

# **A literature review on accessibility using bibliometric analysis techniques**

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# **A literature review on accessibility using bibliometric analysis techniques**

**Abstract:** Accessibility is a key concept in the field of transportation, and there is a rich amount of reviews available on this topic which concentrate on certain perspectives. However, none of them presents a comprehensive and quantitative overview on accessibility-related publications. To fill this gap, this study reviewed two decades of publications (during 2000-2019) drawn from Web of Science (WoS), and aims to figure out the evolution pathway of accessibility related studies so that future research directions can be recognized. By employing the bibliometric analysis techniques, this study provides the potential to trace historical and geographic trends at global level, covering leading journals and institutions, keywords characteristics, citation network analysis, and a qualitative review of the most influential papers. The output results show that there is an increasing geographic spread along with the growth spurt of research publications on the topic of accessibility especially since 2010s. Both the keywords' characteristics and citation network analysis help to identify research hot points, categorized as new indicators development and accessibility-based applications. Finally, this paper highlights the need for further studies for those two hot points respectively. It is hoped the results output here could benefit researchers engaging in this field to sharpen their own future research directions, and provide practitioners with a greater understanding of the various types of accessibility metrics and help them to identify the most appropriate practice for their specific situation.

**Keywords:** accessibility; review; bibliometric analysis; content analysis

## 1. Introduction

Accessibility, firstly introduced by Hansen (1959), can be broadly defined as the ease with which activities at one place may be reached from another via a particular travel mode or any available modes (such as walk, bus, rail, bike, car, etc.) (Geurs and van Wee, 2004). According to the definition, accessibility combines not only the state of transportation networks, but also land uses and individuals with differing characteristics. Therefore, the concept of accessibility has long been central to many academic fields, such as transport engineering, regional geography, public health, spatial economics and so on (Páez et al., 2012; Geurs et al., 2015).

In the literature, various measures have been developed to quantify accessibility for different application contexts, and the majority of available reviews concerned with the comparison of conceptual and computational issues of those accessibility indicators, such as well-cited reviews by Handy and Niemeier (1997), Kwan (1998), Geurs and van Wee (2004). Handy and Niemeier (1997) bridged the gap between the theoretical definition and practical applications of location-based accessibility measures and provided a conceptual framework to facilitate this gap that covered specification, calibration and interpretation. The review by Kwan (1998) concentrated on the comparison of location-based and individual-based accessibility measures by their data requirements, calculation process, and the degree of correlation between measures in practice. Compared with Handy and Niemeier (1997) and Kwan (1998), Geurs and van Wee (2004) adopted a broader base for their review. They compared and analyzed the theoretical basis, interpretability and communicability, data requirements and usability in social, and economic evaluations of various categories of accessibility measures, including infrastructure-based, location-based, individual-based, and utility-based measures.

In addition to updating these reviews cited above, more current reviews take an alternative perspective and focus on tracing the utilities or implications of accessibility measures in specific research field, such as park/green space accessibility (Park, 2017; Ekkel and De Vries, 2017), health-care facility accessibility (Guagliardo, 2004), accessibility and social equity (Tijs, 2015), accessibility instruments for planning practice (Papa et al., 2016).

Although these available reviews have provided valuable references that help to clarify the current state of accessibility-related research field, they often focus on certain perspectives and none of them presents a comprehensive and quantitative overview on accessibility-related publications. A global review could offer robust and holistic background knowledge and figure out current progress and hot topics related with accessibility with a quick glance, thus could be an excellent resource for people new to accessibility research, and benefit researchers engaging in this field to sharpen their own future research directions. Moreover, it could provide practitioners with a greater understanding of the various types of accessibility metrics, improve their knowledge on how to generate such metrics, and help them to identify the most appropriate practice for their specific situation.

To fill this gap, this study reviewed approximately 20 years of publications (during 2000-2019) drawn from Web of Science (WoS), and aims to figure out the evolution pathway of accessibility related studies so that future research directions can be recognized. This research aim would be achieved by employing bibliometric analysis, which are set of methods to quantitatively analyze academic publications using statistical techniques, thus provide potential to trace the research trends and popular issues at global level. In detail, the specific contributions of this study include: (1) for characterizing the historical evolution of accessibility-related research, the bibliometric analysis techniques are firstly proposed in corresponding review studies; (2) a global, comprehensive and quantitative map of knowledge development and trajectory of efforts to understanding the accessibility research field are clarified; (3) useful guidance about where and how future research on accessibility is offered based on the well-understanding of current state of accessibility research field.

The remainder of the paper is organized as follows. The next section presents a brief introduction on methods employing in this study, as well as data collection criteria. Then it is followed by section 3, which displays the key findings of current knowledge development of accessibility research field. Section 4 highlights academic hot topics and discusses pathways of future research. The paper concludes with a summary of results obtained so far and possible policy implications.

## 2. Methods and data

## 2.1. Methods

For achieving the research aim, bibliometric analysis techniques were employed in this study. The bibliometric analysis is an effective method to quantitatively analyze academic publications using statistical techniques, consists of citation analysis and content analysis (Zhong et al., 2016). The citation network analysis implies the linkages between citing and cited publications as well as researchers' interactions, thus helps to visualize the sub-fields and corresponding intellectual interconnections (Peris et al., 2018). Within the citation network map, a node (circle) refers to a publication, and the size of the node is determined by its academic influence, such as the citation number. The link (line) between nodes refers the direct citation flow between these two publications. The location of each node in the map is determined based on its connections to each other by adopting visualization algorithms, such as force-directed visualization algorithm. The closer the nodes locate, the more connections they share. Finally, corresponding clusters/ communities are further detected by modularity-based algorithms (van Meeteren et al., 2016). While the content analysis aims to identify current hot topics on the basis of frequency of keywords and other distributions, and was always applied after the citation network analysis among available research (van Meeteren et al., 2016; Leung et al., 2018; Wu et al., 2020).

In summary, the bibliometric analysis offers a useful tool to shift from micro (one publication, scientist or institute) level to macro (national or global) level, and provides a potential to trace the research trends and popular issues. Through the application of the freely available software VOSviewer, this study adopted the bibliometric analysis techniques to trace the historical evolution of accessibility-related research, investigate leading journals and institutions, identify research hot topics, thus help to provide more reliable research directions in the future.

## 2.2. Data collection criteria

The collection of relevant publications on accessibility is a very important and sensitive step because it potentially has a strong influence on the outcomes of the analysis (Peris et al., 2018). Despite the various limitations that have already been discussed in the literature, the academic database WoS was chosen to compile the literature dataset since it remains one of the most important instruments for the collection of global scientific literature, as well as its ability to download complete and standardized citation records (Sedita et al., 2018).

