

Research Article

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Understanding the Application of Science Mapping Tools in LIS and Non-LIS Domains

<https://doi.org/10.2478/dim-2020-0006>

received December 28, 2019; accepted March 28, 2020.

Abstract: As a scientific field, scientific mapping offers a set of standardized methods and tools which can be consistently adopted by researchers in different knowledge domains to answer their own research questions. This study examined the scientific articles that applied science mapping tools (SMT) to analyze scientific domains and the citations of these application articles. To understand the roles of these application articles in scholarly communication, we analyzed 496 application articles and their citations from 14 SMT by classifying them into library and information science (LIS) and other fields (non-LIS) in terms of both publication venues and analyzed domains. In our study, we found that science mapping, a topic that is deeply situated in the LIS field, has gained increasing attention from various non-LIS scientific fields over the last few years, especially since 2012. Science mapping application studies practically grew up in LIS domain and spread to other fields. The application articles within and outside of the LIS fields played different roles in advancing the application of science mapping and knowledge discovery. Especially, we have discovered the important role of articles, which studied non-LIS domains but published in LIS journals, in advancing the application of SMTs.

Keywords: science mapping tools, scholarly communication, scientific software, scientific evolution

1 Introduction

Software is the engine of the contemporary scientific system. It covers almost every aspect of the scientific

practice that researchers are conducting on a daily basis in the increasingly more data-driven environment (Hey, Tansley, & Tolle, 2009). While data analysis is the focus of the majority of scientific software, many software objects in scientific contexts are dedicated to representing scientific data and results in visual manners.

These visualization tools play important roles in the production of scientific knowledge, often more than they are credited. One such example is that they are a central part of the mechanism of science as “inscription device,” i.e., the function to create inscriptions that can be used for scientific arguments (Latour & Woolgar, 1979). Another example is the strong rhetorical abilities of scientific graphs that is reflected in their capacity as immutable mobile (Latour, 1987), i.e., objects that can maintain their identities and meanings across time and space. This is also consistent with the idea that scientific visualization method is a boundary object (Star & Griesemer, 1989) across different knowledge domains. As a highly standardized set of methods and tools, scientific visualizations can be easily used on different research problems by researchers from various communities.

One type of scientific visualization that is strongly connected with the field of information science is science mapping. Science mapping is a generic process of domain analysis and visualization (Chen, 2017). The process utilizes various methods and techniques including scientometrics methods (Callon, Courtial, & Laville, 1991; Kessler, 1963; Small, 1973; White & McCain, 1998), visualization techniques (Chen, 2006; Herman, Melancon, & Marshall, 2000; Shneiderman, 1996), and research metrics (Hirsch, 2005). The data used for the analysis process are scientific publications reflecting the scientific knowledge of the analyzed domain, which are usually collected from scholarly databases, such as the Web of Science (WoS), Google Scholar, and Scopus. Due to the availability of methods, techniques, and data, various science mapping tools (SMT) have been developed to facilitate the process. These tools have become a necessary component in the science mapping study.

The methods and tools of scientific mapping are an important site to understand how the material and

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methodological practice of science are represented in literary outputs of science, which in turn moderates how science is communicated. Several studies have examined the role of science mapping in scholarly communication by literature review (Chen, 2017), comparing SMT (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011b) and analyzing the usage of SMT (Pan, Yan, Cui, & Hua, 2018). However, the domain analyzed by using SMT in scientific articles and the impact of science mapping studies that applied SMT were rarely involved.

Understanding which domains have been analyzed in articles applied SMT along with where these studies published can provide insights of the evolutionary patterns of science mapping. The citation analysis of these application articles can reveal the role of application articles for overcoming the domain boundary between Library and Information Science (LIS) and non-LIS domains. In this study, we examined the different kinds of SMT application articles in terms of their analyzed domains and journal domains and map out the citation impact of application articles. Specifically, the following research questions are pursued in this article.

What is the evolutionary pattern of SMT application articles in LIS domains and non-LIS domains?

What are the scientific impacts of the application articles?

2 Literature Review

To display the structure of knowledge flow and diffusion (Chen, 2017), SMT based on literature have been developed with a series of theoretical support. Science mapping analysis is composed of a few steps in the workflow, including information retrieval, data cleaning, information extraction and formalization, network analysis, and visualization (Cobo et al., 2011b). Every step has its theoretical support to ensure the assistance of science mapping. Studies tend to investigate the latter three till present. In the step of information extraction and formalization, co-word analysis (including document co-occurrence, co-author analysis, etc.) (Borgman & Furner, 2002; White & McCain, 1998), bibliographic coupling (Kessler, 1963), and co-citation analysis (White, 2003) have been mostly discussed and even improved to comprehend the object precisely. During the network analysis, previous studies have explored social network analysis (Barabási & Albert, 1999; Lazega, 1995), temporal analysis (Garfield, 1994; de Solla Price & Gürsey, 1975), burst detection (Chen, Wang, & Wang, 2010; Kempe, Kleinberg,

& Tardos, 2015), and geospatial analysis (Leydesdorff & Persson, 2010; Small & Garfield, 1985) to deconstruct the network and detect the patterns of knowledge structure. The theoretical studies on visualization used to improve the methods of tree structure (Johnson & Shneiderman, 1991) or geospatial structure. Finally, more studies have been recently debating on the display format based on human search behavior (He, Ping, Lou, & Chen, 2019; Lou, Wang, & He, 2018). These discussions have brought up the diversity of SMT from the perspective of both usage and visualization.

Intentionally, SMT are expected to be used to generate the knowledge structure and history of the disciplines and research areas (Chen, 2017). During the process of this study, among all the usage articles we collected, one-third of them have applied at least one science mapping tool to describe the evolution of the target research areas, such as business and biology (Jahangirian, Eldabi, Naseer, Stergioulas, & Young, 2010; Oldham, Hall, & Burton, 2012). Also, one-quarter of researches mentioned earlier have discussed the transformation status on LIS (Zhao & Strotmann, 2014). In other words, many studies must have mentioned SMT for other reasons, for instance, comparing the algorithm that one paper developed with the other science mapping software (Y. Chen, Xu, & Xu, 2015).

Since more studies have been applied SMT on special subjects, many scientists have attempted to compare the feasibility and efficiency among SMT and software (Huang, Ding, Lee, Lu, & Gu, 2013). The assessment approaches came from different intentions. Some studies have measured the usage of SMT on particular disciplines (Li, Yan, & Feng, 2017; Pan et al., 2018; Pan, Yan, Cui, & Hua, 2019). Other studies have empirically examined the impact types of applying software in scientific literature (Pan, Yan, & Hua, 2016; Pan, Yan, Wang, & Hua, 2015).

Scientists have gained the awareness of the full track study on SMT from theory to application and estimation. The assessment on the application of SMT specifically comparing LIS with other domains has been hardly discussed. Yet, the usage of these application articles has not been explored. In this article, we examined the differences of the distributions how SMT have influenced on LIS and other domains and specifically addressed the implication of the articles that applied SMT.

3 Methods

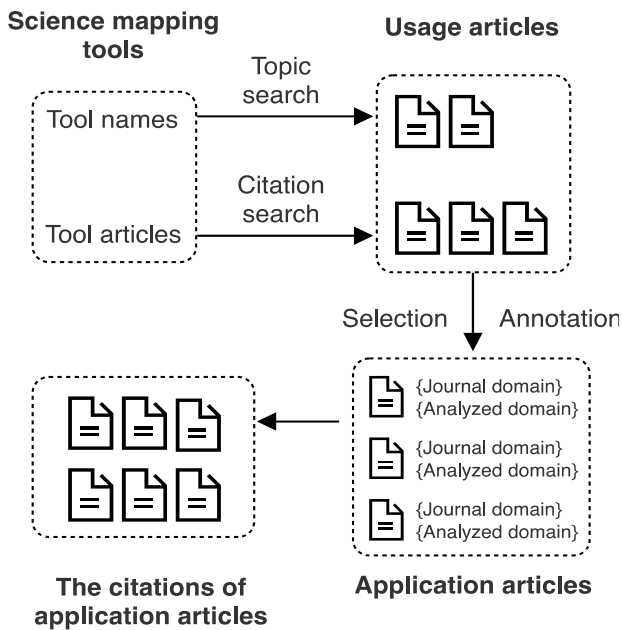


Figure 1. Procedure of data collection.

