Scientometrics

Mapping the intellectual structure of GIS-T field (2008–2019): A dynamic co-word analysis
--Manuscript Draft--

Abstract:	Using geographic information systems (GIS) widely for dealing with transportation problems (is well-known as GIS-T), has made it nessasary for researchers to discover the current state-of-the-art and predict the trends of future research. This paper aims to contribute to a better understanding of GIS-T research area from a longitudinal perspective, over the period 2008-2019. A co-word analysis was used to illustrate all the underlying subfields of GIS-T based on published papers in the Web of Science (WoS) database service. The main knowledge areas representing the intellectual structure of GIS-T including a) sustainability, b) health, c) planning and management, and d) methods and tools, were detected. Finally, in order to illustrate the structure and development of the identified clusters, two-dimensional maps and strategic diagrams for each period were drawn. This study is the first attempt to employ a text mining method so as to detect the conceptual structure of GIS-T research area from a complex and interdisciplinary literature.

Response to Reviewers:	Dear editor and reviewers, We would like to heartily thank the editorial office for giving us further time (about one more month) to revise the paper. Also, we need to thank reviewers for providing us with several constructive and positive comments on the paper, which helped us to

improve that to the best. We hope the new version of the paper meet your expectations.

Sincerely,
Gyozo Gidofalvi, PhD

Comments for the reviewer #1

Reviewer #1: I read the comments on the manuscript, and mostly, authors give some arguments to do not apply the changes. And some changes are just minors.

First of all, I do not pretend to authors change the software, and instead, use VosViewer, Bibliometrix or other one. But, since exist a great variety of useful and powerful science mapping software tool, I wonder for the necessity of do not use them.

In what follows I add some comments following the number of the item.

1. Unfortunately, the results are different.

The initial query return a total of 4770 documents: TS=("GIS" AND ("transportation" OR "road network" OR "traffic accident" OR "traffic noise" OR "transit" OR "cycling" OR "walking"))

Adding just Geographical information systems, return a total of 4988 documents: TS=(("GIS" OR "GEOGRAPHICAL INFORMATION SYSTEM*") AND ("transportation" OR "road network" OR "traffic accident" OR "traffic noise" OR "transit" OR "cycling" OR "walking"))

And finally, adding all the variants suggested by authors, the query return one thousand more documents, that is, a total of 5904 documents: TS=(("GIS" OR "Geographical Information System*" OR "Geographic Information System*" OR "Geographical Information Science" OR "Geographic Information Science" OR "Geospatial Information System*" OR "Geospatial Information Science") AND ("transportation" OR "road network" OR "traffic accident" OR "traffic noise" OR "transit" OR "cycling" OR "walking"))

That is, the different between the initial query, and the final query is great. So, I think authors must to consider the full query.

Answer:

As you truly implied, the suggested query was applied for the data collection process in WOS Core Collection. Also, data was retrieved on a more extensive period (from 2008 to the end of 2019). The new results are affected by data modification.

6. I know that any science mapping software is used, but you mentioned some of them in your paper. I just said that if authors mentioned this software, at least, they should be cited. Also, I recommend to read (and cite only if authors think it is right), some papers comparing science mapping software tools. This read could help the authors to know the capacities of these software, and in fact, explain better why the do not use them in this paper. Please, do not misunderstand me. I do not want to change the software, I just want to justify better you choice.

Answer:

Thank you for pointing this out. We have incorporated your suggestion throughout the manuscript. We added the citations of VOSviewer, SciMAT, and bibliometrix software in the manuscript as follows:
•Eck, N.J., & Waltman, L. (2009). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84, 523 - 538.
•Cobo, M.J., L´opez-Herrera, A., Herrera-Viedma, E., & Herrera, F. (2012). SciMAT: A new science mapping analysis software tool. Journal of the Association for Information

Science and Technology, 63, 1609-1630.
•Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11, 959-975.
•Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An open source software for exploring and manipulating networks. International AAAI Conference on Weblogs and Social Media (ICWSM).

7. The more parameters it is not a valid argument to decline the use of this clustering algorithm. I hoped to get a different argument. But, again, I do not want to change the clustering, if authors considered that their algorithm is valid.

Answer:

It would be quite interesting to explore this aspect for our researches. We will consider that for our new researches in the future.

8. I am not talking about the quality of dpi of the figures. I mean, that the figures have a lot of colours, texts, and nodes, overlapped among all, and impossible to get ant insight. On the other hand, LaTex does not decrease the quality. If you export the figure as .eps, the figures will be drawn properly. But in that case, the problem is no with the resolution, instead with the big amount of information shown.

Answer:

You have raised an important point here. In order to increase the clarity of the graphs, we considered the most stringent conditions so that fewer keywords would appear in the graph. At first, keyword frequency, which was 2 in the previous version of the manuscript, was changed into 10 for this version. Another restriction was applied to expert judgment about removing general keywords. In the previous version, a list of keywords was given to three experts in the GIS-T field to eliminate the general words, and a keyword is removed from the list, in case two or all of the experts determine that as a general keyword. In this version, only if one of the experts determines a keyword as a general keyword, we eliminated from the analysis. Overall, total keywords of the graph were changed from 529 to 336. Additionally, to better and easier understand of the graphs, SVG format has been exported from Gephi and uploaded with the submitted manuscript in a separate file.

9. I do not understand the authors' answer. I did not want authors justify the use of strategic diagram. I know them, and I know that they are a great visual tool to highlight the clusters. But, I just want to cite some references that support them. Also, there are some software that use them as visual output.

Answer:

Thank you for this suggestion. We cited some software and libraries supporting strategic diagram in the manuscript. We also found an authoritative review paper exploring software tools for conducting bibliometric analysis in science. According to a conducted research by Moral-Muñoz et al. (2020), some science mapping software such as SciMAT, and libraries such Bibliometrix support strategic diagram.
•Moral-Muñoz, J.A., Herrera-Viedma, E., Santisteban-Espejo, A. and Cobo, M.J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. El professional de la informacion, 29(1), e290103.

Thanks for your time and your consideration.

Mapping the intellectual structure of GIS-T field (2008–2019): A dynamic co-word analysis

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Contents

Abstract

Using geographic information systems (GIS) widely for dealing with transportation problems (is well-known as GIS-T), has made it nessasary for researchers to discover the current state-of-the-art and predict the trends of future research. This paper aims to contribute to a better understanding of GIS-T research area from a longitudinal perspective, over the period 2008-2019. A co-word analysis was used to illustrate all the underlying subfields of GIS-T based on published papers in the Web of Science (WoS) database service. The main knowledge areas representing the intellectual structure of GIS-T including a) sustainability, b) health, c) planning and management, and d) methods and tools, were detected. Finally, in order to illustrate the structure and development of the identified clusters, two-dimensional maps and strategic diagrams for each period were drawn. This study is the first attempt to employ a text mining method so as to detect the conceptual structure of GIS-T research area from a complex and interdisciplinary literature.

Keywords: GIS-T; Text mining; Dynamic co-word analysis; Co-occurrence network; Community detection; Research trends

Article highlights

In summary, the main findings and implications of the paper are listed as follows:

- Using co-word analysis method provides us with a powerful tool for better understanding of the current status of GIS-T field.

- Studying GIS-T field from a dynamic perspective gives us new insights into the recent trends in this field.

- GIS-T is a relatively young and immature research field, and research studies conducted in this field are comprised of widely varied knowledge areas.