This review targeted the accessibility literature during 2000 and 2019 that involves “accessibility” OR “access” in title, keywords or abstract. This search was conducted in February 2020, and 62,232 matching records were found. This initial dataset provides a large spectrum of the accessibility-related research covering over 200 disciplines and majority of them are not truly relevant in our field, thus a multi-step cleaning approach was developed to refine it. At first, all publications labeled with the WoS discipline category of “Transportation” OR “Transportation Science Technology” OR “Geography” OR “Urban studies” were selected, resulted in a set of 3,888 publications. Then they were visualized using the citation network analysis approach where publications are nodes and citations are edges, returned with a big connected graph of publications in the center and a ring of unconnected publications surrounding this center. Inspired by Peris et al. (2018), a random sample of 100 publications from the connected graph in the center and the outer ring were selected respectively, and their title, keywords and abstract were traced manually. The vast majority of the out-ring sample publications only contain certain keywords, but their research objectives are neither new accessibility indicators development or accessibility-related applications. While 95% of the sample publications from the connected graph in the center were found to meet all the selection criteria and are appropriate to be investigated in depth. Therefore, the dataset was further refined by extracting the biggest connected graph in the center and excluding the out-ring, returned a set of 2,394 publications. After all duplicates had been removed, a total of 2,356 publications were selected and downloaded for further examination in this research. Of all publications retrieved from WoS, peer-reviewed research articles account for 48.88%, followed by conference papers 47.17%, review papers 1.09% and others 2.86% (e.g. books, book chapters, article in press, reports and so on). In terms of publication language, English is the most frequently used (98.77%), followed by Spanish (0.78%), Slovenian (0.17%), etc.

Although the data collection approach developed above could help to figure out the evolution pathway of accessibility-related research field, there are two limitations in the resulting dataset. Firstly, due to limitations of the selected query database, this review mainly focused on journal articles in English, we have to accept that some contributions (e.g. sourced from book chapters and non-English publications) might be missing. Secondly, the output dataset only represents a comprehensive overview of the academic state of the research filed of accessibility a few years ago, since there is considerable delay for academic publications to gain measurable influence (i.e. it takes time for people to read new work, take notice, and publish their own work that cite these new work).

### 3. Key findings

#### 3.1. Overview of the historical and geographical trends

Figure 1 represents the historical trends of annual published papers number and total citations frequency between 2000 and 2019. According to Figure 1, the number of annual publications kept increasing during the past two decades: in the early 2000s, the publication number kept relatively stable; it started to increase from the late 2000s, followed by a sharper growth in the 2010s. As a result, there is a total of 1600% growth during the past two decades, outrunning the average number of 520% in the field of transportation. While, annual citations number increased with some fluctuations during the 2000s and early 2010s, followed by a sharp decrease since the year 2012. This is expected because there is a considerable delay for academic publications to gain measurable influence, as it takes time for others to read new studies, take notice and cite these new studies to publish their own work (van Meeteren et al., 2016). Thus, studies that have been published in most recent years are naturally have a lower number of citations.

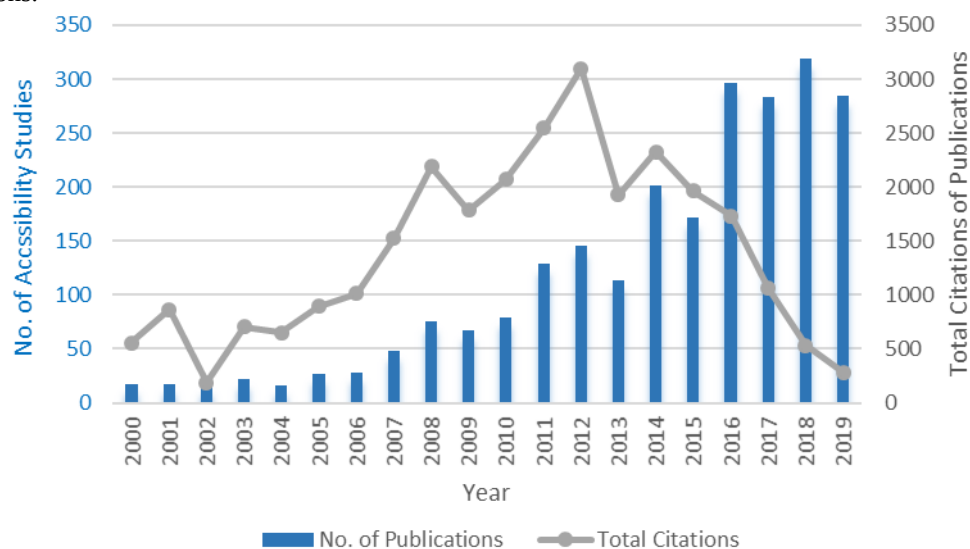


Figure 1: The number of publications and total citations from 2000 to 2019

Figure 2 illustrates major contributions of the top 10 countries to the accessibility-related literature, rank-ordered by the number of accessibility-related publications. The national property of one paper depends on the full address of its first author when multiple authors come from different countries. As shown in Figure 2, USA kept its leading position in the research area of accessibility, accounting for more than quarter of the total publications during the past two decades. Besides USA, other important contributors include UK, Canada, China, Netherlands, Australia, Spain, Italy, Sweden, Germany, mainly located in North America and Europe. Consequently, those top 10 countries contributed to over 70% of total publications and over 80% of total citations between 2000 and 2019.

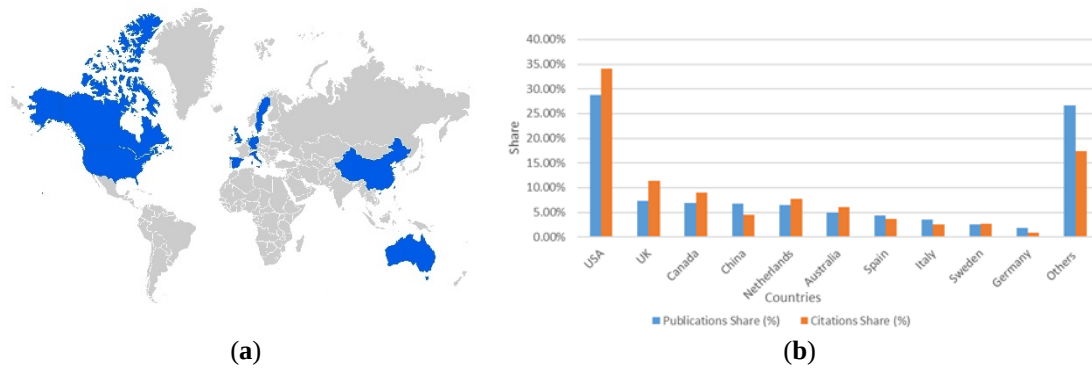


Figure 2: (a) Geographic distribution of top 10 leading countries during 2000 and 2019; (b) Publication share and citation share of top 10 leading countries during 2000 and 2019.

Figure 3 traces through the annual publication number as well as relative share of the top 5 most important contributors, they are USA, UK, Canada, China and Netherlands. It illustrates that although USA kept a shape increasing trend in paper publications and left other countries behind so far away, it continued to lose its annual publications share. This is because there is an increasing geographic spread along with the growth spurt of research publications on the topic of accessibility. For example, only 4 countries contributed to in total 16 published papers in 2002 (USA, 12 papers; UK, 2 papers; Australia, 1 paper; France, 1 paper); while in 2019, the numbers are 46 countries and 283 papers, including China as the top 2 productive country with 63 papers (or 22.26% share). This remarkable rise of Chinese contributions in accessibility-related research mainly comes from its increasingly-large academic labour market and central government’s willingness to invest in science and technology (Derudder et al., 2019).