3.1 Collecting SMT Information

Science mapping software tools have been developed to visualize scientific development. Some of these software tools were designed to characterize only scientific mapping and others may adopt only general information. Some of these software tools are adept at visualization and others may assist only the mapping process (Cobo et al., 2011b). The definition of science mapping software has yet been unified. We defined SMT in this article as scientific mapping software (1) whose data sources are based on scientific literature and (2) which aim to understand and visualize the evolution of scientific domains. The procedure of data collection is described in Figure 1.

We first summarized 34 existing science mapping software on April 25, 2018. By looking into individual software, we excluded 20 of them which are not qualified for the criteria of SMT. Some software, e.g., BibExcel, are designed to assist the further visualization processing (Persson, Danell, & Schneider, 2009). Others are designed for generic network analysis, modeling, and visualization, such as Gephi (Bastian, Heymann, & Jacomy, 2009) and Network Workbench (NWB Team, 2006). The information of 14 SMT was collected including website, developers, and seed articles (see Table 1).

Table 1
Basic Information of SMT

SMT	Seed articles	Usage articles	
		Cited seed articles	Topic search result
BiblioTool	Grauwin and Jensen (2011)	0	0
CiteSpace	Chen (2006); Chen, Ibekwe-SanJuan, and Hou (2010)	469	97
CitNetExplorer	Van Eck and Waltman (2014)	37	7
CoPalRed	Bailón-Moreno, Jurado-Alameda, and Ruiz-Baños (2006); Bailón-Moreno, Jurado-Alameda, Ruiz-Baños, and Courtial (2005)	30	3
CRExplorer	Leydesdorff, Bornmann, Marx, and Milojević (2014); Marx, Bornmann, Barth, and Leydesdorff (2014)	44	8
HistCite	Garfield, Pudovkin, and Istomin (2002, 2003)	75	42
IDR Toolkit	Rafols, Porter, and Leydesdorff (2010)	137	0
ITGInsight	–	0	0
NEViewer	Wang, Cheng, and Lu (2014)	8	1
SciCurve	–	0	2
Sci2 Tool	Börner (2011)	25	15
SciMAT	Cobo, López-Herrera, Herrera-Viedma, and Herrera (2012)	43	8
VOSViewer	Van Eck and Waltman (2010); Waltman, Van Eck, and Noyons (2010)	485	93
VxInsight	Davidson, Hendrickson, Johnson, Meyers, and Wylie (1998)	45	5
Total (distinct)	17	1,398 (1,264)	281 (246)

3.2 Collecting Seed Articles of SMT

Every SMT was introduced by the developers in one or more scientific articles. We defined these articles as seed articles of SMT. Seed articles are the pioneer articles. Usually, articles used or mentioned a SMT should cite the corresponding seed article. Therefore, seed articles will lead us to find usage articles. Seed articles are normally listed in the website of SMT. In some cases, the developers

tended to publish a series of articles to guide users. Since our following data analysis will be based on WoS, we included only at most two articles that are comparatively highly cited in WoS if the developers introduced more than two articles. Seventeen articles that are most highly cited individually and for establishing the SMT were selected as seed articles (see Table 1).

3.3 Collecting Usage Articles of SMT

SMT has become a research topic as more SMT have been widely used. Many types of articles have discussed SMT (e.g., literature review) and compared their new tools with SMT, while other cases except for making use of them. We defined these articles with a wide range of SMT as usage articles. According to the definition, usage articles are composed of two parts. The first part that SMT were directly applied in the articles can be queried by topic search in WoS. We adopted search queries and received 246 distinct articles (see Table 1). The other part that SMT were discussed is the articles that cited seed articles. Previous studies dominated only the analysis by topic search in WoS. But topic search in WoS is limited in bibliography search, i.e., title, abstract, and keywords (Chen, 2017; Pan et al., 2018). The articles that mentioned or applied SMT in full text would be lost if only using topic search because some authors tend not to write the names of SMT in bibliography. Therefore, we came up the idea to complement usage articles. Of note, 1,264 distinct articles that cited seed articles were downloaded (see Table 1). In total, 928 distinct usage articles were collected.

Articles and citations were downloaded in the WoS core collection (searching time span is till 2017) on June 5, 2018. Topic search was performed according to the rule defined by Pan et al. (2018).

3.4 Identifying Application Articles of SMT

We defined application articles as scientific articles in which one or more SMT were used to (1) model and analyze the structures, dynamics, or collaborations or (2) measure and analyze the scientific contributions and impacts of a scientific discipline, a field of research, or topic areas concerning specific research questions based on a literature collection (Chen, 2017). Application articles were identified from usage articles manually. We downloaded and read the full texts of all usage articles to make sure that they (1) qualified to be application articles and (2) applied the SMT in this article rather than other tools. To elevate the accuracy, we dominated the process

in the following protocol. Two collaborators identified the usage articles 928 independently by marking Yes (Y) as an application article or No (N). Cohen's kappa coefficient was used to measure the inter-coder reliability (IRR) and the result is 0.929 ($p = 0.000$). The cases of disagreement would be assigned to the third collaborator. Finally, 496 application articles were identified.

3.5 Identifying Articles in LIS Domain

Researchers are more likely to use SMT to conduct domain analysis. The applications in different domains, e.g., LIS and non-LIS domains, provide different insights of the evolving role of science mapping as tools. Before identifying whether an application article is in LIS domain, we asked all collaborators to fully understand the LIS topic classification and read through the papers about contents of LIS (Tuomaala, Järvelin, & Vakkari, 2014; Zins, 2007). Two collaborators identified all application articles independently by marking Y/N according to the classification. Two collaborators achieved an IRR of 0.951 ($p = 0.000$). The cases of disagreement would be consulted with the third collaborator.

3.6 Identifying Articles in LIS Journals

The domains of journals in which application articles are published are another necessary dimension for our analysis. We decided to identify whether an article is published in a LIS journal or the journal is indexed in LIS category in Journal Citation Report (JCR) 2017. Twenty-eight LIS journals were automatically identified. However, JCR2017 contains only journals indexed in SCI and SSCI in 2017. Our records were downloaded from the overall WoS core collection. We included extra 10 journals, whose subject category (SC in WoS Core Collection Field Tags) is information science and library science. Additionally, changes in journals' names were considered.

Four categories were annotated as follows, which are combinations of LIS domains (LD), non-LIS domains (ND), LIS journals (LJ), and non-LIS journals (NJ):

- Articles studied a LIS domain and published in a LIS journal (LD-LJ);
- Articles studied a LIS domain but published in a non-LIS journal (LD-NJ);
- Articles studied a non-LIS domain but published in a LIS journal (ND-LJ);
- Articles studied a non-LIS domain and published in a non-LIS journal (ND-NJ).

3.7 Identifying Scientific Impact of Application Articles

Citing articles are articles which cited application articles. We looked into citing articles to measure the impact of application articles. Since application articles are case study-oriented, we wondered the intention to cite them and what contribution of citing articles would make to scientific domains (both LIS and non-LIS domains). On August 5, 2018, we downloaded all records of citing articles in WoS core collection. Also, citing articles were categorized into LIS and non-LIS journals in the same way as application articles.

With the help of citing articles, annual citation of each single application article can be measured. Since 2-year citation is normally used in scientific evaluation (Garfield, 2006), we purposely calculated 2-year citation of each application article to reduce the effect from citation time span of total citation count.

4 Results

4.1 Overview of Science Mapping Applications

A total of 496 articles were identified as application articles, which were published in a total of 275 journals. SMT has been widely used not only in 38 LIS journals but also in 237 journals in other domains. In average, every journal has published at least two articles that have made use of SMT. LIS journals have published 172 application articles whereas 324 articles were published in other journals (see Table 2).

Table 3 summarizes the journals that published 42.14% of application articles. Seven out of 24 journals are LIS journals, sharing 27.01% of application articles. Although LIS journals are fewer than non-LIS journals, they published twice as many articles as non-LIS journals did (134/72). *Scientometrics*, *Journal of the American Society for Information Science and Technology*, and *Journal of Informetrics* have published 23.79% of application articles as the top three LIS journals in the statistics. *Scientometrics* hold a 19.96% proportion of total articles. This implies that *Scientometrics* is the major resource of case studies.

