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Mapping intellectual structures and dynamics of transport geography research: a scientometric overview from 1982 to 2014

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Abstract To date, less care has been taken to quantitatively visualize the intellectual evolution of transport geography research than to qualitatively review this field. Based on big-data literature from the Thomson Reuters Web of Science as well as scientometric mapping analysis, this important research topic is analyzed by techniques from informetric domains to detect its developmental landscape. After data reduction and clean-up, 4840 articles published from 1982 to 2014 are identified on which two network analyses are conducted: a bibliometric approach (i.e. co-occurrence and co-citation network) and a complex network approach utilizing C. Chen's CiteSpaceII, O. Persson's BibExcel and ESRI's ArcGIS. Results illustrate the following: (1) periods including the rise (1960–1970s), to a stagnation period (1980–1990s), to a boom (since 1990); (2) that the change of research frontiers and hot issues is either social oriented or topic oriented; (3) that its development owes a good deal to cooperative subnetworks (schools) of six academic communities—Urban Planning, Marxist Geography, Mobility Turn, New Economic Geography, Port Geography, and Time Geography; and (4) that its research methods tend to be diversified and integrated, while its research perspective is inclined to be microcosmic and oriented to social hot issues. Finally, 23 documents are identified as playing the pivotal role in its knowledge evolution as an intellectual base.

Keywords Transport geography · Intellectual structures and dynamics · Scientometric mapping · Complex network

Introduction

Transport geography, which was initially aligned with a quantitative revolution in human geography during the late 1950s and early 1960s (Goetz et al. 2009; Curl and Davison 2014), has made vibrant advances and wide circulation in major fields, as well as emergence of new methodologies (Schwanen 2016).

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Over more than half a century, the viewpoints of transport geography have been full of diversity (Schwanen 2016; Shaw and Sidaway 2011), ranging from an initial focus on spatial structure and process, spatial interaction, urban transportation, and spatial organization (Taaffe et al. 1996), to transport and economy, environment, society and policy (or planning) (Hoyle and Knowles 1999; Knowles et al. 2008; Rodrigue et al. 2013), to recent 'network analysis return' (or complex network approach) (Lin and Bai 2013; Ducruet and Lugo 2013; Gorman et al. 2007), 'critical return' (Kwan and Schwanen 1999), 'cultural turn' (Walton 2006; Attoh 2014), 'mobility turn' (or 'new mobilities paradigm') (Sheller and Urry 2006; Hall 2010; Shaw and Sidaway 2011; Shaw and Hesse 2010; Cresswell 2010, 2011, 2012, 2014; Merriman 2015a, b), and social topic or problem orientation (e.g. economic inequality, climate change and public health, c.f. Schwanen 2016).

Furthermore, its methodologies are multifold. They include traditional spatial or quantitative positivist models (i.e. gravity models, network models, selected models, and allocating models, etc.), GIS-visualization and geo-computation, and newly developed qualitative or critical approaches (i.e. behavior models, visual analysis, critical geography, new mobilities, time geography, and feminist geography, etc.) (Goetz et al. 2009). They also include overlapping multiple scales (Curl and Davison 2014; Knowles et al. 2008; Button and Reggiani 2011) ranging from global and national (i.e. global airlines and maritime shipping) (Grubesic et al. 2008; Tavasszy et al. 2011), regional and inter-urban (i.e. subnational, megaregional, megapolitan railway or road transport) (Erath et al. 2009; Wang et al. 2009), and local (i.e. urban or metropolitan road and street network) (Wang et al. 2011) to neighborhood (Hu and Wang 2015) or even to household and individual (Buliung and Kanaroglou 2006; McDonald 2008).

Despite its enhancing importance and interest, when compared with other subfields in human geography, transport geography is still regarded as a peripheral area of study (Goetz 2006; Vowles 2006; Shaw and Hesse 2010), full of questions and criticisms (Hanson 2006; Shaw and Sidaway 2011), and located in 'a quiet, some might say moribund, corner of our discipline' (Hanson 2003). This is largely owed to self-constraint from its technocratic and positivist tradition (Hall 2010) and path-dependence on its analytical frameworks of the 1960s (Hanson 2003). Consequently, some profound introspections or suggestions are further addressed, one of which needs to raise its profile (Hall 2010).

