Cluster Two	Cluster Three	Cluster Four
Checkland (2000) [131]	Sterman (2002) [116]	Sterman (1994) [114]	Bazilian et al. (2011) [115]
Sterman (2006) [29]	Wilensky and Resnick (1999) [118]	Forrester (1994) [117]	Kay et al. (1999) [121]
Rubenstein-Montano et al. (2001) [120]	Sweeney and Sterman (2000) [15]	Holmberg (2000) [119]	van Ittersum (2003) [132]
Dekker et al. (2011) [25]	Richmond (1993) [70]	Hjorth and Bagheri (2006) [133]	Kuramitsu et al. (2007) [134]
Jackson et al. (2014) [42]	Assaraf and Orion (2005) [44]	Senge and Sterman (1992) [84]	Robert et al. (2002) [135]
Söderström et al. (2014) [43]	Foxon and Pearson (2008) [136]	Mingers and White (2010) [28]	Plummer and Armitage (2007) [137]
Flood (2010) [5]	Robert (2000) [138]	Skyttner (2005) [139]	Head and Alford (2015) [140]
Leveson (2011) [141]	Richardson (2011) [142]	Leischow and Milstein (2006) [143]	Fiksel (2003) [144]
Courtney (2001) [145]	Ulrich (2003) [146]	Stave (2002) [147]	Kassam et al. (2009) [148]
Trochim et al. (2006) [149]	Kreuter et al. (2004) [150]	Arnold and Wade (2015) [24]	Marshall and Farahbakhsh (2013) [151]

5. Discussion

Systems thinking as an interdisciplinary domain includes a diverse and wide range of perspectives, definitions and approaches across different domains of science (e.g., management, education, systems engineering, psychology and others). Co-citation and data clustering techniques indicated that four distinct research areas are main themes that exist in the systems thinking literature. With a detailed examination of top publications in each cluster, the theme and area of each cluster are defined and presented in Table 13.

Table 13. Four major research clusters.

Cluster(s)	Research Area and Themes	Median of Publication Year
One	systems thinking theory, concept and methodology	2008
Two	systems thinking characteristics and tools	2002
Three	systems thinking perspectives and frame of reference	2004
Four	systems thinking applications, implementations and approaches	2007

The publications in the first cluster are dominated by the development of theoretical frameworks and methods of systems thinking. These frameworks and methods are adopted to address different research areas such as complex systems problems in public health [29,149], decision support system and knowledge management [120,145], complex systems failure [25], management and operation research [131], strategic human resource management [42], smart cities [41], action research [5] and safety engineering [141]. Many theories and methods are proposed to enhance the holistic perception of complex systems. The publications in the first cluster have helped in developing a dominant pattern of thoughts pertaining to systems thinking. This pattern is focused on the need to move toward a new way of thinking, holistic thinking approaches, for better navigation and management of complex system problem domains. In the first cluster, the median of publications year is 2008.

The second cluster's publications mainly discuss the development of systems thinking tools and techniques. For example, Sweeney and Sterman [15] and Sterman [116] talked about the necessity of bathtub dynamic and simulations models as a systems thinking tool to develop an understanding of different concepts including, feedback, stocks and flows, time delays and nonlinearity. Other publications use different tools, case studies and frameworks to develop systems thinking characteristics including, "StarLogo" modeling language [118], The Natural Step framework for sustainable development [138], "critical thinking skills" framework [70] earth systems-based curriculum [44], a case study of low carbon energy innovation for sustainable innovation [136], "endogenous point of view" framework [142], "critically systemic discourse" framework [146] and "the precautionary principle" as a systems thinking framework for Environmental Health Promotion [150]. The work in cluster two focused on the identification of complex systems characteristics and attributes. Within this cluster, some tools and methods are proposed for systems thinking; however, most of these tools focused on one small setting or context. The median of publication year in this cluster is 2002.