In all application articles, only 13.51% (67 articles) of them have applied SMT on research objects in LIS domain. The number of articles in LIS domain (13.51%) is smaller than that in journals (34.68%), meaning that at least

Table 2

Summary of Journals that Published SMT Application Articles

Categories	# Journals	# Articles in journals	# Articles in domains
LIS	38 (13.82%)	172 (34.68%)	67 (13.51%)
Non-LIS	237 (86.18%)	324 (65.32%)	429 (86.49%)
Total	275 (100%)	496 (100%)	496 (100%)

20% of total articles have discussed other domains in LIS journals.

SC is used to classify journals in WoS. SC can be informative to identify the domains of articles. A total of 22 SC (out of 84) in Table 4 shares 85.05% of the total number of distinct SC. More than 30% of application articles are in Information Science & Library Science and Computer Science. Articles that made use of SMT have been published in many domains but LIS is the most conspicuous research area. The reason for the high proportion of Computer Science is that many journals are classified into Information Science & Library Science and Computer Science. All these phenomena describe that SMT have been widely used in many domains and condensed in LIS domain.

The specific situation of application articles is shown in Table 5. Statistics show that only 57 articles (11.49%) discussed LIS domains in LIS journals. Of note, 23.19% (115) of articles revealed scientific development of other domains but they were published in LIS journals. On the contrary, only 10 articles were published in non-LIS journals topicalized within LIS domain. Of note, 63.31% (314) of articles made use of SMT in other domains and were accepted by non-LIS journals.

We excluded the category of LD-NJ in the following study, because it covers only 10 articles in our dataset, most of which are in the fields of health informatics and knowledge management. The rest of 486 application articles grouped into three categories (LD-LJ, ND-LJ, and ND-NJ) were used hereafter.

4.2 Evolution of Science Mapping Applications

Figure 2 shows the comparison of application articles from journal and domain perspectives between LIS and non-LIS groups. As seen from the linear trends in both (A) and (B), the common ones are (1) every line tends to rise, (2) the tendencies of up and down in each line are almost

Table 3
Journals that Published SMT Application Articles

Journals	# (%) of articles	Journals	# (%) of articles
<i>Scientometrics</i> (LJ)	99 (19.96)	<i>European Journal of Operational Research</i> (NJ)	3 (0.60)
<i>PLOS ONE</i> (NJ)	13 (2.62)	<i>Technology Analysis & Strategic Management</i> (NJ)	3 (0.60)
<i>Journal of the American Society for Information Science and Technology</i> (LJ)	12 (2.42)	<i>Malaysian Journal of Library & Information Science</i> (LJ)	3 (0.60)
<i>Sustainability</i> (NJ)	8 (1.61)	<i>BMJ Open</i> (NJ)	3 (0.60)
<i>Journal of Informetrics</i> (LJ)	7 (1.41)	<i>International Journal of Intelligent Systems</i> (NJ)	3 (0.60)
<i>Current Science</i> (NJ)	7 (1.41)	<i>Renewable & Sustainable Energy Reviews</i> (NJ)	3 (0.60)
<i>Aslib Journal of Information Management</i> (LJ)	6 (1.21)	<i>Journal of Intelligent & Fuzzy Systems</i> (NJ)	3 (0.60)
<i>Neural Regeneration Research</i> (NJ)	5 (1.01)	<i>COLLNET Journal of Scientometrics and Information Management</i> (LJ)	3 (0.60)
<i>Information Research—An International Electronic Journal</i> (LJ)	4 (0.81)	<i>International Journal of Hospitality Management</i> (NJ)	3 (0.60)
<i>Technological Forecasting and Social Change</i> (NJ)	4 (0.81)	<i>International Journal of Project Management</i> (NJ)	3 (0.60)
<i>Globalization and Health</i> (NJ)	4 (0.81)	<i>Medicine</i> (NJ)	3 (0.60)
<i>Environmental Science and Pollution Research</i> (NJ)	4 (0.81)	<i>International Journal of Production Research</i> (NJ)	3 (0.60)

Note: LJ and NJ present LIS journals and non-LIS journals (# >3).

Table 4
Summary of Domains that Published SMT Application Articles (# >5)

Subject category	# (%) of articles	Subject category	# (%) of articles
Information Science & Library Science	172 (34.68)	Social Sciences—other topics	9 (1.81)
Computer Science	161 (32.46)	Neurosciences & Neurology	9 (1.81)
Business & Economics	59 (11.9)	Cell Biology	9 (1.81)
Science & Technology—other topics	49 (9.88)	Chemistry	9 (1.81)
Environmental Sciences & Ecology	35 (7.06)	Education & Educational Research	9 (1.81)
Engineering	33 (6.65)	Energy & Fuels	9 (1.81)
Public, Environmental & Occupational Health	20 (4.03)	Research & Experimental Medicine	7 (1.41)
General & Internal Medicine	14 (2.82)	Biotechnology & Applied Microbiology	6 (1.21)
Materials Science	11 (2.22)	Pharmacology & Pharmacy	6 (1.21)
Psychology	11 (2.22)	Physics	6 (1.21)
Operations Research & Management Science	11 (2.22)	Public Administration	6 (1.21)

Notes: Of note, 252 out of 496 application articles have more than one SC. The order of SC was not considered. The percentage of articles was calculated via dividing the number of articles in one SC by 496 articles.

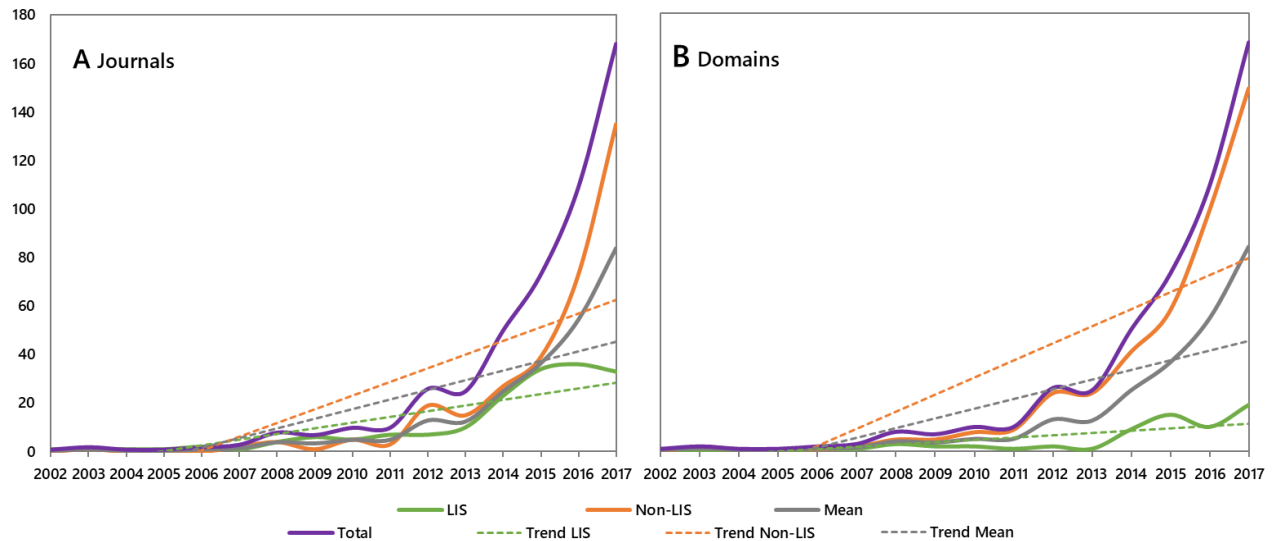


Figure 2. Timelines and linear trends of SMT application articles. (A) Application articles from journal perspective. (B) Application articles from domain perspective.