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1   Introduction

Managing spatial information has become an interesting research topic, as a result of the development of smart city concept and its applications (Wang et al. 2019). Transportation research requires a wide range of models and analyses, and nearly always the used data have spatial reference (Goodchild 2000). Employing geographic information system (GIS) is widely regarded as a great way of dealing with transportation problems. In addition, GIS plays a crucial role in addressing the growing need for obtaining adequate data for transportation models. A GIS can be defined as a computer-based system to capture, storage, retrieval, analysis, and display of a portion of the Earth's surface (Lewis 1990). A GIS toolkit not only plays as a database system with specific functions for handling spatial reference data, but also it has a set of operations for the manipulation of spatial data. Due to the capabilities of GIS to deal with spatial data, it is wildely used in a broad range of applications, from urban and regional planning to environmental management, traffic and transportation engineering, and other purposes.

Relying on the sophisticated database management system (DBMS), GIS has the ability to handle immense and diverse sets of spatially referenced data in transportation applications. Moreover, topology operations in a GIS make transportation experts enable to understand how elements contained in the database are related to each other spatially (Simkowitz 1988). Regarding the specific requirements of transportation applications, research has been directed toward enhancing the current GIS approaches to gain their full potential benefits and capabilities (Thill 2000). Over the last few years, the active application of GIS in transportation research, planning, and management has become ubiquitous increasingly, so that it is now regularly referred to by the acronym GIS-T (Waters 1999). The GIS-T can be defind as the application of information technology and related knowledge to transportation problem (Miller and Shaw 2001). In another definition suggested by Fletcher (2000), GIS-T are interconnected systems of hardware, software, data, people, and organizations for collecting, storing, analyzing, and disseminating spatial information that are used for, or influenced by transportation activities.

While GIS-T dates back to the very earliest interest in GIS in the 1960s (Goodchild 2000), the first widespread use of GIS in transportation traces back to late 1980s (Thill 2000). Three stages of development of GIS from a tool, to a technology, and finally to a legitimate domain of scientific inquiry has leaded the GIS-T into a stage of maturity (Goodchild 1992). Meanwhile, transportation has evolved from its origins in pure spatial sciences to the multidisciplinary and multi-faceted reality of transportation infrastructure and flows of passengers and freight (Thill 2000). Goodchild (2000) characterizes the evolution of GIS-T in three steps: a) map view, which favors GIS-T applications linked to data inventory, data accuracy and interoperability; b) navigational view, which mostly concentrates on the storage of time-dependent attributes and also miscellaneous representations related to map scales; c) behavioral view, which derives from Hägerstrand's time geography, treating transportation events as dynamic and occurring within the largely static transportation space. All in all, a review of the past GIS-T advances implies that progress has been made in the areas of using GIS-T as spatial databases, analysis and modeling tools, and communication tools (Shaw 2010).

The existing literature in a field commonly provides a good scientific research base for researchers to develop new frameworks and hypotheses (Hoz-Correa et al. 2018). Co-word analysis enables us to illustrate an overall picture of contents on a specific domain through counting and analyzing the co-occurrences of words in bibliographical units such as journal and conference papers, research reports, book chapters, and the like (Liu et al. 2011). Co-word analysis is a quantitative method to map the relationships and interrelationships among concepts, ideas, and problems in different scientific fields (Zhang et al. 2017). Co-word analysis is widely used in bibliometric and scientometric studies, whose theoretical roots go back to actor-network theory (Yang et al. 2012; Igami et al. 2014; Nguyen 2019). Many researchers have used the co-word analysis to explore conceptual network in different subjects and disciplines such as Library and Information Science (Liu et al. 2011; Olmeda-Gómez et al. 2017), Medicine (Xie 2015; Hoz-Correa et al. 2018; Nguyen 2019), International Management Science (Yue 2012), Urbanization (Zhang et al. 2017), Epidemiology (Baziyad et al. 2020), Supply Chain Management (Shiau et al. 2015), Software Engineering (Coulter et al. 1998), Scientometrics (Ravikumar et al. 2015), Information Metrics (Khasseh et al. 2017), Neural Network (Noyons and van Raan 1998), Internet of Things (Yan et al. 2015), Social Media (Gan and Wang 2015), Open Data (Corrales-Garay

et al. 2019), and Marketing (Wang et al. 2015).

To our knowledge, no research based on text mining methods has been carried out for discovering the hidden information in the field of GIS-T. Therefore, this study attempts to map the knowledge domains of GIS-T through the co-word analysis, over the years 2008–2019. This paper will be helpful for the researchers quickly grasping the current state-of-the-art and providing a basis for its future direction and development. The remainder of this paper is organized as follows: In the next section, we introduce the constructing process of co-word network and essential network theories. Section 3 presents the analytical results, elaborates on the underlying discussions and proposes some valuable implications for further academic studies or policy formulation. In the last section, we summarize the major conclusions for the paper.

2 Methodology

The present paper applies co-word analysis to visualize all the interconnected subjects of GIS-T research field, and find out the interrelationships of keywords. The main aim of this study is to present the current status of research on GIS-T and analyze the future trends of its development from a longitudinal perspective. Diversity and variety of research topics in different scientific fields, have made it necessary for researchers to identify the areas and domains of the current research. Bibliometric term was defined by Pritchard (1969) as "the application of mathematical and statistical techniques to books and other communication means". Bibliometrics applies different quantitative analysis methods including citation-based, co-authorship and co-word analysis to explore the existing patterns in a specific field (Van Eck and Waltman 2014).