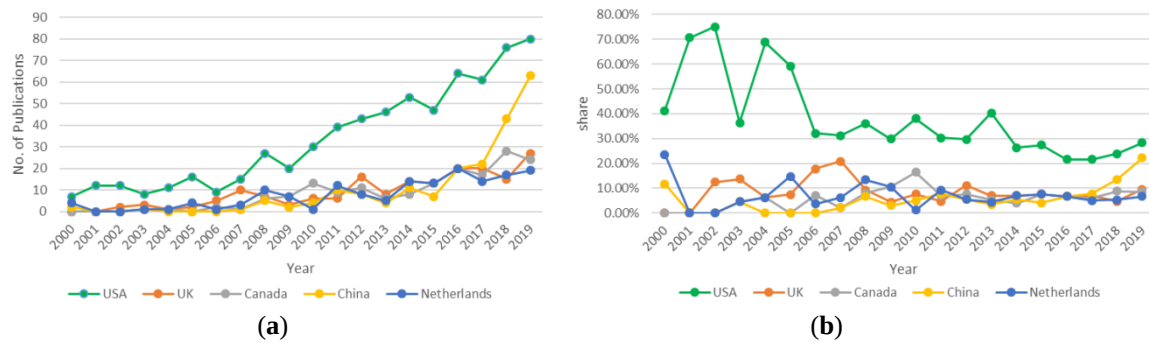


Figure 3: (a) No. of publications of top 5 leading countries from 2000 to 2019; (b) Publication share of top 5 leading countries from 2000 to 2019.

### 3.2. Key journals in accessibility-related research

The collected 2,356 articles were published in 230 journals indexed in WoS, which indicates the diversified publication distribution as well as the broad interests on the research area of accessibility. This section selected and investigated 10 journals which published the greatest volume of accessibility-related research during the past two decades (from 2000 to 2019), as well as during the recent decade (from 2010 to 2019). Table 1 presents a rank-ordered overview of those journals by total publications, total citations, and percentage of publications on accessibility in journal’s total publications. The reason for highlighting a close-up for the recent decade from 2010 is to avoid the errors brought by the delay for academic publications to gain measurable influence (e.g. number of citations is a function of time since the paper published).

Among all journals, Journal of Transport Geography (JTG) tops the list, which published 16.70% of total publications on accessibility and gained 26.49% of total citations during the past two decades. Furthermore, 18.98% of papers published by JTG are accessibility-related. Transportation Research Record (TRR) comes close to JTG in terms of total publications on accessibility, accounting for 14.54%

of total publications on accessibility during the past two decades. As the journal of the Transportation Research Board (TRB) which holds a highly influential annual conference, TRR is published throughout the year and consists of extensive collections of papers on various subject areas (Derudder et al., 2019). For example, over 15,000 papers have been published during the past two decades, dwarfing all other journals involved in this review. As a consequence, accessibility-related publications only account for 2.12% of the total publications in TRR, and we believe it is fair to state that TRR is a repository of state-of-the-art research on general transportation, in which accessibility is just one of them. In terms of the percentage of publications on accessibility in journal's total publications, Journal of Transport and Land Use (JTLU) comes close to JTG: approximately 1 in 5 papers published in JTLU is accessibility-related. As a small-size and new journal, JTLU naturally have a lower number of total publications and total citations. But its high percentage of publications on accessibility in journal's total publications indicates that JTLU is a key journal in the field of accessibility research, especially after the formation of JTLU, World Society of Transport and Land Use Research (WSTLUR), and the NECTAR group.

Table 1: Top 10 leading journals in accessibility-related research from 2000 to 2019 as well as from 2010 to 2019

Journal Name	All time (2000-2019)			After 2010 (2010-2019)		
	TP No. (rank) <sup>1</sup>	TC No. (rank) <sup>2</sup>	% of journal's publications <sup>3</sup>	TP No. (rank)	TC No. (rank)	% of journal's publications
Journal of Transport Geography	370 (1)	7391 (1)	18.98%	347 (1)	6088 (1)	20.33%
Transportation Research Record	322 (2)	1982 (4)	2.12%	264 (2)	1322 (4)	2.81%
Transportation Research Part A: Policy and Practice	149 (3)	3633 (2)	6.16%	115 (3)	1709 (2)	6.23%
Transport Policy	124 (4)	2615 (3)	8.09%	108 (4)	1518 (3)	8.30%
Transportation	79 (5)	1492 (5)	7.90%	66 (5)	910 (5)	9.55%
International Journal of Sustainable Transportation	55 (6)	786 (8)	10.28%	51 (6)	423 (7)	10.63%
Journal of Transport and Land Use	50 (7)	375 (14)	19.01%	50 (7)	375 (10)	19.01%
Research in Transportation Economics	47 (8)	128 (23)	8.56%	47 (8)	128 (19)	8.56%
Journal of Transport & Health	46 (9)	203 (19)	4.85%	46 (9)	203 (15)	4.85%
Transportation Research Part D: Transport and Environment	45 (10)	970 (7)	2.28%	40 (10)	264 (12)	2.43%
<b>Total</b>	<b>1287</b>	<b>19575</b>	<b>-</b>	<b>1134</b>	<b>12938</b>	<b>-</b>

<sup>1</sup>The total number of publications in that journal and its rank;

<sup>2</sup>The total number of citations of publications in that journal and its rank;

<sup>3</sup>The percentage of publications on accessibility in that journal.

### 3.3. Key institutions in accessibility-related research

Table 2 lists top 10 institutional contributors to accessibility research during the past two decades and during the recent decade, rank-ordered by the number of accessibility-related publications. Most of them are from top 10 leading countries, except for University of Ghent in Belgium. Among all 850 institutions traced in this review, Delft University of Technology is the largest provider of accessibility research with the largest publications share (1.94%) and third largest total citations share (2.57%) from

2000 to 2019. Tongji University is the only institution located in developing country in the list, but its total citations share only accounts for 0.11%, much lower compared with other European institutions with the same number of published articles, such as Complutense University of Madrid, Spain (1.30%), University of Ghent, Belgium (1.35%), and Eindhoven University of Technology, Netherlands (0.38%). This is partly because accessibility-related research attracted wide interests in China is much later than other American and European countries, and most papers were published during the 2010s (among 18 publications, 17 of them are published after 2010).