Table 5

Basic Statistics of Application Articles

		Journal domain		
		LIS	Non-LIS	Total
Analyzed domain	LIS	57 (11.49%)	10 (2.02%)	67 (13.51%)
	Non-LIS	115 (23.19%)	314 (63.31%)	429 (86.49%)
Total		172 (34.68%)	324 (65.32%)	496 (100%)

synced, and (3) the number of application articles in either non-LIS journals or domains is chiefly higher than those in LIS journals or domains. However, the dissimilarities are (1) the difference in slopes between non-LIS and LIS from the domain perspective is higher than those from the journal perspective. The tendency of application articles in LIS domain is slowly growing but apart from the trend in non-LIS domain. Both LIS and non-LIS journals retain publishing application articles but in different speeds. This will lead to more research applying SMT out of LIS domain. (2) Unlike from the domain perspective, there are a few times that the number of articles in LIS journals is higher than those in non-LIS journals. To be exact, the articles in LIS journals had outnumbered those in non-LIS journals till 2011. The articles in non-LIS domains have always outnumbered those in LIS domain. (3) The increasing speed of non-LIS journals departed from that of LIS journals in 2015. To explain these two phenomena, we explained the logic of SMT application. We considered SMT applying on some research areas as application, thought

application articles that were published in journals as recognition, and admitted published articles that were cited as being acknowledged even more. Thus, the slower changes in SMT application in journals than those in domains can be explained by the gradual process: SMT applied on non-LIS research areas in the earlier time and then has been accepted as general methods for non-LIS communities.

The numbers above every bar in Figure 2 are the total numbers of application articles every year, denoting that more application articles have been published over years. This could be explained by that SMT has been more widely used and more SMT have been developed.

Science mapping determines to reveal the bibliometrics relationships among literature when it was first proposed. Science mapping first appeared in the 1970s. It naturally takes time for a tool to be widely used after its development. This explains the year 2002 as the first year that SMT application article was published while the first SMT was introduced in 1998. Many milestones can be identified between 2002 and 2016 (Figure 2). It is only till 2008 that SMT have started to be paid attention. It is noticeable that there were three burst of the number of application articles in 2012, 2014, and 2016. The first burst in 2008 results from the increasing application of CiteSpace. In 2010, three SMT, CoPalRed, VOSViewer, and IDR Toolkit, were first to be public, which caused the burst in 2012. The continuous increases from 2014 to 2017 result from wide usability of CiteSpace and VOSViewer. We believed that continuous updates in both of them

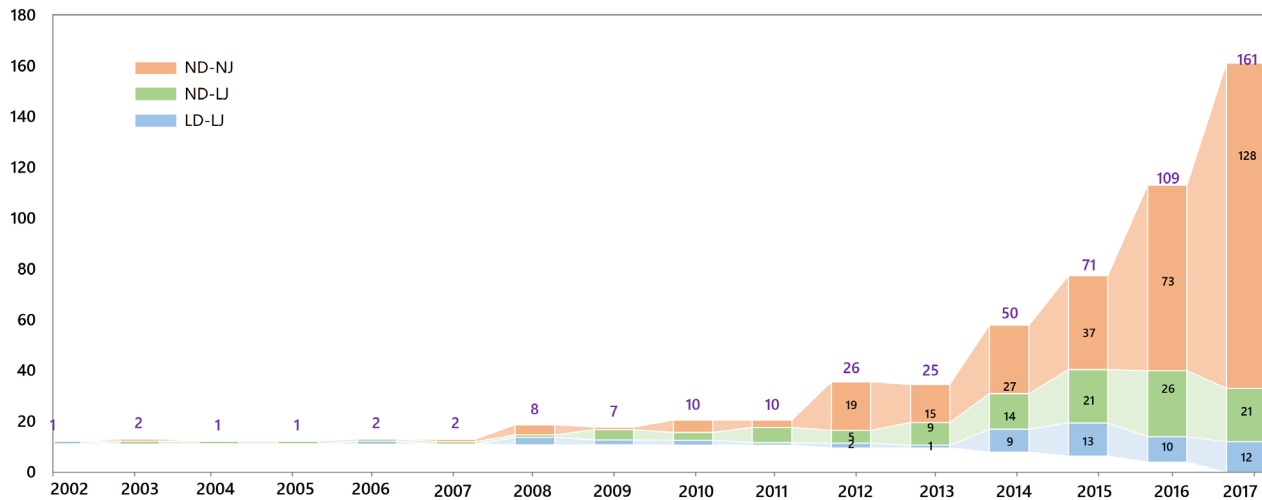


Figure 3. Timelines trends of SMT application articles in three groups.

have attracted more applications. Also another three SMT, CRExplorer, NEViewer, and CitNetExplorer, were published in 2014, which assure the burst in 2016.

It is for sure that the trends of four groups are in line with the increasing trend of the total number. It is till 2012 that non-LIS journals accepted more SMT application articles. Before 2012, the total number of articles is relatively small and articles in LIS journals were the mainstream. So far, the year 2012 is a major point for science mapping transformation.

As for the changes between groups, the mainstream changed from LJ-LD (before 2008) to LJ-ND (2008–2012), and then to NJ-ND (after 2012) by time. This transformation represents the evolutionary path of SMT and science mapping. In the beginning, SMT was applied only in its own domain, also known as LIS domain. This kind of application articles could be normally accepted by LIS journals. Then science mapping methods were used in non-LIS domains but they were limited to be published in LIS journals. To date, SMT has been testified by many domains on top of LIS. Science mapping has been acknowledged by other domains so that SMT application articles can be published in non-LIS journals. However, most non-LIS journals accept only articles discussing certain topics related to these journals. It is rare to see non-LIS journals published papers about LIS topics (10 articles in total). This indicates LIS could become more explicit with the help of expansion of science mapping (Figure 3).

Figure 4 enlarges a part of Figure 3 from 2008 to 2017. The majority of articles in our sample (481 out of 490) were published during this period. Most of application articles were published in LIS journals (11 out of 17), which

include five articles studied LIS domains and six articles studied non-LIS domains before 2008. At that time, LIS researchers contributed most application articles, which is reasonable as science mapping itself is a LIS domain. This situation greatly changed after 2012 when there was a burst in the number of articles published in non-LIS journals where 19 articles were published. The burst was followed by a rapidly increasing trend in publishing SMT application articles in non-LIS journals, which demonstrates the extended scientific impact of science mapping as a research method. It should be noted that various tools, including CiteSpace, IDR Toolkit, VOSViewer, and CoPalRed, have been used by the articles published in non-LIS journals.

The number of articles published in LIS journals has also been increasing, but not as fast as those in non-LIS journals in recent years. SMT were developed for analyzing various scientific domains. We believed that publishing a SMT application articles in journals focusing on a domain can be beneficial for disseminating the knowledge created by using the SMT, since the article can get exposure to scientists in the domain.

Besides visualizing the evolving patterns of the three categories, we also addressed the articles that applied two most widely used SMT, CiteSpace (197 articles, 40.2%) and VOSViewer (192 articles, 39.2%), respectively. The rest of SMT following CiteSpace and VOSViewer are HistCite (38, 7.8%), IDR Toolkit (25, 5.1%), and CoPalRed (13, 2.7%). CiteSpace and VOSViewer were the leading tools in all the three kinds of application articles. In comparison with articles studied non-LIS domains (ND-LJ and ND-NJ), articles studied LIS domains (LD-LJ) tended to more commonly use CiteSpace and VOSViewer.