Co-word analysis was firstly introduced by Callon, Courtial, Turner and Bauin (1983), which became an effective technique for mapping the strength of association between information sections in textual contexts (Viedma-Del-Jesús et al. 2011). This technique is based upon the assumption that a group of aggregated keywords could provide an adequate description of a papers's content, thus underlying themes in a research field can be characterized by a list of the most important keywords (Cambrosio et al. 1993; Yan et al. 2015; Khasseh et al. 2017; Hoz-Correa et al. 2018). The more overlapping pair of keywords within the analyzed papers, the higher probability of a relationship among them (Igami et al. 2014). Co-word analysis makes it possible that researchers demonstrate a comprehensive picture of a specific domain through words' co-occurrence in different types of bibliometric units such as book chapters, journal and conference papers, and books (Liu et al. 2011). In this paper, a co-word analysis method is employed for mapping the intellectual structure of "GIS-T" field through a collection of papers from Web of Science (WOS). Fig. 1 illustrates an overall picture of method employed in this study.
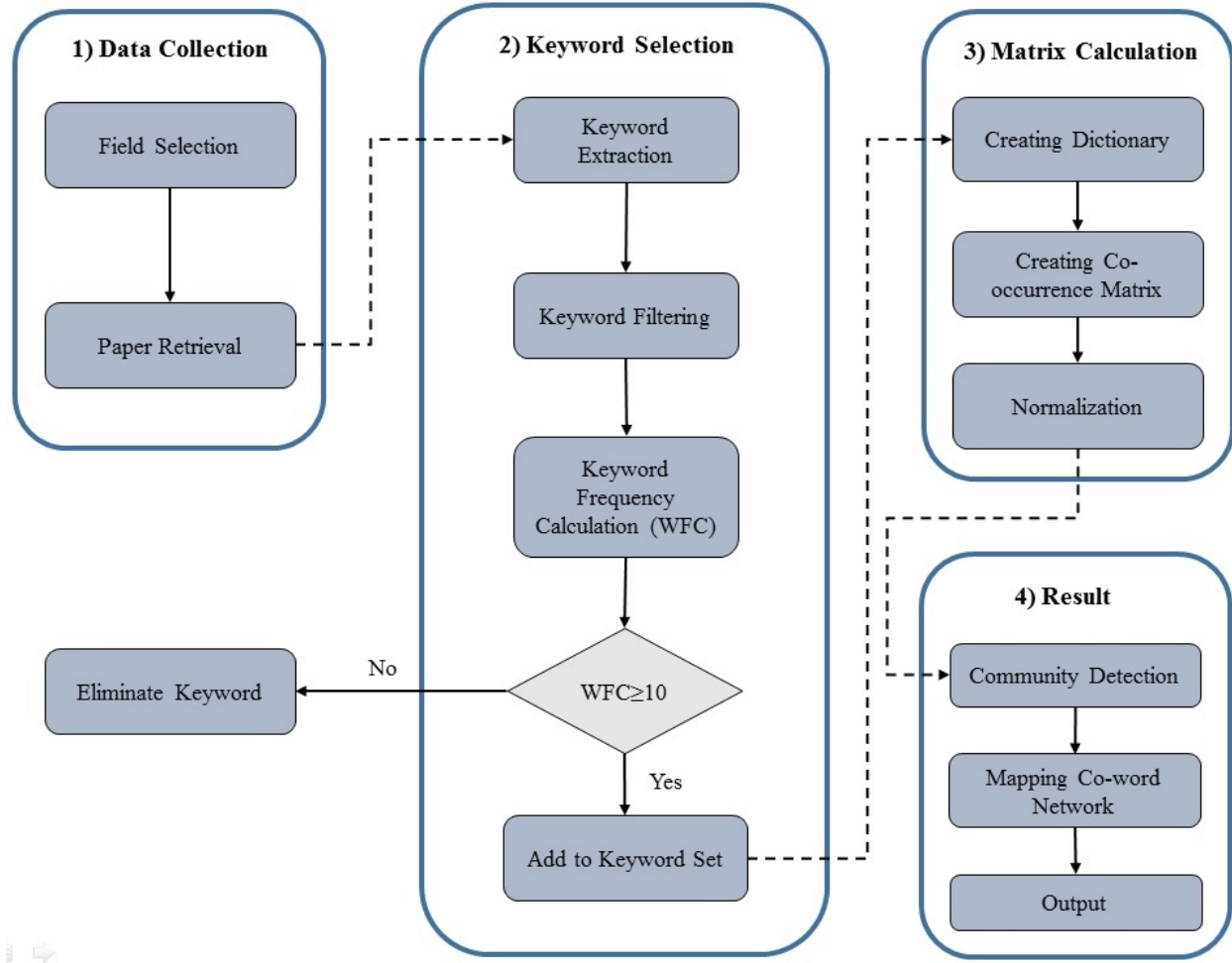
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Fig. 1: A comprehensive framework for designing intellectual structure based on co-word analysis.

2.1 Data collection

To fulfill our goal in this study, the relevant publications accepted as GIS-T in academic literature were screened. The literature was retrieved on December 31, 2019 from all the existing publications on the topic included in the core database of Web of Science (WoS). Using the data extracted from Web of Science, a new dataset including all journal and conference papers from 2008 to 2019 was generated. Relying upon several highly frequent keywords extracted from previous research works, the keyword combinations used to search were as follows: TS=(("GIS" OR "geographical information system*" OR "geographic information system*" OR "geographical information science" OR "geographic information science" OR "geospatial information system*" OR "geospatial information science") AND ("transportation" OR "road network" OR "traffic accident" OR "traffic noise" OR "transit" OR "cycling" OR "walking")).

TS field is a search based on the "Topic" including title, abstract and keywords. The structured search returned 4236 records. Afterwards, the authors eliminated the partially duplicated records in the dataset, then read the titles and abstracts of papers to leave immaterial papers out. After examining the results, we found 171 of records completely irrelevant and off-topic (such as transportation of wind, dust, animals etc.). Another part (around 80) of cleaning process was for the elimination of papers that were published in the less prestigious journals and conferences, based on the authors' knowledge. Also, we had to exclude the papers without any keywords from the analysis (219 papers). Finally, the

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new dataset of 3,766 bibliographic records was designed. The final dataset contains the following information: publication title, author name, journal title, year published, abstract, keywords provided by publication authors and keywords indexed by Web of Science.

2.2 Keyword selection

It is assumed that the more relevant keywords chosen for the research, the better quality of the knowledge gained from the co-word network. Keyword selection helps researchers to study on a set of keywords that are more relevant to the topic. One of the most frequently used criteria for keyword selection in co-word analysis is frequency, which is used in this paper, too. In this paper, keywords with at least ten frequencies were applied for participation in co-word network. There are two stages prior to final keyword selection, namely keyword extraction and keyword filtering:

- **Keyword extraction**
  Keyword extraction is the process of choosing an initial set of keywords for studying. There are two ways to extract keywords from texts, namely non-parametric and parametric. Non-parametric method retrieves keywords, titles and abstracts cited by academic publications manually. Parametric approach uses different software to extract keywords from text such as Ti.exe, GenEx etc., which employ an algorithm to select keywords illustrating main topics of a particular subject (Ravikumar et al. 2015). In this study, the non-parametric way of keywords extraction is employed.

- **Keyword filtering**
  In keyword filtering, we try to clean and refine the extracted keywords, based on different criteria. The keywords of papers included in the dataset were filtered based on the following criteria: a) standardization of keywords in singular and plural forms (e.g., "street", "streets"); b) combination of acronyms (e.g., "GIS", "Geographic Information System"); c) elimination of general keywords (e.g., "data", "information", "model", "system"); d) combination of the British and American spelling of keywords (e.g., "optimize", "optimization"); e) standardization of derived keywords (e.g., "access", "accessibility"). Once the keywords of publications are filtered, a sample of 1498 individual keywords remained. The findings reveal that 1,498 keywords were repeated 15,145 times in 3,766 papers. The combination of "transportation" keyword with other words in the contexts has led to creation of expressions such as "transportation system", "public transportation", "transportation planning" etc. Consequently, for this study, only the existing expressions of "transportation" were taken into account.

2.3 Matrix calculation

Co-word network works based on co-occurrences of keywords extracted from feature selection phase. First, a dictionary including a number of each two keywords co-occurrences is created. For instance, ("Built Environment", "Walkability", 25) explains that "Built Environment" and "Walkability" are appeared simultaneously in 25 papers. Then, the co-occurrence matrix of the dictionary is created. Various approaches have been employed for normalization of co-occurrence network, such as Pearson (Yan et al. 2015; Wu et al. 2018), Jaccard index (Peters and van Raan 1993), Salton index (Ravikumar et al. 2015; Yue 2012), and Equivalence index (Muñoz-Leiva 2012; Zong et al. 2013). Normalization of co-occurrence network is still a controversial issue (Leydesdorff and Vaughan 2006), thus researchers utilize different methods for normalizing the co-word networks. In this paper, we utilized the Jaccard index for normalization of the co-occurrence matrix.