The third cluster consists of publications with different perspectives and viewpoints toward systems thinking approaches. Mingers and White [28] reviewed a systems thinking perspective with regard to operational research and management science. Senge and Sterman [84] introduced an organizational learning perspective and elements of an effective learning laboratory. Leischow and Milstein [143] introduced the concept of population health dynamics and Stave [147] proposed a systems thinking perspective on public participation and involvement in environmental decisions. Based on a review of systems thinking literature, Arnold and Wade [24] presented a unified definition of systems thinking consisted of eight elements including, recognizing interconnections, identifying and understanding feedback, understanding system structure, differentiating types of stocks, flows and variables, identifying and understanding nonlinear relationships, understanding dynamic behavior, reducing complexity by modeling systems conceptually and understanding systems at different scales. Sterman [114] discussed barriers to learning complex dynamic systems including, improper result feedback, misperception of systemic feedback, poor understanding of the human cognitive map, poor systemic inquiry capability and poor scholarly reasoning capability. Sterman emphasized those successful approaches for learning complex dynamic systems must address all the mentioned learning barriers. Hjorth and Bagheri [133] suggested a system dynamics approach for sustainable development to improve system performance. Forrester [117] discussed the relationship between soft systems thinking, systems thinking and systems dynamics. Skyttner [139] explored the nature of systems theory and its application in different domains. Holmberg [119] presented a systemic perspective on supply chain measurement. The median of publication year in this cluster is 2004.

Since there are diverse and divergent perspectives regarding the systems thinking definitions and approaches in the domain, it is necessary to comprehend the existing systems thinking perspectives and frames of reference to better analyze the contributions, implications and limitations of each one of them. Considering different systems thinking perspectives and definitions are consistent with the concept of "holistic view" that emphasize on reviewing a system as a whole rather than a combination of segregated parts. The holistic point of view is the cornerstone of systems thinking.

The fourth cluster of systems thinking publications is devoted to diverse systems thinking applications and approaches. For example, Robert et al. [135] investigated the relationships between different systems thinking tools called, the natural step framework, factor 10, ecological footprinting, zero emissions, sustainable technology development, cleaner production and natural capitalism, applied for the domain of strategic sustainable development. They concluded that the application of all the above-mentioned systems thinking tools is to assure the sustainable management and monitoring of complex systems. Other researchers applied systems thinking to diverse domains such as energy, water and food [115], the Wageningen crop models [132], resilient sustainable systems [144], conservation agriculture [148], oral microbial [134], adaptive co-management to link ecology, economics and society [137], an ecosystem sustainable approach [121], public policy and management [140] and solid waste management [151]. All of the mentioned systems thinking applications and approaches were introduced in the last two decades and the median of this cluster is 2007. This list of applications shows the efficacy and acceptability of systems thinking across different domains.

Managerial Implications

There are many scattered and different definitions, perspectives, methods, applications, and approaches that exist related to systems thinking. This divergence emanates from the systems thinking literature, which is a fragmented compilation of the use of the term "systems thinking" by practitioners and scholars from different domains. Because of the diverse applications of systems thinking, the existing scope and dominant pattern of thought of systems thinking often vary, and as a consequence, there is no unified and comprehensive perspective and method that all researchers agree. Thus, there is a vital need to conduct a systematic review of the diverse literature of systems thinking to provide a big-picture regarding the contribution of researchers within the different scope of systems thinking. This systematic review assists researchers to trace the commonality among scattered perspectives pertaining to systems thinking and to identify the current gaps that need more attention. In addition, systems thinking is an interesting topic for many different domains such as systems engineering, education, management, social science and others, which resulted in the inclusion of different perspectives and methods from engineers, educators, managers and other researchers. Therefore, by context, any taxonomy is somewhat arbitrary, and no doubt, other classifications or categorizations are possible. Each is correct from a particular vantage point. Below we summarize some of the research implications for academia and practitioners:

- This research paper articulates valuable information on systems thinking research in terms of the most influential journals, most influential affiliations, most influential authors and most influential studies in the extant literature. The new/interested researchers/practitioners can select which papers to cite, what are the most relevant papers, what is the most influential paper within the systems thinking domain.
- This research paper manifests the scope of systems thinking research, theoretical and empirical issues pertaining to the relevant literature by means of content analysis. Therefore, both academicians and practitioners can obtain a broader understanding regarding the extent of a topic, emergent trends and its evolution over time. In this sense, this research is different from a traditional literature analysis.
- The findings of this research study would serve as a "blueprint" for the academicians/practitioners who are keen to conduct research within systems thinking context.