Table 2: Top 10 leading institutions in accessibility-related research from 2000 to 2019 as well as from 2010 to 2019

All time (2000-2019)				After 2010 (2010-2019)			
Institutions	Country	TP No. (rank) <sup>1</sup>	TC No. (rank) <sup>2</sup>	Institutions	Country	TP No. (rank)	TC No. (rank)
Delft University of Technology	Netherlands	43 (1)	716 (3)	Delft University of Technology	Netherlands	32 (1)	417 (3)
University of Minnesota	USA	35 (2)	669 (5)	McGill University	Canada	29 (2)	386 (4)
McGill University	Canada	30 (3)	391 (9)	University of Minnesota	USA	28 (3)	494 (2)
University of Toronto	Canada	29 (4)	369 (11)	University of Toronto	Canada	23 (4)	227 (11)
University College London	UK	24 (5)	247 (21)	University College London	UK	20 (5)	192 (14)
University of Sydney	Australia	22 (6)	346 (15)	University of Sydney	Australia	19 (6)	125 (28)
Complutense University of Madrid	Spain	18 (7)	362 (10)	Complutense University of Madrid	Spain	18 (7)	362 (5)
University of Ghent	Belgium	18 (7)	377 (13)	Tongji University	China	17 (8)	31 (137)
Eindhoven University of Technology	Netherlands	18 (7)	106 (61)	Eindhoven University of Technology	Netherlands	17 (8)	91 (51)
Tongji University	China	18 (7)	31 (180)	Technical University of Madrid	Spain	16 (9)	201 (13)
<b>Total</b>	-	<b>255</b>	<b>3614</b>	<b>Total</b>	-	<b>219</b>	<b>2526</b>

<sup>1</sup>The total number of publications in that institution and its rank;

<sup>2</sup>The total number of citations of publications in that institution and its rank.

### 3.4. Keywords' characteristics

The selected 2,356 articles in total provides 7,680 keywords, on average 4 keywords per article. In order to avoid the problem of duplication, 7,680 keywords were categorized into 4,513 groups, and their corresponding frequencies is illustrated in Figure 4. 3,650 keywords only appear once, accounting for 80.88% of entire 4,513 categories of keywords, indicating the diversified studies in the field of accessibility research. Besides “accessibility” (438 times), other keywords with more than 50 times appearance include “transportation planning” (124), “social equity” (119), “land use” (110), “travel behavior” (95), “walkability” (66) and “GIS technology” (50).



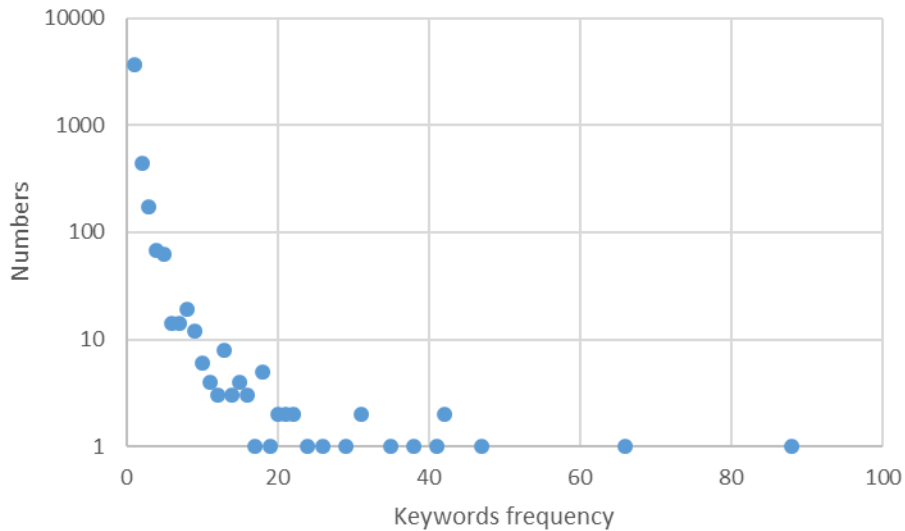


Figure 4: Frequency of keywords

In order to improve the efficiency of keywords analysis, keywords with spelling variants (such as “high-speed rail” and “high speed rail”, “GIS” and “Geographic Information System”) or with similar meanings (such as “active travel” and “active transportation”, “public transport” and “public transit”) were grouped, thus 1204 categories were left. Then these 1204 categories were further classified into three categories based on research objective, methods, and applications (see Figure 5). In terms of research objective, accessibility-based research mainly focuses on public transportation (such as bus, high speed rail, bus rapid transit, subway, etc.) and active transportation (i.e. walking and cycling) for specific population groups (such as elderly, commuters, disability, low-income, etc.). As shown in Figure 5, over half of keywords refer to the corresponding applications of accessibility, such as in the field of transportation network evaluation, planning and optimization, passengers’ mode choice decision, and further social development (consist of social equity, land use, sustainability, and transit-oriented development). Undoubtedly, GIS technology is the most traditional and most popular tool in context of research methods applied in the accessibility research. Other methods include survey-based approach (econometric analysis) and economic-based approach (cost-benefit analysis).

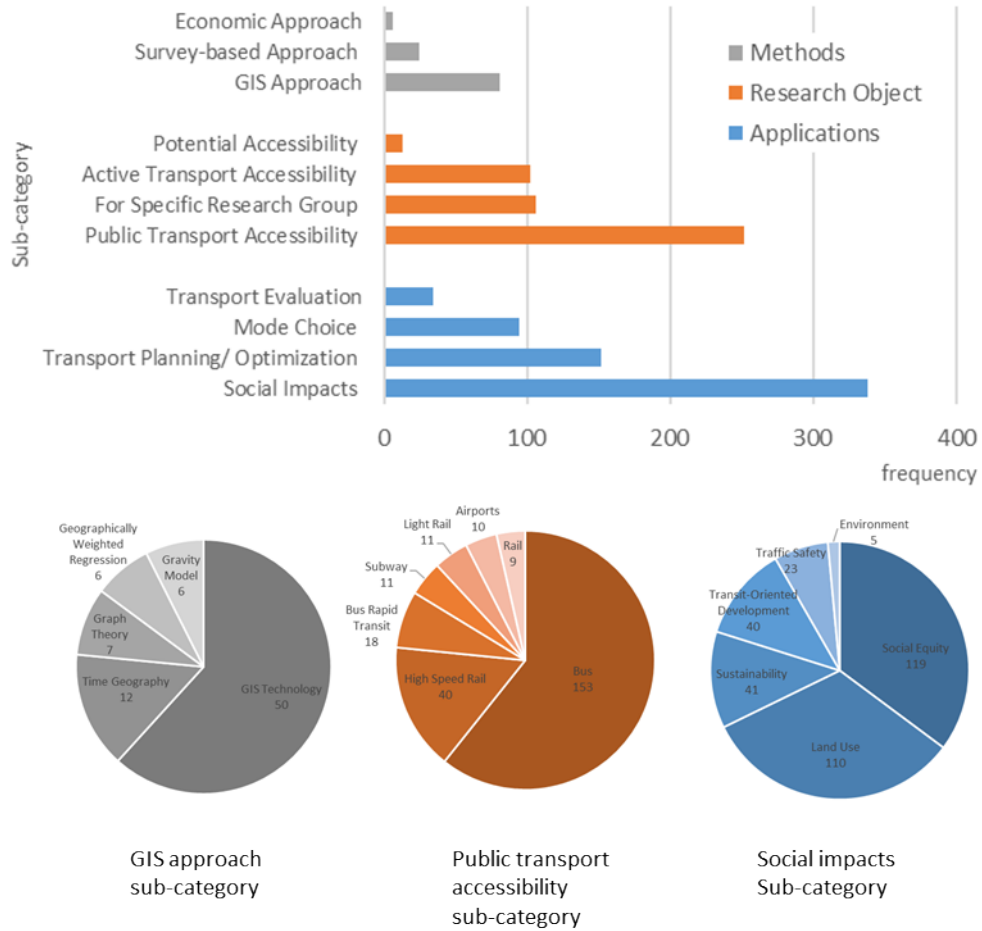


Figure 5: The classifications of keywords

### 3.5. Citation network analysis

By applying the citation network analysis capability of VOSviewer, the citation network was visualized, as shown in Figure 6. A node (circle) refers to one article, and the size of the node is determined by its citation number. Only the articles with citation number over 25 times were labeled in Figure 6, showing as the first author and the publication year only. The link (line) between the nodes refers the direct citation flow between these two articles. All the articles with over 25 times of citations were grouped into six clusters, and each of them were colored and were shaded by oblique dotted ovals, listed as follows:

- Cluster 1 Social Equity: the impact of accessibility in social equity (or social exclusion);
- Cluster 2 Build Environment: accessibility application on build environment assessment;
- Cluster 3 Travel Behavior: to explore the relationship between travel behavior and built environment;
- Cluster 4 New Accessibility Indicators: develop new accessibility indicators in the context of specific data sources, research objectives or population groups;
- Cluster 5 Investment /Project Assessment: applying accessibility indicators on investment or project assessment or evaluation;
- Cluster 6 Transportation System Evaluation: applying accessibility indicators on transportation system performance evaluation, consist of accessibility, vulnerability, resilience, efficiency and reliability.

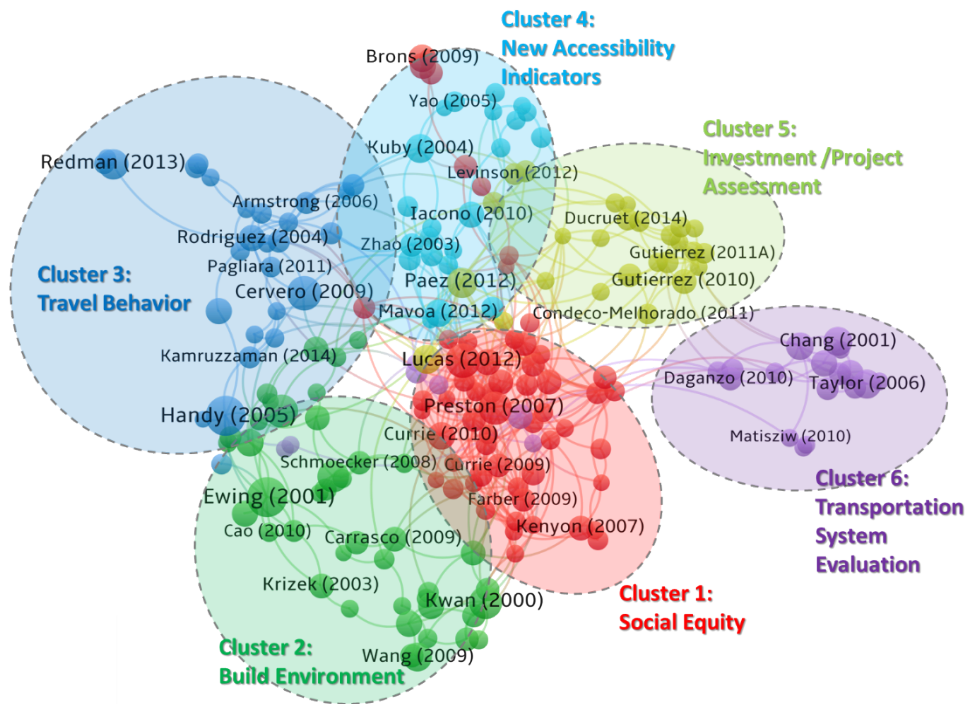


Figure 6: Citation network of publications with over 25 times of citations

Under the constraint of minimum 25 citation counts, approximately 65% of the studies displayed in Figure 6 are published before 2010, which mainly brought by the delay for academic publications to gain measurable influence. In order to overcome this limitation, studies whose average citations per year are greater than or equal to their age were selected and further analyzed in this section. For example, for papers published in 2000, their age is 20, thus only papers with more than 20 of average yearly citation number (i.e. with over 400 times of total citations so far) will be shortlisted; while for papers published in 2019, the papers with more than 1 citation meet the selection criterion. As result, a total of 701 publications were selected and over 96% of them are published after 2010. Figure 7 illustrates the citation map as well as the corresponding clusters, listed as follows:

- Cluster 1 Social Equity: similar to the cluster of social equity in Figure 6, involving accessibility measures in the process of social exclusion, social equity, and/or social justice evaluation;
- Cluster 2 Transport System Evaluation: similar to the cluster of transport system evaluation in Figure 6, mainly focus on designing new accessibility measures for evaluating the transportation systems, especially for the high-speed rail network (as the hot topic in 2010s);
- Cluster 3 Accessibility and Autonomous Vehicles (AV): as the development of AV-based research in the field of transportation, the research field of accessibility in the context of autonomous vehicles is thriving in 2010s, especially since 2015;
- Cluster 4 Travel Behavior: is a combination of build environment cluster and travel behavior cluster in Figure 6, and to explore the relationship between travel behavior and built environment (including accessibility as one of key factors);
- Cluster 5 New Accessibility Indicators: similar to the cluster of new accessibility indicators in Figure 6, to develop new accessibility indicators based on the high spatial-temporal resolutions data from the increasing development of Information and Communication Technologies (ICT) during the past decade.

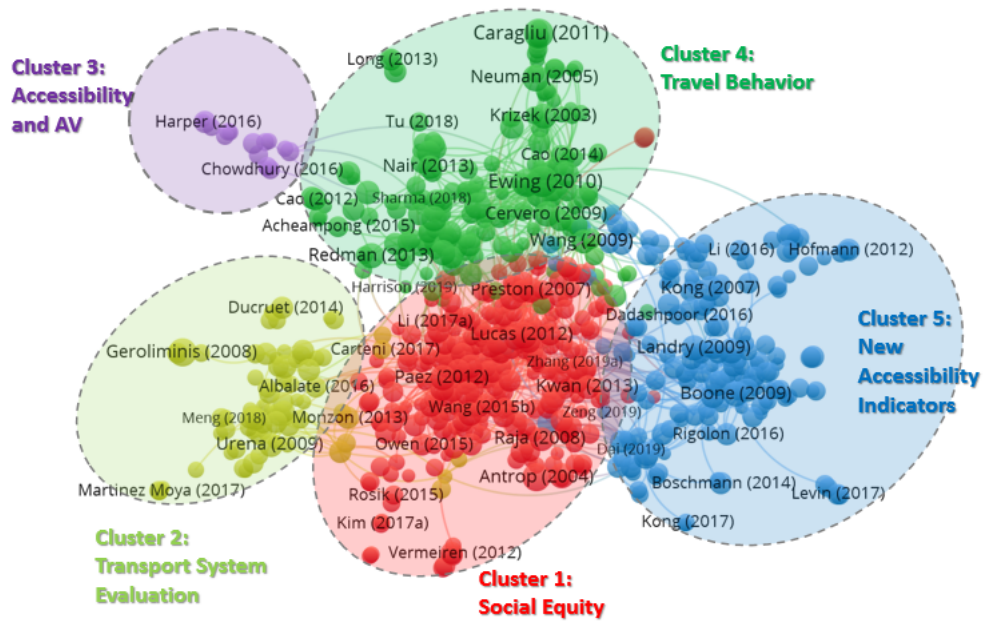


Figure 7: Citation network of publications whose average citations per year are greater than or equal to their age