2.4 Result

A clustering method needs to be used on normalized co-occurrence network to find different existing themes of the field. Clustering methods try to group similar and more relevant keywords into a cluster. In this paper, a community detection algorithm is employed on co-word networks. In addition, Modularity index was utilized to evaluate the quality of clustering result, which is missed in many co-word analysis papers. If clustering method satisfy the validation criteria, then co-word network is visualized.

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An appropriate visualization method could bring researchers a comprehensive overview of a field in a quick look. Various software can be used for the visualization of co-word network, such as VOSviewer (Eck and Waltman 2009), SciMAT (Cobo et al. 2012), Bibliometrix (Aria and Cuccurullo 2017), Gephi (Bastian et al. 2009) and so on. In this paper, Gephi was used, due to its flexibility and powerful visualization. Finally, based on the clustered co-word map, different types of research themes are identified and labeled according to total involved keywords of each cluster.

3 Results and discussion

3.1 Statistical analysis

Fig. 2 shows the quantification of papers chronologically between 2008 and 2019 (3,766 papers). It can be vividly seen that research into GIS-T witnessed almost a moderate rate of growth between 2008 and 2019.
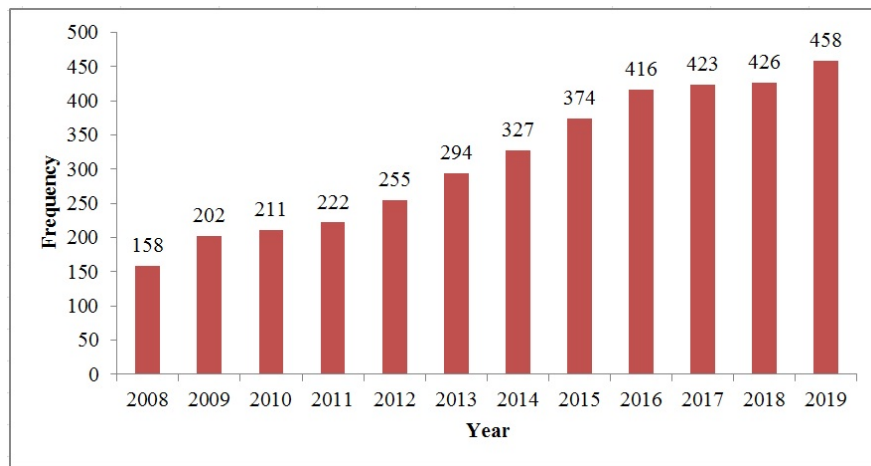

Fig. 2: Number of papers published in years from 2008 to 2019.

Table 1 lists the journals with most papers published on GIS-T. The "Transportation Research Record" contains 119 published papers during the analyzed period. With regard to the variety of journals that have published papers on GIS-T, it can be concluded that research on this research area is multidisciplinary, from transportation to GIS, computer science etc. The journals "Journal of Transport Geography", and "International Journal of Environmental Research and Public Health" have ranked second and third accounting for 117 and 56 respectively. Moreover, according to our database, "Billie Giles-Corti" is the most prolific author with 41 papers, James F. Sallis and Suzanne Mavoa with 30 and 25 respectively (see Table 2).

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Table 1: Distribution of the papers among different journals.

Journal	JCR Rank	Frequency	%
Transportation Research Record	Q2	119	0.031%
Journal of Transport Geography	Q1	117	0.031%
International Journal of Environmental Research and Public Health	Q2	56	0.015%
Sustainability	Q3	54	0.014%
Applied Geography	Q1	46	0.012%
ISPRS International Journal of Geo-Information	Q1	44	0.011%
International Journal of Health Geographics	Q2	44	0.011%
International Journal of Behavioral Nutrition and Physical Activity	Q2	42	0.011%
International Journal of Geographical Information Science	Q1	41	0.010%
Transportation Research Part A: Policy and Practice	Q2	36	0.009%
Transportation Research Part D: Transport and Environment	Q1	36	0.009%

Table 2: Top ten authors in the topic GIS-T.

Author	Knowledge areas	Frequency	%
Billie Giles-Corti	Urban Planning / Physical Activity / Health	41	0.010%
James F. Sallis	Physical Activity / Built Environment / Health	30	0.008%
Suzanne Mavoa	Health / Built Environment / Spatial Analysis	25	0.007%
Lawrence Frank	Transportation / Urban Planning / Physical Activity	24	0.006%
Brian E. Saelens	Obesity / Physical Activity / Policy	21	0.005%
Terry L. Conway	Physical Activity / Built Environment / Health	20	0.005%
Neville Owen	Physical Activity / Built Environment / Public Health	19	0.005%
Jacqueline Kerr	Physical Activity / Built Environment / Health	17	0.004%
Biswajeet Pradhan	GIS / Geoinformatics / Geospatial Analysis	17	0.004%

As mentioned earlier, the papers without keywords were eliminated from our analysis. Also, in our study, both author keywords and keyword plus were analyzed. Once the keywords of publications are filtered, a sample of 1,498 individual keywords remained. The findings reveal that this 1,498 keywords were repeated 15,145 times in 3,766 papers. The top ten frequently occuring keywords are "walking", "transportation", "built environment", "health", "accessibility", "physical activity", "obesity", "GPS", "spatial analysis" and "network analysis" (see Table 3).

Table 3: Highly occuring keywords covered in 3,766 papers.

No.	Keyword	OCC.	%	No.	Keyword	OCC.	%
1	Walking	479	0.031%	13	Simulation	68	0.004%
2	Transportation	435	0.028%	14	Mobility	65	0.004%
3	Built Environment	327	0.021%	15	Road Network	63	0.004%
4	Health	297	0.019%	16	Transit	62	0.004%
5	Accessibility	232	0.015%	17	Land-use	60	0.003%
6	Physical Activity	187	0.012%	18	Urban Design	55	0.003%
7	Obesity	150	0.009%	19	Logistics	45	0.002%
8	GPS	110	0.007%	20	Urban Planning	43	0.002%
9	Spatial Analysis	99	0.006%	21	Pollution	40	0.002%
10	Network Analysis	71	0.006%	22	Travel Behaviour	38	0.002%
11	Urban Form	92	0.006%	23	Sustainability	36	0.002%
12	Network Analysis	72	0.004%	24	Public Transport	34	0.002%

OCC. occurence of keywords

3.2 Calculation of co-occurrence matrix and creation of thematic network

A co-occurrence matrix was calculated based on common keywords in a paper for providing co-word network. For instance, the keywords "built environment" and "walkability" are appeared in author keywords of 25 papers simultaneously. As a result, the weight of their co-occurrence equals to 25. After the calculation of co-occurrences matrix, a square matrix comprising 636 frequently repeated keywords was formed. The top 10 keywords with a highest degree centrality and betweenness centrality among our dataset are listed (see Table 4). The degree centrality of a node equals to total summation of direct links related to a node. The more degree centrality for a specific keyword indicates that the keyword is used more frequently in papers. The degree centrality is employed to calculate the level of centrality in strategic diagrams. As such, the total number of degree centrality of nodes in a community, regardless of internal links, with other communities is equal to centrality in a strategic diagram. The degree centrality of a node is defined based on its direct links in the network and equals to total summation of direct links related to chosen node as shown in Eq. 1. In a co-word network, the keywords with high degree centrality represent the current main research subjects in GIS-T such as "physical activity", "emission", "sustainability", "connectivity", "health", and so on.