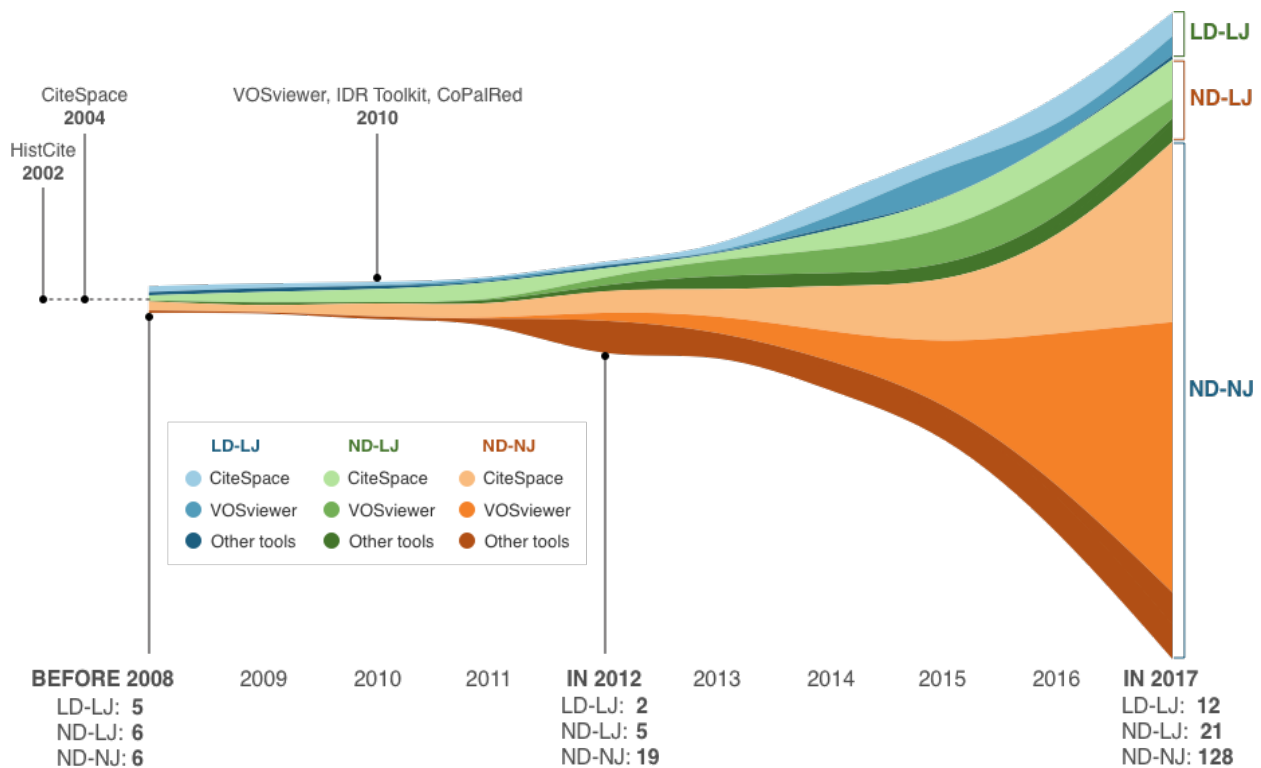


Figure 4. An evolution of SMT application articles in the three categories. The color is used to show the paper category and the shade of each color is used to depict tools in each category.

4.3 Impact Evolution of Science Mapping Applications

A total of 4,052 citing articles were downloaded, which cited all application articles for 4,466 times. The difference in the number of citation results from that sometimes a single application article has been cited in a citing article more than once. The comparison in citation shows the same tendency as that in publication, which is that most articles published in non-LIS domains from both journal and domain perspectives. We measured 2-year citation to look into momentary usage of application articles.

As for citation per paper, one of the LIS domain researches published in LIS journals is the highest while the one of the NJ-ND is the lowest, which is contrary to the overall citation in Table 6. That is to say, although the citation of NJ-ND is high, the citation per paper of it is low. However, for 2-year citation per paper, the situation changed again, where LJ-ND is the lowest and NJ-ND is the highest.

In average, every article has been cited at least eight times. There are articles in LIS journals or domains, and, in average, the citations of these articles have been cited more than those in other journals or domains. The gaps

between average citation in total and average citation in 2 years are significantly different. All application articles have been cited in a total of 2,059 times and in average 4.33 times in first 2 years after published.

Even though it is similar to see that most citations happen in non-LIS journals and domains in 2-year citation situation as it is in terms of overall citation, the gap of citation between LIS journals and non-LIS journals in 2-year citation situation (32.54% and 67.46%) is bigger than that in overall citation (41.42% and 58.58%). Besides, the circumstance that citations per paper in LIS are always larger than those in non-LIS is different in terms of 2-year citation. Unlike citation per paper in LIS journal, 2-year citation per paper in LIS journal (3.90) is smaller than that in non-LIS journal (4.56) and also smaller than 2-year citation per paper in total (4.33). In scientific evaluation community, citation per paper is normally considered as one of the representatives as the quality of publications, which directly leads to a way to represent the impact of researches. Then 2-year citation per paper can be regarded as a kind of instant impact of research. We noticed that the gap of 2-year citation per paper between LIS and non-LIS venues is not as big as the one of citation per paper. This indicates that science mapping implication researches

Table 6
Statistics of Citing Articles and Citation of Application articles

Citing articles		Journal domain		Total
		LIS	Non-LIS	
Analyzed domain	LIS	586 (14.46%)	–	586 (14.46%)
	Non-LIS	1,077 (26.58%)	2,389 (58.96%)	3,466 (85.54%)
Total		1,663 (41.04%)	2,389 (58.96%)	4,052 (100%)
Citation		Journal domain		Total
Analyzed domain	LIS	638 (14.29%)	–	638 (14.29%)
	Non-LIS	1,212 (27.14%)	2,616 (58.58%)	3,828 (85.71%)
Total		1,850 (41.42%)	2,616 (58.58%)	4,466 (100%)
Two-year citation		Journal domain		Total
Analyzed domain	LIS	239 (11.61%)	–	239 (11.61%)
	Non-LIS	431 (20.93%)	1,389 (67.46%)	1,820 (88.39%)
Total		670 (32.54%)	1,389 (67.46%)	2,059 (100%)

Table 7
Means of Citation of Citing Articles

Citation per paper		Journal domain		Total
		LIS	Non-LIS	
Analyzed domain	LIS	11.19	–	11.19
	Non-LIS	10.54	8.33	8.92
Total		10.22	8.33	9.19
Two-year citation per paper		Journal domain		Total
Analyzed domain	LIS	4.19	–	4.19
	Non-LIS	3.75	4.42	4.24
Total		3.90	4.42	4.24

tend to benefit non-LIS research areas in a shorter term than they do to the LIS community (Table 7).

However, the absolute numbers of citations from the three categories are not sufficient to support more findings, as all the citing articles were published in different disciplines and different years. Therefore, we introduced the following longitudinal analysis (see Figure 5) to see the trend and reflect the influence.

The time trend lines in Figure 5(A)–(H) are consistent, showing an upward trend, although Figure 5(C) and (D) are on the decline. Every trend with ups and downs in journals is also consistent with the one in domains

accordingly in a pair. For instance, both peaks in Figure 5(A) and (B) have an outbreak in 2012. Both peaks in Figure 5(E) and (F) happened in 2016. It is expected that SMT has been widely used year by year so that more publications and citations have shown upon correspondingly as well. However, for comparison between the trends of LIS and non-LIS, it seems that the two trends are quite opposite in terms of the citations, while they are in line with each other in the 2-year citations. In other words, whenever there is an increase for the citation of LIS venues in Figure 5(A) to (D), the citation of non-LIS venues faces a decline. This must be related to our binary coding mechanism.

The similarity among all figures is that no matter from the perspective of journal or domain, the citations in non-LIS are higher than those in LIS from both citations and 2-year citation. This indicates again that SMT application has been extended to other disciplines except for LIS itself. Exceptions appear only in Figure 5(C) and (G) that in most years the citations of non-LIS venues are smaller than those in LIS venues. To percept this, we mentioned that the advantages of citation, as well as 2-year citation, for non-LIS venues was dominated from the large scale of publications. For (2-year) citation per paper, the advantages of being large size shrink back. It is in line with the scenario in Figure 2 that science mapping application researches are more acceptable in LIS community (journal perspective) even though they have been widely used in non-LIS areas (domain perspective).

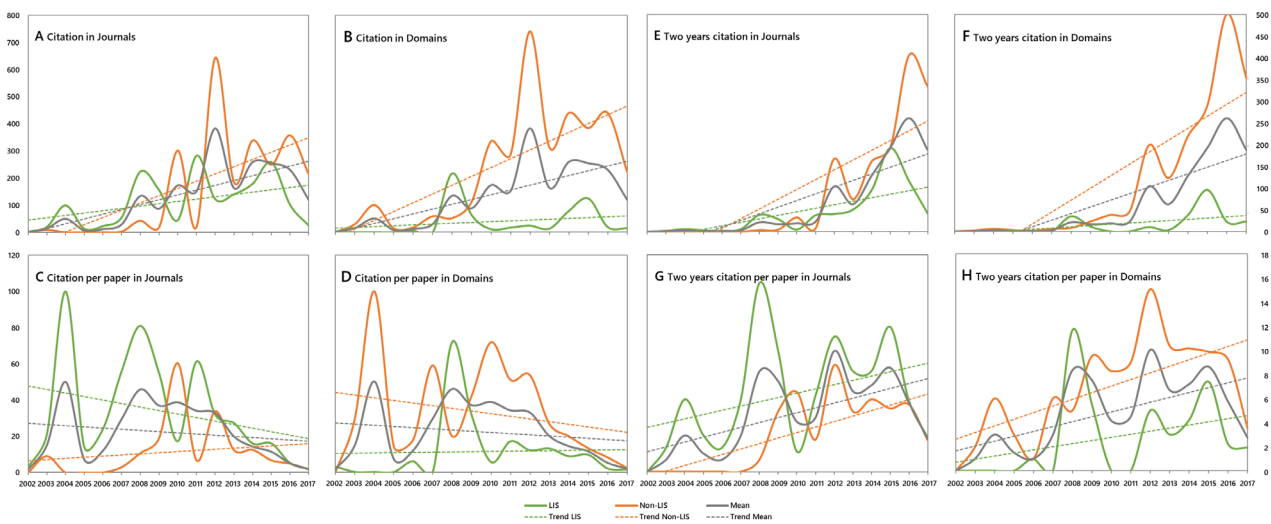


Figure 5. Timelines and linear trends of citation of application articles and 2-year citation between LIS and non-LIS journals and domains.