### 3.6. Qualitative content analysis

In order to present a complete picture on the research filed of accessibility, the content analysis was based on the top 3 most cited article in each year during the period of 2000 and 2019. The selected 60 publications were firstly grouped based on article type they belong to: regular papers (49 articles, account for 81.67%) and review papers (11 articles, 18.33%). Then the group of regular papers was further categorized into two groups based on differing research objectives: new accessibility indicators development (15 papers) and accessibility-based application implementations (34 papers). Each category of the yearly most cited articles will be described below in turn, and Table 3-5 will list their details at the end of this section.

Compared with regular papers, reviews always received more citations because they discuss and summarize results from recent literature on the corresponding topics. Table 3 lists the most cited reviews on the topic of accessibility during the past two decades, in total 11 papers. Using qualitative systematic strategy, those reviews have provided valuable references that help to clarify the current state of accessibility-related research field, and most of them were published in 2010s. In terms of research objectives, the available reviews are largely application-driven, such as accessibility implementation in demand modelling (Ewing and Cervero, 2001), policy making (Marsden, 2006), travel behavior analysis (Redman et al., 2013, Yue et al., 2014), service area for health care facilities (Neutens, 2015), vulnerability and resilience of transport systems examination (Mattsson and Jenelius, 2015), transportation-related social exclusion measurement (Pereira et al., 2017), smart city and smart urban mobility (Lyons, 2018).

Table 3: The most cited reviews on accessibility from 2000 to 2019

<b>Reviews</b>	<b>Research objective</b>
Ewing and Cervero (2001)	a review of studies on accessibility and demand modelling
Marsden (2006)	a review of studies on accessibility and parking policies
Neutens et al. (2011)	a review of time-space accessibility studies
Redman et al. (2013)	a review of studies on accessibility and travel mode choice (promoting the shift from private cars to PT and active transport)
Yue et al. (2014)	a review of accessibility and travel behavior studies categorized by trajectory data types
Ducruet and Beauguitte (2014)	a review of studies on accessibility and complex network research
Mattsson and Jenelius (2015)	a review of studies on accessibility and vulnerability of transport systems
Neutens (2015)	a review of studies on health-care accessibility
van Wee (2016)	main challenges in the area of accessibility research in the future
Pereira et al. (2017)	a review of studies on accessibility and social equity
Lyons (2018)	a review of studies on accessibility and smart mobility

In regard of designing new accessibility indicators (see Table 4), the available studies mainly focus on designing new accessibility measures for public transport (Mavoa et al., 2012) and active transport (Iacono et al., 2010). For example, studies by Keijer and Rietveld (2000), Givoni and Rietveld (2007) and Brons et al. (2009) developed accessibility measures to evaluate the accessibility levels to railway stations, and provided potential recommendations on attracting potential passengers based on the output accessibility assessment results. Nair et al. (2013) made a quantitative analysis of one large-scale bicycle sharing system in Paris called Velib', and designed an accessibility indicator to evaluate the connection between Velib' and public transport networks.

When tracing the evolution characteristics of the most cited studies on new accessibility indicators development, the definition of accessibility was involved as one of variables in designing ex ante or ex post evaluation indicators for candidate policy plans during the early 2000s (Hensher and Ton, 2002; Ewing et al., 2003). This followed the continuing trend from the past two decades to develop more complex and disaggregated accessibility measures, such as space-time accessibility (Kwan, 2000; Polzin et al., 2002), virtual accessibility (Golob and Regan, 2001), positive and normative accessibility (Páez et al., 2012), and equitable accessibility (Lucas et al., 2016). Furthermore, recent public availability of navigation system and social media data give room for a growing field of research on temporal dynamics in accessibility. For instance, Moya-Gómez et al. (2018) developed a temporal dynamic approach to analyze urban accessibility levels considering both the performance of the transport network and the attractiveness of the destinations using data from TomTom and Twitter.

Table 4: Most cited papers on new accessibility indicators development from 2000 to 2019

Category	Examples
<i>Categorized by Travel Modes</i>	
<ul style="list-style-type: none"> <li>for public transport</li> <li>for active transport</li> </ul>	Keijer and Rietveld (2000), Givoni and Rietveld (2007), Brons et al. (2009), Mavoa et al. (2012) Iacono et al. (2010), Nair et al. (2013)
<i>Categorized by Specific Dimension</i>	
<ul style="list-style-type: none"> <li>space-time accessibility</li> <li>virtual accessibility</li> <li>positive and normative accessibility</li> <li>equitable accessibility</li> </ul>	Kwan (2000), Polzin et al. (2002) Golob and Regan (2001) Páez et al. (2012) Lucas et al. (2016)
<i>New Technology</i>	
<ul style="list-style-type: none"> <li>based on big data</li> </ul>	Moya-Gomez et al. (2018) Xiao et al. (2019)

Traditionally the accessibility literature focus on designing new measures for specific research objectives and spatial context, and recently there is an increasing interest in accessibility-based applications. It therefore is unsurprising that the papers of this category account for 56.67% of the in total 60 yearly most cited papers. In terms of corresponding accessibility-based applications, available research mainly concentrates on the topics of transport network performance measurement, demand modelling, vulnerability and resilience of transport systems, social exclusion/equity, travel behavior, and autonomous vehicles, listed as follows (see Table 5):