$$DC(x) = dig(x) \qquad dig(x) \text{ is the degree of node } x. \qquad (1)$$

On the other hand, betweenness centrality is calculated based on shortest path in a network. The betweenness centrality shows that to what extent the knowledge points are able to link with other independent subjects in the field. Betweenness centrality is defined as a proportion between the total numbers of the shortest path passes from node connecting node i to node j and the total number of shortest paths existing between node i and node j as represented in Eq. 2. Keywords with great betweenness centrality like "urban form", "physical activity", "walking", "sustainability", "GIS data" etc., are regarded as connectors among research topics. In other words, these keywords have interdisciplinary resources and concepts, thus they are supposed to greatly affect the co-occurrence of other keywords (Zhang et al. 2017).

$$BC(x) = \sum_{s,t \in x} \frac{\sigma_{\text{st}}(x)}{\sigma_{\text{st}}} \qquad (2)$$

Where σ_{st} is the total number of shortest paths between node s and t as their end nodes, while $\sigma_{\text{st}}(x)$ is the total number of shortest paths that pass through node x (Freeman 1997). High centrality scores indicate that a vertex lies on a considerable fraction of shortest paths connecting pairs of vertices (Raghavan et al. 2014).

Table 4: Top keywords with high degree centrality and betweenness centrality.

No.	Keyword	DC	No.	Keyword	BC
1	Physical Activity	148	1	Urban Form	0.031
2	Emission	143	2	Physical Activity	0.030
3	Sustainability	139	3	Walking	0.026
4	Connectivity	135	4	Sustainability	0.023
5	Health	133	5	GIS Data	0.022
6	Pedestrian	132	6	ArcGIS	0.021
7	Built Environment	129	7	Network Analysis	0.020
8	Transport System	127	8	Transport System	0.019
9	Mapping	127	9	Built Environment	0.019
10	Urban Mobility	125	10	Health	0.019

DC degree centrality; *BC* betweenness centrality

A network has cluster structure if it categorizes into different groups of vertices with dense connections within groups and sparser connections between groups (Xie and Szymanski 2011). In order to design a visual keyword co-occurrence network, the keywords with a minimum frequency of two were selected for the co-occurrence analysis. The quality of a particular part of network into clusters is commonly measured through modularity (Newman 2004).

$$Q = \frac{1}{4} \sum_{ij} (A_{ij} - \frac{k_i k_j}{2m}) S_i S_j, \qquad m = \frac{1}{2} \sum_i k_i \qquad (3)$$

Where k_i and k_j are the degrees of nodes and m is total number of edges. A_{ij} is the number of edges between vertex i and j. The quantities A_{ij} are the elements of the so-called adjacency matrix. The expected number of edges between vertices i and j if edges are placed at random is $\frac{k_i k_j}{2m}$. A network with modularity in the range between 0.3 and 0.7, usually is identified a strong cluster structure (Xie and Szymanski 2011). The rate of modularity for the network in this study accounted for 0.321. According to the standard value, this is not great, but acceptable and satisfying. One justification for achieving this value would be the interdisciplinary nature of GIS-T including transportation, GIS, computer science and so on, that leads to a stack of papers with diverse viewpoints and objectives.

Over the last years, a variety of softwares have been developed in order to visualize emerging trends and transient patterns in scientific literature such as MedlineR (Lin et al. 2004), CiteSpace (Chen 2006), Gephi and so on. Figs. 3-6 illustrate thematic networks of GIS-T research for periods between 2008 and 2019, which were built up using the Gephi 0.9.2. Gephi software is able to visualize and analyze co-word network as a type of co-occurrence networks. One of the main advantages of Gephi is its capability to visualize co-occurrence networks with a more beautiful appearance. Many researchers have applied this software in co-word analysis networks (Feng et al. 2017; Li et al. 2018; Rashidi et al. 2020). In a thematic network, the weight of each topic represents its total link strength which are shown by the size of each corresponding node. The links indicate co-occurence relationships among keywords, and the distances among the nodes are inversely related to the closeness of subjets. Total link strength is defined as the sum of the number of links a node shares with all other nodes in the network. Concepts related to the same communities are presented in the same colour (see Figs 3-6, and section 3.3). Based on co-word network analysis, there will be an edge between two-keywords existing in a paper, which indicates the co-occurrence of these keywords. Apparently, it is not feasible to show all nodes in each clusters owing to the limitations of two-dimensional visualization.

Network density (D) is the ratio between the actual number of edges and the maximum possible number of edges that can be obtained from the network, which is calculated by the formula in the following:

$$D = \frac{2E}{N(N-1)} \qquad (4)$$

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where:

D = density of co-word network
E = numbers of edges in the network
N = numbers of nodes in the network

Table 5: Co-word structure of the thematic maps between 2008 and 2019.

Period	Nodes	Edges	Density	No. of clusters
2008-2010	14	17	0.186%	4
2008-2013	94	465	0.106%	4
2008-2016	236	3157	0.113%	4
2008-2019	336	6949	0.123%	4

The higher value of density for co-word network infers that research subjects have been well-developed and thus more mature evolution of the knowledge system (Liu et al. 2011; Zhang et al 2017). The network density of four steps from 2008 to 2019 changed from 0.186% to 0.106%, 0.113% and finally 0.123% (see table 5). Jaccard index is used to normalize the co-occurance links in the network. Regarding the minority of literature for the period between 2008 and 2010, there was a close relationship between the keywords, and consequently greater density. From 2011 to 2013, the number of subjects was rising, but the quantification of publications for each subject was still limited. As a result, the relation between the keywords became more divergent. Since that time to 2019, both the subject diversity and the publication quantification for each subject was rising gradually until it reached an equilibrium point 0.123%. According to the results of network density equation, it can be concluded that the research into GIS-T is not mature sufficient yet.
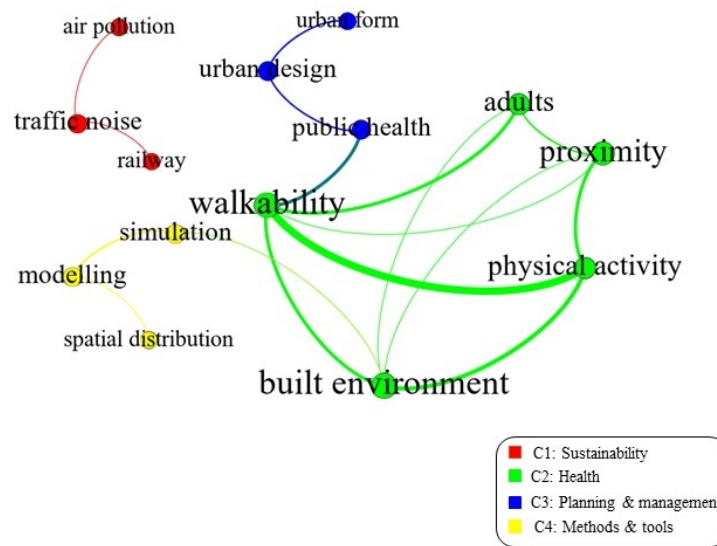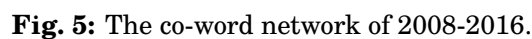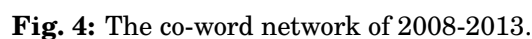

Fig. 3: The co-word network of 2008-2010.

Fig. 4: The co-word network of 2008-2013.

Fig. 5: The co-word network of 2008-2016.