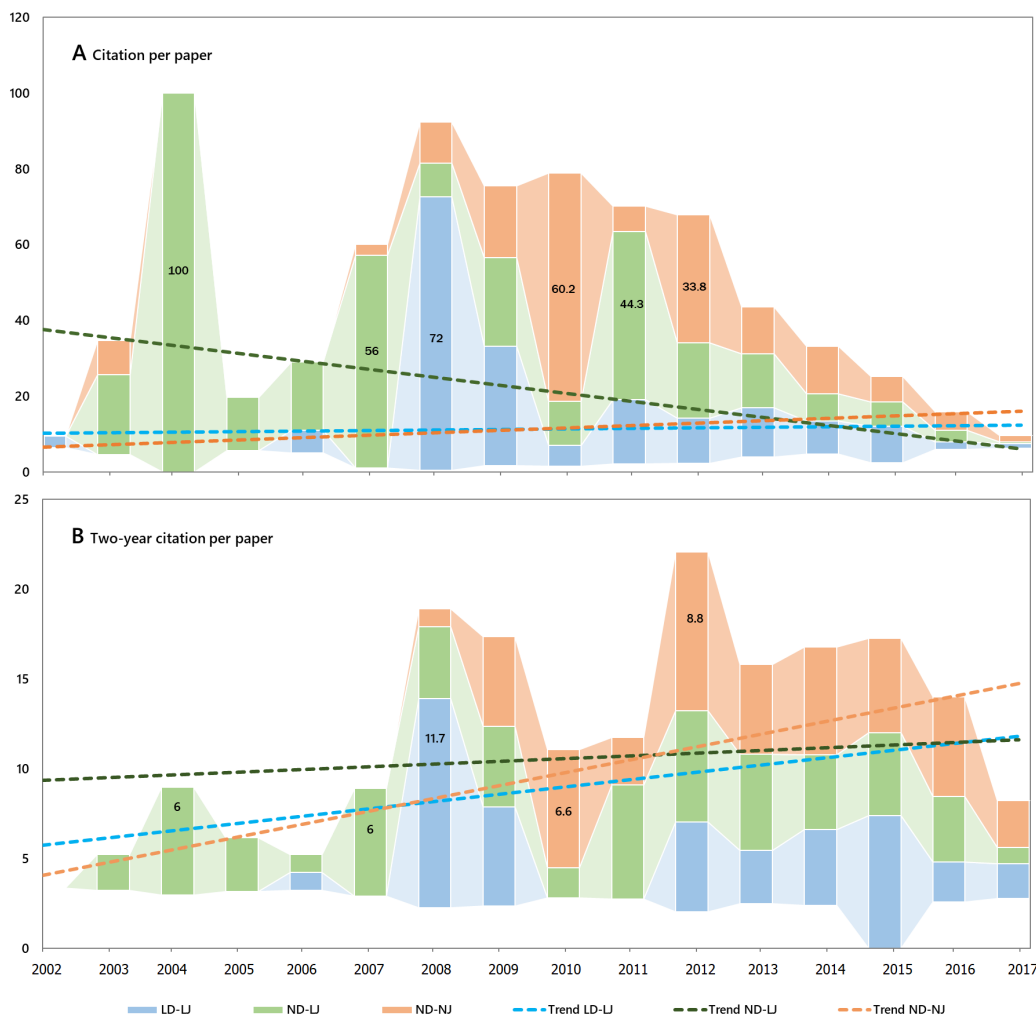


Figure 6. Timelines and linear trends of citation of application articles highlighting three groups.

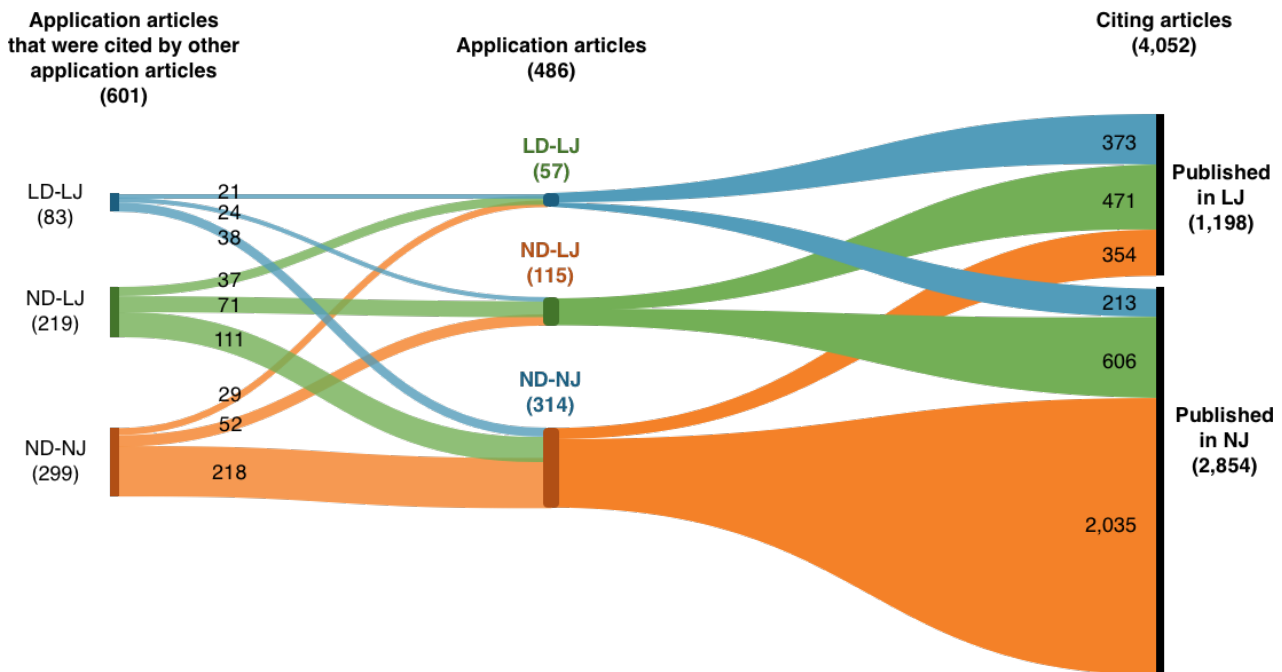


Figure 7. Citation flow of application articles. (#) represents the number of articles in a category. The numbers in the shades represent the citation/cited times toward a category.

We deepened our research granularity to citation per paper per year of application articles so that we would be able to locate some breaking points (see Figure 6). We explored the most cited articles each year and found that many so-called milestone articles have been published in LIS journals. The only LIS research in LIS journals which was highly cited was a review paper (Bar-Ilan, 2008) which applied CiteSpace on informetrics evolutionary study. Other articles which applied CiteSpace (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011a; Leydesdorff et al., 2014) and HistCite (Garfield, 2004) have pioneered the use of SMT to non-LIS research areas. We also surprisingly found that in non-LIS communities, science mapping application researches can be highly cited via using CiteSpace (Jahangirian et al., 2010) and VOSViewer (Rafols, Leydesdorff, O'Hare, Nightingale, & Stirling, 2012) as a research method.