- Moving beyond the existing literature, this research would foster and propagate a richer dialog that may be fruitful to the body of knowledge of systems thinking.

6. Conclusions

Systems thinking is a fast-growing and interesting topic for practitioners, government, military and researchers in diverse domains including, systems engineering, management, education, healthcare and others. However, there is a lack of unified linkage among different and scattered articles relevant to the systems thinking domain. Bibliometric and network analyses were performed to find the top contributing authors, journals, organizations, countries and keywords in the systems thinking domain, to rank top influential articles using co-citations and PageRank analyses from 1991 to 2018 and to cluster four major categories of research in the systems thinking domain. Bibliographic and network analyses assist in identifying the significant contributor, valuable publication, research type and design that moves the systems thinking domain forward. Additionally, this article tries to exhibit the existing literature gaps and research trends that need more attention from researchers in the systems thinking domain.

As we have applied a robust technique to conduct a systemic review of the last thirty years of the literature of systems thinking, our research still subjected to some limitations. One of the limitations is that the influential works were decided by the usage of citation and co-citation analysis; however, some of the potential articles, which may be influential, but published recently, may not appear in the current research. This limitation is related to the likelihood that recent articles to get significant and reliable PageRank is less than the older articles. In other words, a recent article may be rigorous, but since it has not been widely cited or recognized by other researchers yet, it has a low PageRank now. PageRank analysis has another limitation in terms of the stability of journals' reputation over time. Since the reputation of the journal, which is fundamental in PageRank calculation, may change over time, the PageRank of articles published in that journal needs to be upgraded. An avenue for future research can be the usage of other methods such as SCImago Journal Rank and comparison of results from different methods. The comparison is important because it gives better estimates of the validity and reliability of each method. The future research can be extended by (i) Expanding the current keywords to broaden the scope of the search (ii) Performing joint author-cluster analysis to observe the authors' contribution to the evolution of clusters (iii) Performing dynamic co-citation analysis to understand the evolution of systems thinking research over time.

The intent of this work is to provide a comprehensive review of previous and current research trends and themes in the field of systems thinking. Due to diverse perspectives, convergence and applications of systems thinking among worldwide researchers, this work reports the influential statistics pertaining to systems thinking and provides an avenue for interested researchers to better understand the nature of the field by exploring the content of the report. It is apparent from the results that there are four clusters in the field are still under-development. The first cluster is related to theoretical, conceptual and methodological aspects of systems thinking. The research in this cluster is gradually improving and expanding; however, it is still in the maturation phase since there is no universally accepted theories and concepts. This is also the case for the second and third clusters in the sense that different schools of thought and perspectives, as well as tools and techniques pertaining to systems thinking, are not fully accepted or validated. With respect to the fourth cluster, many diverse systems thinking applications, implementation and approaches are still emerging. As a result, we believe that the fourth cluster will remain expanding since systems thinking is used across different disciplines. Another noticeable fact is that the countries where English is the first language have dominated the publication frequencies in the field of systems thinking, which may also suggest that other countries where English is not the first language need more time to conduct more research in this field.

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resources, N.U.I.H., V.L.D., and M.N.; data curation, N.U.I.H., V.L.D., and M.N.; writing—original draft preparation, N.U.I.H., V.L.D., and M.N.; writing—review and editing, R.J.; visualization, N.U.I.H.; M.N.; supervision, R.J.; project administration, R.J.; funding acquisition, R.J. All authors have read and agreed to the published version of the manuscript.

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