Fig. 6: The co-word network of 2008-2019.

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3.3 Construction of strategic diagram

Using the information included in the Table 6, we are able to form strategic diagrams for each period. A strategic diagram is used to illustrate the status quo and direction of research themes on GIS-T more vividly. Relying on the clustering results, strategic diagrams enable us to visualize the cohesion and maturity of the research themes in GIS-T, using the centrality and density of each cluster (Callon et al. 1991; Liu et al. 2014a; Liu et al. 2014b; Wanying et al. 2018; Giannakos et al. 2019). The centrality indicates the strength of an interaction between nodes, while density shows the internal coherence of a cluster (Giannakos et al. 2019). In other words, centrality shows how "central" a theme is to the whole field, and the level of internal relationships and connections in a particular research field is illustrated by density (Liu et al. 2011; Liu et al. 2014a; Liu et al. 2014b; Wanying et al. 2018; Giannakos et al. 2019). Strategic diagrams have been utilized in wide range of studies such as iMetrics (Khasseh et al 2017), social media (Gan and Wang 2015), computer behavior (Muñoz-Leiva et al. 2012), information science (Zong et al. 2013; Hu et al. 2013), digital library (Liu et al. 2012), stem cells (An and Wu 2011), gender differences (Dehdarirad et al. 2014). According to a conducted research by Moral-Muñoz et al. (2020), some science mapping software such as SciMAT, and libraries such Bibliometrix support strategic diagram.

According to Fig. 7, the strategic diagram divides the clusters into four individual quadrants, which x-axis and y-axis are labeled with degree centrality and density respectively (Callon et al. 1991). The level of development and maturity of a specific cluster is defined based on the quadrant it is located, as follows: a) quadrant I: well-developed and mainstream, b) quadrant II: developed but isolated, c) quadrant III: emerging or declining, d) quadrant IV: undeveloped and general (Callon et al. 1991). In order to estimate the origin of each diagram, the average of degree centrality and density for each period is calculated (see Table 6). Based on the clustering results, we plotted the strategic diagram for the years 2008–2019 to visualize the cohesion and maturity of the research themes in GIS-T, using the centrality and density of each cluster (see Fig 8).
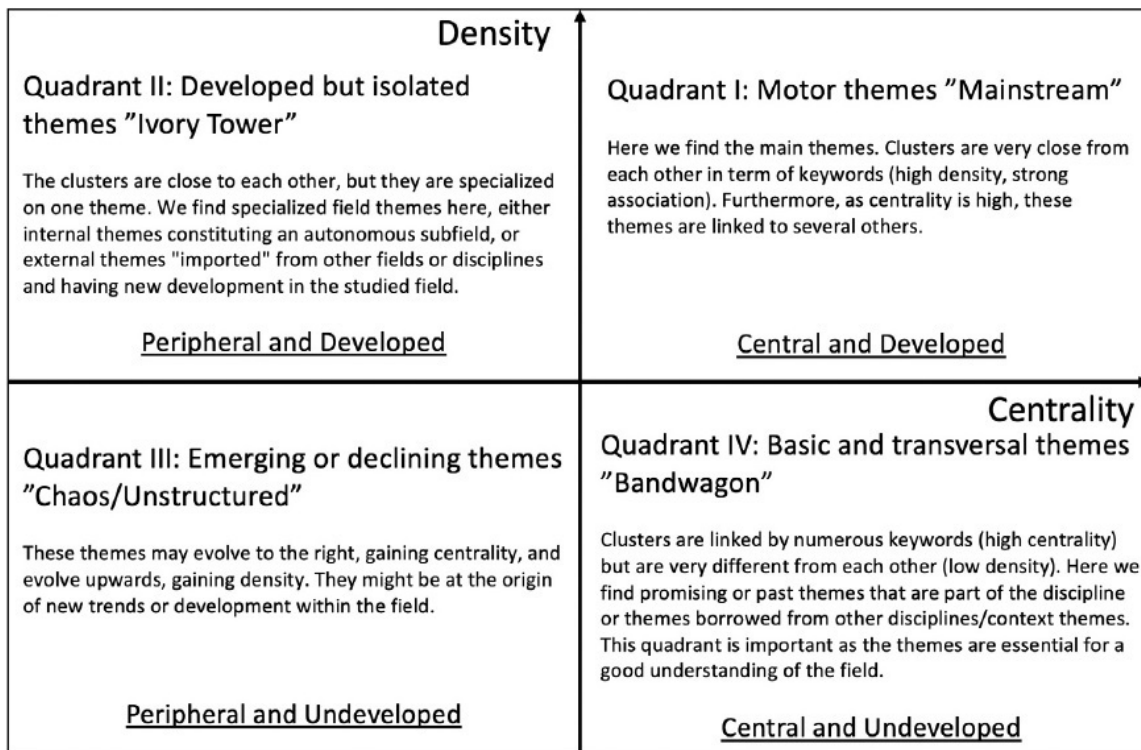

Fig. 7: Density and centrality in a strategic diagram (Giannakos et al. 2019).
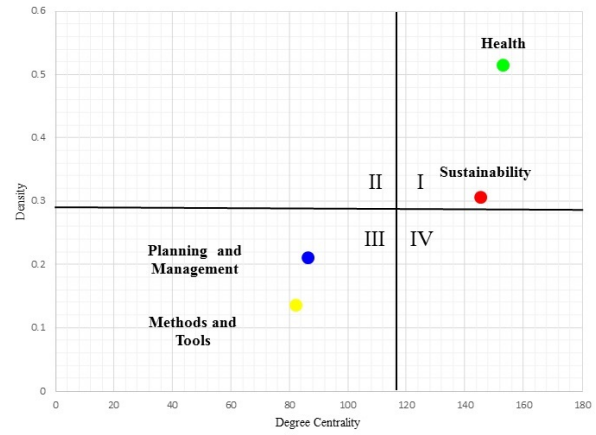
Table 6: Degree centrality and density of clusters in the co-word analysis.

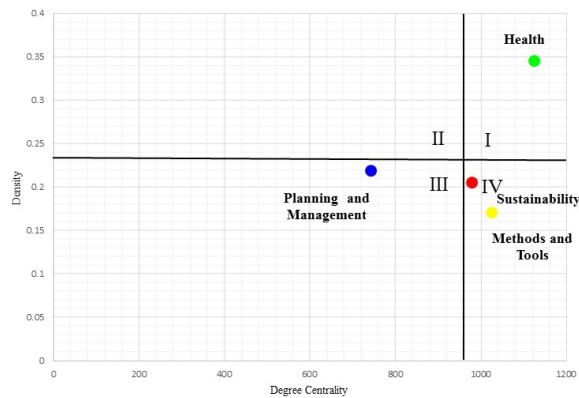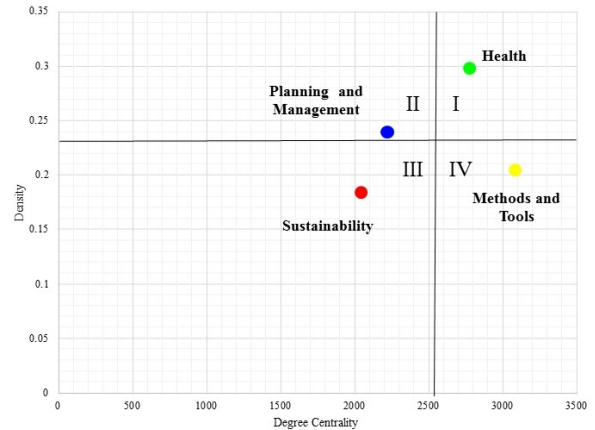| ***	2008-2010		2008-2013		2008-2016		2008-2019	
Clusters	*DC*	*D*	*DC*	*D*	*DC*	*D*	*DC*	*D*
1: Sustainability	4	0.16	145	0.30	978	0.20	2041	0.18
2: Health	5	0.13	153	0.51	1124	0.34	2773	0.29
3: Planning and Management	0	0.16	86	0.21	743	0.21	2225	0.23
4: Methods and Tools	1	0.16	82	0.13	1025	0.16	3083	0.20