Since the first progress in transport geography research (Rimmer 1988), a limited number of its investigations have been documented as some response to the call. One path of investigation is represented by recent reports led by such authorized research groups as the Association of American Geographers (AAG) and the Royal Geographical Society (with the Institute of British Geographers) (RGS-IBG) through their international workshops or journal special issues. For instance, AAG and RGS-IBG transport research groups have recollected their sub-disciplinary achievements and identified future research agendas at their annual conferences (Goetz 2013; Jones 2012; Curl and Davison 2014; Pangbourne et al. 2015). Further published reports targeted 'new directions' (i.e. future trajectories), 'new paradigm' (i.e. 'regional mobilities') and 'new challenges' (i.e. 'global contexts') (Goetz 2006; Horner and Casas 2006; Keeling 2007, 2008, 2009; Schwanen 2016).

In the same vein, another path of investigation is recalling earlier strides of transport geographers (Knowles 1993; Taaffe and Gauthier 1994; Oliveira and Hanson 1998). As briefly described above, historical reflections and future topic challenges within transport geography research were more considerably taken for granted than its intellectual structures and evolutions. Moreover, these traditional reviews were almost qualitative or critical, which possibly leads to subjective over- or under-valuation of certain scholars' contributions, whether intentional or unintentional (Liu et al. 2015).

In the last decades, some scientometric approaches have provided new perspectives to contend with objectively and visually mapping disciplinary dynamics. They have been applied not only to a quantitative analysis of knowledge evolution laws in some bibliographies and informatics (Cobo et al. 2011; Hu et al. 2011; Shao et al. 2013; Ortega 2014; Small et al. 2014; Feng et al. 2015), but also to a structural visualization of research status and trends in other extensive fields (Liu 2013; Liu et al. 2014; Qian 2014; Fang 2015; Xie 2015; Yu 2015; Zhang et al. 2015; Zhou and Zhao 2015) including sub-geographies (i.e. regional innovation system) (cf. Lee and Su 2010; Liu et al. 2015).

For example, several geographers have implemented a scientometric approach to map the changing tides and research trends of port geography (Ng 2013; Ng and Ducruet 2014), GIS (Wei et al. 2015), vulnerability studies (Fuller and Pincetl 2014), and economic geography (He et al. 2014) in order to point out their research shortcomings and future directions. Recently, some emerging visualization techniques such as complex network (or social network) (Lee and Su 2010; Ortega 2014), computer graphics analysis (Chen et al. 2008), and zooming techniques (i.e. Google Earth, Google Maps) (cf. Leydesdorff and Persson 2010; Yu 2015) have been used to vividly created the thematic and citation landscape of research literature through visualization mapping (Börner et al. 2003; Chen and Paul 2001), which is well known to contribute to more scientific and comprehensive depiction and detection of disciplinary dynamics based on big-data literature mining.

Overall, more efforts have been made to investigate the changing landscape of geographical research in the transport domain qualitatively or critically than have been made quantitatively or visually. Its intellectual dynamics and bases have not been fully and objectively documented and imaged. For this purpose, a longitudinal and visualizing survey of its evolution was proposed through integrating scientometric mapping, complex network and GIS analyses in order to portray its intellectual landscape, to discover its structural changes, and to demonstrate its knowledge base. Its contributions are expected to be threefold. First, based on big-data tech mining from a literature data covering the period 1982–2014, it can reveal a more systematic and holistic picture of transport geography research. Second, according to empirical data and knowledge visualization, its intellectual structure and evolution may be identified objectively, rather than some subjective intervention or prior working (Liu et al. 2015). Third, by combined complex network and GIS analysis, it would provide not only a new perspective to a controversial discipline but also a more explanatory research approach, especially through geographical visualization of co-occurrence networks.

To this end, the rest of this article is organized as follows. "Methods, tools and data" section introduces the scientometric mapping approaches, data processing and main tools used in this research. "Intellectual structures" section depicts its historical changes and spatial distribution of authors and institutes, academic communities, and flagship journals by integration of CiteSpace co-citation analyses and GIS geospatial analysis. "Intellectual dynamics" section refines and monitors its intellectual evolutions such as research fronts, emerging hot issues, academic landmarks, bursting references, etc. using literature co-occurrence and co-citation analysis. Conclusions are presented in final section.