On the left part of Figure 7, the composition of references of application articles in every category exists in all three categories. Articles published in non-LIS journals (ND-NJ) are less likely to be cited by articles in LIS journals. However, a considerable number of articles in LIS journal were cited by articles in non-LIS journals, especially articles studied non-LIS domains but were published in LIS journals (ND-LJ). For instance, 115 articles in ND-LJ were cited 111 times by 314 articles in ND-NJ.

The citation patterns of application articles on the right part of Figure 7 are clear. The citations of articles in

LD-LJ were from articles published in LIS journals, but also have some citations from non-LIS journals. Although articles in ND-LJ were published in LIS journal, they attracted even more attention from non-LIS communities which cited ND-LJ for 606 times larger than the citation from LIS journal (471 times). Relevantly, articles in ND-LJ which focused on non-LIS domains but were published in non-LIS journals get much fewer citations from the LIS community.

5 Conclusion and Discussion

This article has presented the findings from quantitative scientometrics investigations of science mapping applications to comprehend the evolutionary patterns of SMT and the dynamic impact of which has brought forward on LIS and other research areas. To answer our previous questions, we would address several statements as follows.

SMT have been significantly gained awareness from other research areas on top of LIS community. SMT have been widely applied in various research areas ranging from natural science to humanity science. We demonstrated that journals from various science communities beyond the LIS community are interested in publishing studies based on science mapping applications. As a matter of fact, if only considering the amount of publications and journals,

non-LIS communities have diverse interests to publish science mapping application researches. Relatedly, approaches based on science mapping application have benefited not only LIS but also other advanced scientific communities.

The evolutionary patterns of science mapping applications were revealed in this study. It started since 2002 and sprang up in 2008 mostly in LIS community. But not till 2012 that non-LIS communities began to acknowledge the utility of science mapping and of which tools. It is conspicuous that science mapping application has been recognized by non-LIS communities from domain science mapping studies by both LIS and non-LIS scientists. The year of 2012 was considered as a breaking point. Before 2012, LIS journals published most of the science mapping application studies no matter under which domain. After the burst of arising publications in non-LIS journals in 2012, non-LIS studies have generated science mapping as a research method to construct knowledge scales of their own domains. The disparity of distribution of preferred application objects may have shown that LIS community has permitted knowledge from non-LIS areas to flow into its society. In the meantime, CiteSpace and VOSViewer have clearly become the most popular SMT worldwide although non-LIS communities have many other options of tools to display relevant knowledge structure.

The wide applications of SMT have ensured that non-LIS communities appreciated the influence from LIS. Several milestone researches have arranged the patterns of science mapping applications and increased the spreading of the usage of SMT. However, the omitted 10 articles of LIS research published in non-LIS journals cannot be ignored from our sight. With the increasing number of publications on non-LIS domain which have been published in LIS journals, the reverse situation has to warn LIS community that it has been challenging for us to expose our knowledge to other societies (Tang, Mehra, Du, & Zhao, 2019). In addition, we noticed articles in non-LIS domain published in LIS journals, surprisingly, played an important role in advancing the wide application of SMT. For the LIS community, the articles validate the effectiveness of SMT for analyzing various domains. They also provided practical guidelines and successful showcases for non-LIS communities. It suggests that case studies which normally have been considered as little contribution (Editorial Board, 2019) should be reconsidered its place in the society.

Acknowledgments: This article is an extended study of which we presented at ASIS&T2019 entitled *How were science mapping tools applied? The Application of science*

mapping tools in LIS and non-LIS domains. This study is supported by China Postdoctoral Science Foundation (Grant No. 2019T12035).

References

- Bailón-Moreno, R., Jurado-Alameda, E., & Ruiz-Baños, R. (2006). The scientific network of surfactants: Structural analysis. *Journal of the American Society for Information Science and Technology*, 57(7), 949–960. doi:10.1002/asi.20362
- Bailón-Moreno, R., Jurado-Alameda, E., Ruiz-Baños, R., & Courtial, J. P. (2005). Analysis of the field of physical chemistry of surfactants with the Unified Scientometric Model. Fit of relational and activity indicators. *Scientometrics*, 63(2), 259–276. doi:10.1007/s11192-005-0212-4
- Bar-Ilan, J. (2008). Informetrics at the beginning of the 21st century-A review. *Journal of Informetrics*, 2(1), 1–52. doi:10.1016/j.joi.2007.11.001
- Barabási, A. L., & Albert, R. (1999). Emergence of scaling in random networks. *Science*, 286(5439), 509–512. doi:10.1126/science.286.5439.509
- Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An open source software for exploring and manipulating networks. *Third International AAAI Conference on Weblogs and Social Media*, 361–362. doi:10.1136/qshc.2004.010033
- Borgman, C. L., & Furner, J. (2002). Scholarly communication and bibliometrics. *Annual Review of Information Science and Technology*, 36(1), 2–72. doi:10.1002/aris.1440360102
- Börner, K. (2011). Plug-and-play macroscopes. *Communications of the ACM*, 54(3), 60–69. doi:10.1145/1897852.1897871
- Callon, M., Courtial, J. P., & Laville, F. (1991). Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemistry. *Scientometrics*, 22(1), 155–205. doi:10.1007/BF02019280
- Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, 57(3), 359–377. doi:10.1002/asi.20317
- Chen, C. (2017). Science mapping: A systematic review of the literature. *Journal of Data and Information Science*, 2(2), 1–40. doi:10.1515/jdis-2017-0006
- Chen, C., Ibekwe-SanJuan, F., & Hou, J. (2010). The structure and dynamics of cocitation clusters: A multiple-perspective cocitation analysis. *Journal of the American Society for Information Science and Technology*, 61(7), 1386–1409. doi:10.1002/asi.21309
- Chen, W., Wang, C., & Wang, Y. (2010). Scalable influence maximization for prevalent viral marketing in large-scale social networks. *Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 1029–1038. doi:10.1145/1835804.1835934
- Chen, Y., Xu, J., & Xu, M. (2015). Finding community structure in spatially constrained complex networks. *International Journal of Geographical Information Science*, 29(6), 889–911. doi:10.1080/13658816.2014.999244
- Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011a). An approach for detecting, quantifying, and visualizing