DC degree centrality; *D* density
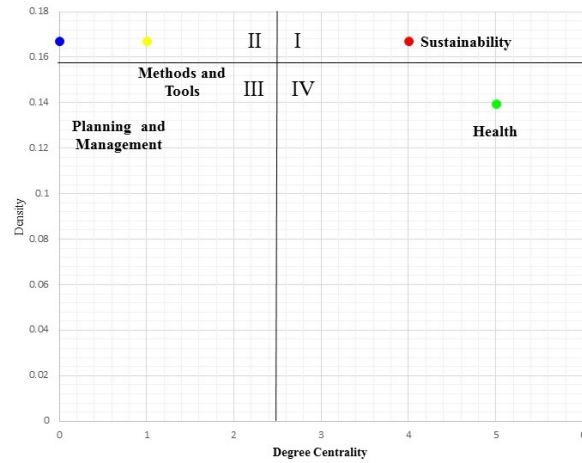
2008-2010

2008-2013

2008-2016

2008-2019

Fig. 8: The strategic diagram of clusters for the periods between 2008 and 2019.

3.4 Detection of research themes

To summarize, the main clusters resulted from the co-word analysis for the period 2008-2019 are listed as follows:

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- **Cluster 1: Sustainability**
  This cluster deals with issues related to challenges and opportunities of sustainable transportation in the modern cities. It refers to the broad subject of transportation that in terms of social, environmental and climate impacts is sustainable. It also is seeking to formulate and implement strategies to address the increasing problems (i.e., environmental and health and so on) of living in the metropolitan areas. Most of papers aim to incentivize people to switch from private cars to more sustainable modes of transportation such as walking, cycling and public transit. The hot keywords group included in this subject are "sustainable transportation", "justice", "exposure assessment", "walkability", "mibility patterns", "daily mobility", "equity", "environmental equity", "risk management", "sustainable assessment", "accessibility modelling" etc.

- **Cluster 2: Health**
  The main objective of publications included in this cluster is improving people's health and decreased health care costs of transportation activities. Moreover, they commonly offer solutions that supports physical activity such as investments in sidewalks, trails, public transit, bike lanes, and other infrastructure. This cluster to the some extent has some similar aspects and objectives to the cluster 1. The hot keywords of this topic consist of "elderly", "healthcare", "obesity", "physical activity", "active commuting", "noise exposure", "walking behaviour", "mortality", "exercise", "active travel", "active living", "ecological models", "bicycling", "biking", "public health", "breast cancer" etc.

- **Cluster 3: Planning and Management**
  This cluster is made up of subjects focusing on defining future goals, policies, and investments to prepare for future needs to efficiently move people and goods to destinations. Studies in this cluster commonly are seeking to find and use practical solutions to improve the performance of urban transportation. They provide comprehensive approaches to analyze a wide range of alternatives and impacts on the transportation system to influence beneficial outcomes. The highly significant keywords in this topic includes "decision support", "standards", "travel cost", "transportation cost", "location model", "municipal solid waste management", "inter-model transportation", "logistics", "environmental assessment", Transit-Oriented Development (TOD), "facility creation", "waste management", "recycling", "air quality" etc.

- **Cluster 4: Methods and Tools**
  The co-word analysis discovered a number of heterogeneous methods and tools that are commonly utilized in the literature. This cluster is connected to the terms such as "GIS analysis", "GIS data", "ArcGIS", "Web GIS", "Spatial Data Infrastructure (SDI)", "Building Information Modeling (BMI)", "Cellular Automata (CA)", "Agent-Based Modelling (ABM)", "graph theory", comparative study", "Intelligent Transportation System (ITS)", "Genetic Algorithm (GA)", "data collection", "simulation", "spatio-temporal anlysis" etc.

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Table 7: Identified clusters in the topic GIS-T for the period 2008-2019.

Cluster	Cluster name	No.	Hot keywords
1	Sustainability	8	sustainable transportation; walkability; justice; mibility patterns; sustainable assessment; environmental equity; accessibility modelling; risk management
2	Health	10	public health; healthcare; active living; active travel; elderly; obesity; physical activity; mortality; exercise; biking
3	Planning and Management	7	decision support; standards; waste management; Transit-Oriented Development (TOD); environmental assessment; logistics; air quality
4	Methods and Tools	13	GIS analysis; GIS data; ArcGIS; Web GIS; Spatial Data Infrastructure (SDI); Building Information Modeling (BMI); Cellular Automata (CA); Intelligent Transportation System (ITS); Genetic Algorithm (GA); comparative study; simulation; spatio-temporal anlysis; graph theory

3.5 Dynamic analysis based on two-dimensional map and strategic diagram

The findings of this paper illuminated that GIS-T topic has an interdisciplinary knowledge system, involving GIS, transportation, computer science, geography, health science, economy, information science, environment, natural resources, and so on. The results of the dynamic co-word network and strategic digrams could provide lots of useful information and implications for researchers seeking to predict its future. Based upon our findings, some of significant points are stated in the following:

In the period between 2008 and 2010, the quantification of literature was limited and sparse, thus there were weak links among nodes in different clusters of network. According to the strategic diagrams (see Fig. 8), density and degree centrality for cluster 1 ("Sustainability") were both high. It indicates that this cluster has high internal correlation, and subjects are widely linked with other clusters. The paper published this period, mostly favoured the environmentally sustainable development of transportation infrastructure taking into account urban design, urban expansion, land-use etc. For example, some studies aimed to improve accessibility to green spaces, public transportation, health services etc. by making minimal changes in land-use and transportation network design. The clusters 3 ("Planning and Management") and 4 ("Methods and Tools") located in the quadrant II, which means that these research topics were well-developed but not central. Some studies concentrated on developing and using new methods and tools that can assist urban planners in management of urban transportation system. We found many papers that applied evolutionary algorithms to find the shortest or best route in travelling salesman problem or vehicle routing problem (e.g., genetic algorithm, ant colony optimization etc.). Many studies used ArcGIS software for presenting spatial data in the format of schematic maps (i.e., service areas of public transportation, traffic maps etc.). Cluster 2 ("Health") positioned in the quadrant IV with high degree centrality but low density. A few studies made efforts to appraise the urban transportation system with regard to public health and sustainability aspects. All in all, in spite of detection of 4 clusters for this era, the research works were inconsistent, thus the network is immature and undeveloped.