- Transport networks performance measurement: as one of the major applications, accessibility has been widely adopted in the transportation planning field, and available research focus on using accessibility as one of indicators for evaluating the performance of transportation systems (Bertolini et al., 2005; Tyrinopoulos and Antoniou, 2008).
- Demand modelling: accessibility, as one of spatial attributes, was widely considered in demand modelling and forecasting (Golob, 2000; Bhat and Zhao, 2002; Yao and Morikawa, 2005; Hymel et al., 2010).
- Vulnerability and resilience of transport systems: a growing number of accessibility studies is examining the vulnerability and resilience of transport systems to sudden disruptions contrasting the mainstream of research examining accessibility under ‘normal’ circumstances. In this issue, Taylor et al. (2006) and Chen et al. (2007) developed assessment frameworks to evaluate the vulnerability and resilience of transport systems using the concept of accessibility, while Chang and Nojima (2001) and Sohn (2006) applied the developed frameworks in real-world case studies (1995 Hyogoken-Nanbu earthquake and Maryland flood respectively). Moreover, the relationship between vulnerability and accessibility was analyzed by Reggiani et al. (2015), and they concluded that the relationship seems not strictly linear.
- Social exclusion/equity: currently another hot topic is to measure the social dimension of transport using accessibility concepts, such as involving accessibility measures in the process of social exclusion, social equity, and/or social justice evaluation (Preston and Rajé, 2007), analyzing spatial gaps in public transport provision for people who are socially disadvantaged (Currie, 2010; Su et al., 2019), and summarized some evidences and recommendations from some well-known successful real-world case studies (Lucas, 2012; Foth et al., 2013).
- Travel behavior: exploring the relationship between travel behavior and built environment (including the factor of accessibility) is a traditional research direction of the accessibility-based applications (Krzizek, 2003; Handy et al., 2005; Chen et al., 2008; Cheng et al., 2019), and results vary spatially (urban v.s. rural) and socially (e.g. age (Alsnih and Hensher, 2003), gender (Rhodes and Pivik, 2011), commuters (Wang and Chai, 2009), low-income (Morency et al., 2011), etc.). In addition, recent studies start to focus on using accessibility concepts in mode choice analysis for promoting the usage of public transport and active transport (Rodriguez and Joo, 2004; Cervero et

al., 2009; Kuby et al., 2004; Zhang et al., 2017). In the era of data abundance, there is also a growing attention for actual measures of travel behavior as perceived by the travelers, also called subjective accessibility (Jarv et al., 2014).

- Autonomous vehicles: as a totally new travel mode, autonomous vehicle is a revolution in the field of transportation, and certainly will and should bring huge changes for the whole transport network, including the current accessibility situation. Therefore, the research field of accessibility in the context of autonomous vehicles is thriving. For example, Harper et al. (2016) forecasted the potential increases in travel in a fully automated vehicle environment due to an increase in mobility from the non-driving and senior populations and people with travel-restrictive medical conditions. Meyer et al. (2017) simulated the impact of autonomous vehicles on accessibility of the Swiss municipalities using the Swiss national transport model.

Table 5: Most cited papers on accessibility-based application implementations from 2000 to 2019

Category	Examples
<i>Transport Network Performance Assessment</i>	Bertolini et al. (2005), Tyrinopoulos and Antoniou (2008)
<i>Accessibility and Demand Modelling</i>	Golob (2000), Bhat and Zhao (2002), Yao and Morikawa (2005), Hymel et al. (2010)
<i>Accessibility and Vulnerability</i>	
<ul style="list-style-type: none"> <li>• assessment frameworks of vulnerability</li> <li>• linkage between vulnerability and accessibility</li> <li>• real world case studies</li> </ul>	Taylor et al. (2006), Anthony et al. (2007) Reggiani et al. (2015) Chang and Nojima (2001), Sohn (2006)
<i>Accessibility and Social Equity</i>	
<ul style="list-style-type: none"> <li>• assessment framework of social equity</li> <li>• public/ active transport accessibility and social equity</li> <li>• real world case studies</li> </ul>	Preston and Rajé (2007) Currie (2010), Su et al. (2019) Lucas (2012), Foth et al. (2013)
<i>Accessibility and Travel Behavior</i>	
<ul style="list-style-type: none"> <li>• general relationship of travel behavior and built environment (including the factor of accessibility)</li> <li>• for specific population groups: e.g. age, gender elderly, low-income people and single-parent household, commuters, etc.</li> <li>• mode choice analysis: aim to promote the usage of PT and active transport by improving accessibility levels</li> <li>• actual measures of travel behavior based on big data</li> </ul>	Krizek (2003), Handy et al. (2005), Chen et al. (2008), Cheng et al. (2019) Alsnih and Hensher (2003), Wang and Chai (2009), Rhodes and Pivik (2011), Morency et al. (2011) Rodriguez and Joo (2004), Kuby et al. (2004), Cervero et al. (2009), Zhang et al. (2017) Jarv et al. (2014)
<i>Accessibility and Autonomous Vehicles</i>	Harper et al. (2016), Meyer et al. (2017)

#### 4. Implications and future research directions

As mentioned in the methods section, bibliometric analysis could serve broader objectives, provide a potential to trace the research trends and popular issues, and identify possible spaces of future progress and engagement. This final section therefore aims to highlight some priorities for further research, categorized by two sub-sections: new accessibility indicators development and accessibility-based applications. This is because current accessibility studies mainly can be divided into those two categories according to the results output from the keywords' distribution and citation network analysis (in Section 3.4 and 3.5).

##### 4.1. New trends of accessibility indicators development

In regard of designing accessibility indicators, research objectives range from defining the concept, translating definitions to indicators, discussing pros and cons of indicators, developing methods to calculate indicators, and applying indicators in real world case studies (van Wee, 2016). According to the analysis from Section 3.5 and 3.6, besides traditional place-based and individual-based measures, recent literature added further dimensions to the definition of accessibility by introducing subsidiary notions, such as space-time accessibility (Kwan, 2000; Polzin et al., 2002), virtual accessibility (Golob and Regan, 2001), positive and normative accessibility (Páez et al., 2012), and equitable accessibility (Lucas et al., 2016). As the increasing development of Information and Communication Technologies (ICT), various sources of big data are generated and innumerable definitions, approaches and models of accessibility with increasingly higher spatial and temporal resolutions are available in literature. Navigation companies such as TomTom (e.g. Moya-Gómez and García-Palomares, 2015; Moya-Gómez et al., 2018), Inrix (e.g. Sweet et al., 2015), websites like Google Maps (e.g. García-Albertos et al., 2019), and the public availability of generalized transit feed specification (GTFS) data and automatic vehicle location (AVL) data from transit authorities (e.g. Farber et al., 2014; Fransen et al., 2015; Boisjoly and El-Geneidy, 2016; Fayyaz et al., 2017; Järv et al., 2018) open up a growing field of research on time-of-day variations in private and public transit accessibility (Geurs et al., 2015).

Another observation revealed in Figure 6 and 7 is that the studies of new accessibility indicators development are being cited widely by clusters of travel behavior and social equity. According to the definition, accessibility can be viewed as the availability of opportunities which is a combination of transport network layout and schedules (Handley et al., 2019). In this view, majority of traditional accessibility models typically pay no attention to traveler behavior (Salomon and Mokhtarian, 1998). However, the passenger travel behavior plays a vital role in determining transit accessibility and availability, and increasing attention has been paid in the literature to improve the conventional accessibility measures by incorporating human mobility patterns for specific individual profiles, such as for aging population (Horner et al., 2015), commuters (Wang and Chai, 2009), low-income (Morency et al., 2011), etc. Taking traveler behavior into account facilitates understanding of diverse transport user groups' perceptions of the transport network, helps researchers and practitioners find optimal policies for improving accessibility for different groups of people, thus could improve social equity, urban livability and therefore local economics through the transport network (Malekzadeh and Chung, 2019).