- the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *Journal of Informetrics*, 5(1), 146-166. doi:10.1016/j.joi.2010.10.002
- Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011b). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology*, 62(7), 1382-1402. doi:10.1002/asi.21525
- Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2012). SciMAT: A new science mapping analysis software tool. *Journal of the American Society for Information Science and Technology*, 63(8), 1609-1630. doi:10.1002/asi.22688
- Davidson, G. S., Hendrickson, B., Johnson, D. K., Meyers, C. E., & Wylie, B. N. (1998). Knowledge mining with VxInsight: Discovery through interaction. *Journal of Intelligent Information Systems*, 11(3), 259-285. doi:10.1023/A:1008690008856
- de Solla Price, D., & Gürsey, S. (1975). Studies in scientometrics I: Transience and continuance in scientific authorship. *Ciência da Informação*, 4(1), 27-40. doi:10.1007/s11434-013-5939-3
- Editorial Board. (2019). *Aims & scope*. Retrieved from <https://www.journals.elsevier.com/journal-of-informetrics/>
- Garfield, E. (1994). Scientography: Mapping the tracks of science. *Current Contents: Social & Behavioural Sciences*, 7(45), 5-10.
- Garfield, E. (2004). Historiographic mapping of knowledge domains literature. *Journal of Information Science*, 30(2), 119-145. doi:10.1177/0165551504042802
- Garfield, E. (2006). The history and meaning of the journal impact factor. *Journal of the American Medical Association*, 295(1), 90-93. doi:10.1001/jama.295.1.90
- Garfield, E., Pudovkin, A. I., & Istomin, V. S. (2002). Algorithmic citation-linked historiography—Mapping the literature of science. *Proceedings of the ASIST Annual Meeting*, 39(1), 14-24. doi:10.1002/meet.1450390102
- Garfield, E., Pudovkin, A. I., & Istomin, V. S. (2003). Why do we need algorithmic historiography? *Journal of the American Society for Information Science and Technology*, 54(5), 400-412. doi:10.1002/asi.10226
- Grauwin, S., & Jensen, P. (2011). Mapping scientific institutions. *Scientometrics*, 89(3), 943-954. doi:10.1007/s11192-011-0482-y
- He, J., Ping, Q., Lou, W., & Chen, C. (2019). PaperPoles: Facilitating adaptive visual exploration of scientific publications by citation links. *Journal of the Association for Information Science and Technology*, 70(8), 843-857. doi:10.1002/asi.24171
- Herman, I., Melancon, G., & Marshall, M. S. (2000). Graph visualization and navigation in information visualization: A survey. *IEEE Transactions on Visualization and Computer Graphics*, 6(1), 24-43. doi:10.1109/2945.841119
- Hey, T., Tansley, S., Tolle, K. (2009). *The fourth paradigm: Data-intensive scientific discovery*. Redmond, WA: Microsoft research.
- Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America*, 102(46), 16569-16572. doi: 10.1073/pnas.0507655102
- Huang, X., Ding, X., Lee, C. P., Lu, T., & Gu, N. (2013). Meanings and boundaries of scientific software sharing. *Proceedings of the 2013 Conference on Computer Supported Cooperative Work*, 423-434. doi:10.1145/2441776.2441825
- Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L. K., & Young, T. (2010). Simulation in manufacturing and business: A review. *European Journal of Operational Research*, 203(1), 1-13. doi:10.1016/j.ejor.2009.06.004
- Johnson, B., & Shneiderman, B. (1991). Tree-maps: A space-filling approach to the visualization of hierarchical information structures. *Proceedings of the 2nd Conference on Visualization 1991*, 284-291. doi:10.1109/VISUAL.1991.175815
- Kempe, D., Kleinberg, J., & Tardos, É. (2015). Maximizing the spread of influence through a social network. *Theory of Computing*, 11(4), 105-147. doi:10.4086/toc.2015.v011a004
- Kessler, M. M. (1963). Bibliographic coupling between scientific papers. *American Documentation*, 14(1), 10-25. doi:10.1002/asi.5090140103
- Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, Massachusetts: Harvard university press.
- Latour, B., & Woolgar, S. (1979). *Laboratory of life: The construction of scientific facts*. New Jersey: Princeton University.
- Lazega, E. (1995). Reviewed work: Social Network Analysis: Methods and Applications by Stanley Wasserman, Katherine Faust. *Revue Française de Sociologie*, 36(4), 781-783. doi:10.2307/3322457
- Leydesdorff, L., Bornmann, L., Marx, W., & Milojević, S. (2014). Referenced publication years spectroscopy applied to iMetrics: *Scientometrics*, *Journal of Informetrics*, and a relevant subset of JASIST. *Journal of Informetrics*, 8(1), 162-174. doi:10.1016/j.joi.2013.11.006
- Leydesdorff, L., & Persson, O. (2010). Mapping the geography of science: Distribution patterns and networks of relations among cities and institutes. *Journal of the American Society for Information Science and Technology*, 61(8), 1622-1634. doi:10.1002/asi.21347
- Li, K., Yan, E., & Feng, Y. (2017). How is R cited in research outputs? Structure, impacts, and citation standard. *Journal of Informetrics*, 11(4), 989-1002. doi:10.1016/j.joi.2017.08.003
- Lou, W., Wang, H., & He, J. (2018). Of the people for the people: Digital literature resource knowledge recommendation based on user cognition. *Information Technology and Libraries*, 37(3), 66-83. doi:10.6017/ital.v37i3.10060
- Marx, W., Bornmann, L., Barth, A., & Leydesdorff, L. (2014). Detecting the historical roots of research fields by reference publication year spectroscopy (RPYS). *Journal of the Association for Information Science and Technology*, 65(4), 751-764. doi:10.1002/asi.23089
- NWB Team. (2006). Network Workbench Tool. Indiana University, Northeastern University, and University of Michigan. Retrieved from <http://nwb.slis.indiana.edu>
- Oldham, P., Hall, S., & Burton, G. (2012). Synthetic biology: Mapping the scientific landscape. *PLoS ONE*, 7(4). doi:10.1371/journal.pone.0034368
- Pan, X., Yan, E., Cui, M., & Hua, W. (2018). Examining the usage, citation, and diffusion patterns of bibliometric mapping software: A comparative study of three tools. *Journal of Informetrics*, 12(2), 481-493.
- Pan, X., Yan, E., Cui, M., & Hua, W. (2019). How important is software to library and information science research? A content analysis of full-text publications. *Journal of Informetrics*, 13(1), 397-406. doi:10.1016/j.joi.2019.02.002
- Pan, X., Yan, E., & Hua, W. (2016). Disciplinary differences of software use and impact in scientific literature. *Scientometrics*, 109(3), 1593-1610. doi:10.1007/s11192-016-2138-4

- Pan, X., Yan, E., Wang, Q., & Hua, W. (2015). Assessing the impact of software on science: A bootstrapped learning of software entities in full-text papers. *Journal of Informetrics*, 9(4), 860–871. doi:10.1016/j.joi.2015.07.012
- Persson, O., Danell, R., & Schneider, J. W. (2009). How to use Bibexcel for various types of bibliometric analysis. In F. Åström, R. Danell, B. Larsen, & J. Schneider (Eds.), *Celebrating scholarly communication studies: A Festschrift for Olle Persson at his 60th Birthday* (Vol. 5, pp. 9–24). Leuven, Belgium: International Society for Scientometrics and Informetrics.
- Rafols, I., Leydesdorff, L., O'Hare, A., Nightingale, P., & Stirling, A. (2012). How journal rankings can suppress interdisciplinary research: A comparison between *Innovation Studies* and *Business & Management. Research Policy*, 41(7), 1262–1282. doi:10.1016/j.respol.2012.03.015
- Rafols, I., Porter, A. L., & Leydesdorff, L. (2010). Science overlay maps: A new tool for research policy and library management. *Journal of the American Society for Information Science and Technology*, 61(9), 1871–1887. doi:10.1002/asi.21368
- Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualizations. *Proceedings 1996 IEEE Symposium on Visual Languages*, 336–343. doi:10.1109/VL.1996.545307
- Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for Information Science*, 24(4), 265–269. doi: 10.1002/asi.4630240406
- Small, H., & Garfield, E. (1985). The geography of science: Disciplinary and national mappings. *Journal of Information Science*, 11(4), 147–159. doi:10.1177/016555158501100402
- Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science*, 19(3), 387–420.
- Tang, R., Mehra, B., Du, J. T., & Zhao, Y. (2019). Paradigm shift in information research. In *Proceedings of ASIS&T 2019 Annual Meeting*, 56(1), 582–585. doi:10.1002/pra2.96
- Tuomaala, O., Järvelin, K., & Vakkari, P. (2014). Evolution of library and information science, 1965–2005: Content analysis of journal articles. *Journal of the Association for Information Science and Technology*, 65(7), 1446–1462. doi:10.1002/asi.23034
- van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. doi:10.1007/s11192-009-0146-3
- van Eck, N. J., & Waltman, L. (2014). CitNetExplorer: A new software tool for analyzing and visualizing citation networks. *Journal of Informetrics*, 8(4), 802–823. doi:10.1016/j.joi.2014.07.006
- Waltman, L., van Eck, N. J., & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics*, 4(4), 629–635. doi:10.1016/j.joi.2010.07.002
- Wang, X., Cheng, Q., & Lu, W. (2014). Analyzing evolution of research topics with NEViewer: A new method based on dynamic co-word networks. *Scientometrics*, 101(2), 1253–1271. doi:10.1007/s11192-014-1347-y
- White, H. D. (2003). Pathfinder networks and author cocitation analysis: A remapping of paradigmatic information scientists. *Journal of the American Society for Information Science and Technology*, 54(5), 423–434. doi:10.1002/asi.10228
- White, H. D., & McCain, K. W. (1998). Visualizing a discipline: An author co-citation analysis of information science, 1972 – 1995. *Journal of the American Society for Information Science*, 49(4), 327–355.
- Zhao, D., & Strotmann, A. (2014). The knowledge base and research front of information science 2006–2010: An author cocitation and bibliographic coupling analysis. *Journal of the Association for Information Science and Technology*, 65(5), 995–1006. doi:10.1002/asi.23027
- Zins, C. (2007). Classification schemes of information science: Twenty-eight scholars map the field. *Journal of the American Society for Information Science and Technology*, 58(5), 645–672. doi:10.1002/asi.20506