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Since 2011, was a turning point as we witnessed two significant changes in literature on GIS-T. First, a marked increase in the volume of academic research works in GIS-T led to the complexity and burgeoning of the network. It means that the knowledge network became richer, so the border of communities was more distinctive. Furthermore, the position of Cluster 2 ("Health") promoted from quadrant IV to I, inferring the increasing attention of researchers to do reaseach into health topic in this period. In this period, the cluster 2 ("Sustainability") still located in the quadrant I, showing the considerable significance of sustainable transportation in the global scale. The academic works published in the area of "Planning and Management" and "Methods and Tools" were sparse and negligible for this period, thus these clusters located in the quadrant III, indicating the marginality and immaturity of this research topic. In this period, some studies tried to employ simulation approaches for transportation applications, for instance, simulation of travel mode of commuters using agent-based modeling, prediction of urbanization in cities by cellular automata, etc. There were many papers which favoured the logistics transportation and distribution topic, which encompass a wide range of applications from the collection of municipal waste and hazardous materials, to distribution of factories and suppliers' products among consumers in the urban areas.
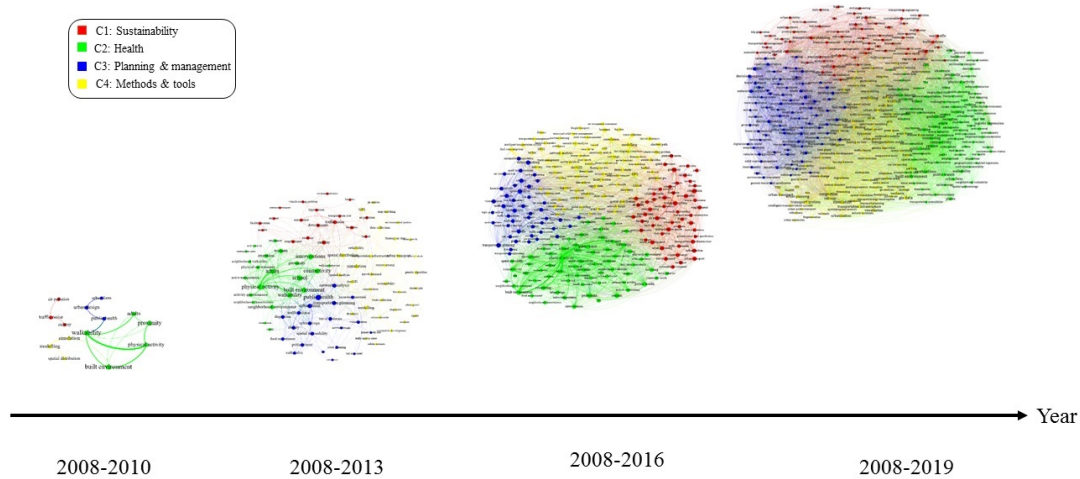

Figure 9: The dynamic network structure of keywords for years 2008-2019.

In the period 2008 to 2016, the cluster 2 ("Health") still located in the quadrant I, due to increasing improvement in quantification and qualification of scientific research in public health concept. A part of studies introduced the irreversible negative consequences of transportation activities on people health and urban environment, which were carried out by scholars from medical science community. The hot research topics were comprised of physical activity, sedentary lifestyle, obesity, air pollution, acid rain, climate change, respiratory diseases etc. It can be seen that the clusters 1 ("Sustainability") and 4 ("Methods and Tools") dropped to quadrant IV, showing high degree centrality but low density. Considering the increase of the spatial data used in transportation applications, we face the difficult task of storage and manipulation of a massive volume of data. Therefore, some studies used ArcSDE software to benefit from Relational Database Management Systems (RDBMS) capabilities for storing and manipulating spatial data related to transportation (i.e., socioeconomics, traffic census etc.). Advancements in information and communication technologies, especially in the Internet led to new capabilities of GIS in the field of transportation such as real-time and interactive traffic maps, mobile GIS etc. Many papers offered new methods and tools to improve the results of previous works in route optimization, collection of hazardous materials, logistics, supply chain, and many more. Also, the cluster 3 ("Plan-

ning and Management") located in the quadrant III. A big portion of papers, made considerable efforts to appraise the urban transportation system with regard to numerous aspects such as equitable cities, the future of mobility, inter-connected cities, intelligent transportation, sustainable transportation and so on.

From 2016, considering the strategic diagram, cluster 2 ("Health") with high density and degree centrality still located in the quadrant I, which indicates that the research topics in this cluster tends to be more and more well-developed. Cluster 1 ("Sustainability") placed in quadrant III with low density and degree centrality, indicating the research topics in this cluster is emerging or declining. Clusters 3 ("Planning and Management") and 4 ("Methods and Tools") are positioned in quadrant II, and IV respectively. Similar to the previous period, many studies worked on using new abilities and capabilities of technologies to improve services of transportation network. New research topics mostly directed towards utilizing new concepts such as Internet of Things (IoT), Deep Learning etc. to open up new opportunities and perspectives on intelligent transportation systems in cities. Emergence of new ideas and applications in transportation planning (i.e., demand-driven transportation, autonomous vehicles etc.) is a clear evidence of revolution in the methods and tools used by scholars in addressing transportation problems.

4 Conclusions, limitations and future research

On the basis of publications included in the Web of Science (WoS) database service, and also utilizing co-word analysis, this study mapped the relationships among research topics of GIS-T field. Furthermore, strategic diagrams are used to show the structure and evolution of communities more clearly. In this study, research scope includes the GIS-T publications available in WoS. The results show that the research interest in GIS-T is rather young, and the subjects studied in this area consist of an interdisciplinary and heterogeneous variety of knowledge areas. This study represented a network map of the main themes grouped in four communities including a) "Sustainability", b) "Health", c) "Planning and Management", and d) "Methods and Tools". For the period from 2008 to 2010, the literature of GIS-T was limited and scattered, with weak edges among nodes in all clusters, but "Sustainability" cluster. Also, the clusters "Planning and Management" and "Methods and Tools" have high internal correlation, with high density and degree centrality. From 2011 onwards, the network is becoming richer and more complex, and it can be seen that the boundaries between clusters seem more clear. The big characteristic of the period 2011-2013 is the displacement of "Health" cluster from IV to I in the strategic diagram, indicating the increasing research works done in health subject. According to knowledge network and strategic diagram, the health issues have been received a considerable after 2010. The researcher mostly have been exploring the positive consequences of active transportation, and investigating the possible solutions for convincing people to avoid driving. In addition, other GIS-T topics keep expanding almost in constant speed. Many researchers made efforts to evaluate the urban transportation system with regard to public health aspects. GIS software and methods have been used to store, manage, analyze and present the pollution data in the urban areas. Also, there are lots of research using optimization approaches for different GIS-T problems, such as route finding, logistics and supply chain management, and so on. From 2008 to 2017 onwards, according to strategic diagram, clusters 2 ("Health") still located positioned in the quadrant I, referring the maturity of these subjects. Day by day, GIS-T filed is experiencing novel concepts and advanced technologies, such as Internet of Things (IoT), Artificial Intelligence (AI) etc. which can open up new opportunities for addressing transportation problems. The future studies can use other databases (i.e., Google Scholar, Scopus etc.) to enrich their dataset. In addition, in order to describe the intellectual structure of the GIS-T field, the next studies can consider complementary bibliometric techniques (i.e., co-citation analysis, co-author analysis etc.). Overall, this study provide researchers with a practical and powerful tool for grasping the current status of GIS-T field, and also better understanding of its evolution. Moreover, as this study was the first attempt to apply text analysis and visualization methods to identification of research subjects of GIS-T, it can be introduced as a roadmap for other applications.

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