Although current literature has provided a diversity of accessibility indicators, it lacks clear demarcations of which is the most proper measure for specific research objective and spatial context. Even for the same research area, different accessibility approaches and specifications (e.g. travel impedance estimation functions) can lead to very different conclusions. Thus, the future research direction would be to focus on comparative accessibility studies to sort out which approaches and model specifications are appropriate for which study purpose and spatial context (Geurs et al., 2015). Furthermore, in recent years the increasing availability of more detailed and disaggregated data has aligned with a growing concern for considering spatial-temporal constraints in accessibility to provide new methods and measures for accessibility analysis. Nevertheless, to date very little attention has been paid to systematically analyze the impact of the selection of specific spatial-temporal resolutions on accessibility results. It therefore is important to investigate whether the results and conclusions being drawn at high spatial-temporal resolutions are actually different than those that would be drawn in more simplified accessibility models, and to provide guidance to researchers and practitioners on the selection of appropriate spatial-temporal resolutions in accessibility studies (Stepniak et al., 2019).

#### *4.2. New trends of accessibility-based applications*

In terms of corresponding accessibility-based applications, current literature mainly concentrates on the topics of social equity, transportation network planning, travel behavior and mode choice decision, etc. Among them, studies on social equity in transport accessibility appear to play a central role, as shown by their locations at the heart of Figure 6 and 7, as they are being cited widely by most other clusters. Those studies consider accessibility as a necessary, though not sufficient, condition for the expansion of people's freedom of choice and promotion of equality of opportunities in terms of employment, healthcare, education services, etc. (Pereira et al., 2017).



As one of the major applications, accessibility has been widely adopted in the transportation planning field, and available research focus on using accessibility as one of indicators for evaluating the performance of transportation systems (Cluster 6 in Figure 6 and Cluster 2 in Figure 7). As many researchers have observed, compared with other evaluation indicators (such as level of services) the accessibility levels quantify the performance of transportation networks by integrating it with land use patterns and individuals' space-time characteristics, thus could provide more accurate results in evaluating how efficient the network is and could display the detailed information on equity and distribution of the network performance (Páez, 2012).

Although the applications of accessibility on transportation network performance evaluation has been extensively researched, its inclusion in the decision process of the transportation planning is limited, the mobility-based approach still dominates (Handy 2005; Levinson and Gillen, 2005; Halden, 2011; Proffitt et al., 2015; Boisjoly and El-Geneidy, 2017). The concept of mobility is defined as the ease of movement within the transportation network. Thus, the mobility-based approach aims at minimizing travel times by increasing travel speeds and reducing travel delays, neglecting either the land use patterns or the characteristics of the passengers. In contrast, accessibility-based planning approach evaluates the ability for passengers to reach their desired activities or locations, considering four components distinguished by Geurs and van Wee (2004), including transportation, land use, individual and temporal components. However, although both the concept of accessibility and its potential for urban planning practice have long been discussed, the translation of these concepts into usable planning instruments is still fairly limited. Only a few studies on the accessibility-based network design problem have been found in the literature, due to the shortage of appropriate mathematical methods for addressing accessibility and its measurement (Santos et al., 2008; Di et al., 2018). Therefore, in the further study high suitable and practical frameworks should be developed to effectively involve accessibility analysis and instruments alongside with the whole process of transportation planning.

Another key observation illustrated in Figure 7 is that investigating the impacts of autonomous vehicles (AVs) on accessibility has been one of hotspots since the year of 2015 along with the rapid development of the research filed of AVs (Cluster 3 in Figure 7). As AVs are still under development and gathering empirical data for further analysis is not yet possible, existing studies mainly applied models and simulations to assess their impact on travel behavior and accessibility, such as Childress et al. (2015), Fagnant and Kockelman (2015), Harper et al. (2016), Meyer et al. (2017), Liu et al. (2017), Soteropoulos et al. (2019) etc. That is the reason why these studies located close to the cluster of travel behavior (Cluster 4) in the citation network map in Figure 7. The results output from available research show that AVs could substantially increase the overall accessibility levels although could lead to a more dispersed urban growth pattern. However, the output results are highly sensitive to model assumptions (e.g. whether considering additional travel due to new customer groups and empty riders of AVs or not), the category of AVs (e.g. in a fully AV environment v.s. AVs and manual vehicles mix environment, private AVs v.s. shared AVs fleet), and for specific population groups (e.g. for people with travel-restrictive medical conditions). Given that many aspects of future AVs are still unclear, the estimation of those accessibility impacts should steadily be refined as more information on the actual implementations and travel behavior impacts become available (Meyer et al., 2017; Soteropoulos et al., 2019).

## 5. Conclusions

Accessibility is a key concept in the field of transportation, as well as geography, public health, spatial economics and so on. There is a rich amount of reviews available on this topic which concentrate on certain perspectives and none of them presents a comprehensive and quantitative overview on accessibility-related publications. To fill this gap, this study reviewed two decades of publications (during 2000-2019) drawn from WoS, and aims to figure out the evolution pathway of accessibility related studies so that future research directions can be recognized. By employing the bibliometric analysis, this study provides the potential to trace historical and geographic trends at global level, covering leading journals and institutions, keywords characteristics, citation network analysis, and a qualitative review of the most influential papers (defined as top 3 most cited article in each year during the period of 2000 and 2019).

From the overview of the literature involved in this review, there is an increasing geographic spread along with the growth spurt of research publications on the topic of accessibility. The number of annual publication number increased by 1600% during the past two decades, outrunning the average number of 520% in the field of transportation. In 2019, in total 283 papers traced in this review are from 46 countries (the numbers are 17 and 7 respectively in 2000), including China as the top 2 productive country with 63 papers (or 22.26% share). This indicates that although much delay compared with other American and European countries (such as USA, UK, Canada), more countries, especially developing countries such as China, have started to pay more attentions in the research field of accessibility.

According to the keywords' distribution and the results output from the citation network analysis, current accessibility studies mainly can be divided into two categories: new indicators development and accessibility-based applications. The new trends of accessibility indicators development include to add further dimensions to the definition of accessibility by introducing subsidiary notions (e.g. space-time accessibility, positive accessibility and normative accessibility), to measure dynamic accessibility levels with increasingly higher spatial and temporal resolutions based on big data sources, and to consider human mobility patterns to output 'positive' measurement results. The future research direction would be to focus on comparative accessibility studies to sort out which approaches and model specifications (such as the selection of travel impedance estimation functions and spatial-temporal resolutions) are appropriate for which study purpose and spatial context. In regards of corresponding accessibility-based applications, current literature mainly concentrates on the topics of social equity, transportation network planning, travel behavior and mode choice decision, etc. There is another hot topic emerging since 2015 which investigates the impacts of AVs on accessibility along with the rapid development of the research filed of AVs. Given that many aspects of future AVs are still unclear, the estimation of those accessibility impacts should steadily be refined as more information on the actual implementations and travel behavior impacts become available.

In summary, this review summaries current progress and hot points and proposes future directions related with accessibility. It is hoped the output results could offer robust and holistic background knowledge for graduate students and researchers new to accessibility research, and could benefit researchers engaging in this field to sharpen their own future research directions based on the evolution pathway figured out in this study. The results can also provide practitioners with a greater understanding of the various types of accessibility metrics, improve their knowledge on how to generate such metrics, and help them to identify the most appropriate practice for their specific situation.

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