Methods, tools and data

Methods: scientometric mapping

Scientometric mapping, or bibliometric mapping (Cobo et al. 2011), is a visual technique of informatics that quantitatively displays structural and dynamic aspect of scientific research (Börner et al. 2003; Chen et al. 2010, 2012). In this research, three mapping approaches were developed: co-occurrence analysis, co-citation analysis, and geospatial analysis. The first is based on the assumption that when two items appear in the same context, they are related to same degree (Liu et al. 2015). Term co-occurrence analysis is used to explore research fronts (clusters of highly cited papers). Keyword co-occurrence analysis tends to investigate research hotspots, for which a precondition is that a set of signal words reflect the core contents of research literature (He 1999). The second approach, co-citation analysis, is based on the assumption that two references are often cited together and they are associated in some ways. This is similar to bibliographic coupling techniques for mapping intellectual connections and changes (Braam et al. 1991a, b; Chen et al. 2010, 2012; Small 1973; Kessler 1963; Cobo et al. 2011). Document or journal co-citation analysis can reveal intellectual base. Author co-citation analysis is able to uncover academic community. The third approach, geospatial analysis, is usually visualized over a worldwide or thematic map based on related spatial attributes or geolocations (i.e. national or urban distributions of authors, journals and institutes) (Batty 2003; Cobo et al. 2011).This approach focuses on collaborative network maps by co-citation analysis and community (cluster) detection (Leydesdorff and Persson 2010; Yu 2015; Small and Garfield 1985). Therefore, city- or country-based GIS mapping was introduced to visualize the geographical distributions of international collaboration networks of main authors as well as institutes.

Tools: CiteSpace, BibExcel and ArcGIS

CiteSpace, developed by Chaomei Chen (http://cluster.cis.drexel.edu/~cchen/citespace/), is a Java-based scientific visualization software that is based on the assumption that scientific knowledge itself is constantly changing (Chen 2004). It provides a multitude of network analysis: co-operative analysis of co-authors (or their institutes and countries), co-occurrence analysis of terms (or keywords and categories), and co-citation analysis of cited references (or authors and journals). BibExcel, a tool-box developed by Olle Persson (https://bibliometrie.univie.ac.at/bibexcel/), facilitates the generation of data files from Excel and the visualization of tabbed data records, especially in a geodatabase, which is a shortcoming of CiteSpace. ESRI's ArcGIS is a geographic information system for working with maps and geographic information. Its ArcMap product is available to discover geographical distribution of authors, institutes and structures of their collaborative networks. It is much more accurate than BibExcel. In order to bring into full play the advantages of these software, this study strove to detect and visualize academic communities, flagship journals, turning fronts and hotspots, and landmark conferences in transport geography using such visualization modes of CiteSpace as cluster view, time line, time zone, and burst detection (Cobo et al. 2011; Chen 2006). BibExcel was applied to mapping the geographic distributions and cooperating networks of authors, institutes and journals. Their geographical mapping was generated by integrating Google, BibExcel and ArcGIS, which included such series of data processing as cities/countries googling, address standardizing,

GPS geocoding, cities/countries coordinating, Google Map zooming and collaboration networking, and ArcGIS spatial analysis.

Data: resources and processing

Thomson Reuters's Web of Science database includes approximately 12,000 authoritative and influential journals encompassing the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI) and Arts & Humanities Citation Index (A&HCI). In this paper, the Web of Science Core Citation Database was extracted to retrieve data according to the strategy "Topics = transport* AND Document Types = (article or review) AND Languages = (English) AND Research Areas = (geography) AND Timespan = 1982–2014". A total of 7545 bibliographic records published from 1982 to 2014 were retrieved and downloaded on February 5, 2015. After a series of data preprocessing steps (removing duplicates or misspellings; cleansing of fragmentary data, i.e. proceedings, book reviews, editorials, letters, and other documents of lack of references; and network simplification, i.e. removing isolated nodes or unimportant links by CiteSpace), 4840 original research articles and reviews remained. These were further partially normalized (i.e. Salton's Cosine Index). In addition, the geolocation (cities and countries) of research authors and groups were retrieved using Google Search Engines, geocoded based on Google source (GPS coordinating), and visualized through ArcGIS and BibExcel.

Intellectual structures

Spatiotemporal distributions

Since the 1980s, transport geography has become a fast-moving interdisciplinary field, and it has received an increasing amount of attention. As shown in Fig. 1, the number of its publications is increasing year by year, as is the volume of its citations, which is consistent with the significant exponential law of $y = 9.256e^{0.1243x}$ (model-adjusted coefficient $R^2 = 0.964$). In terms of temporal variations, the number of publications has climbed

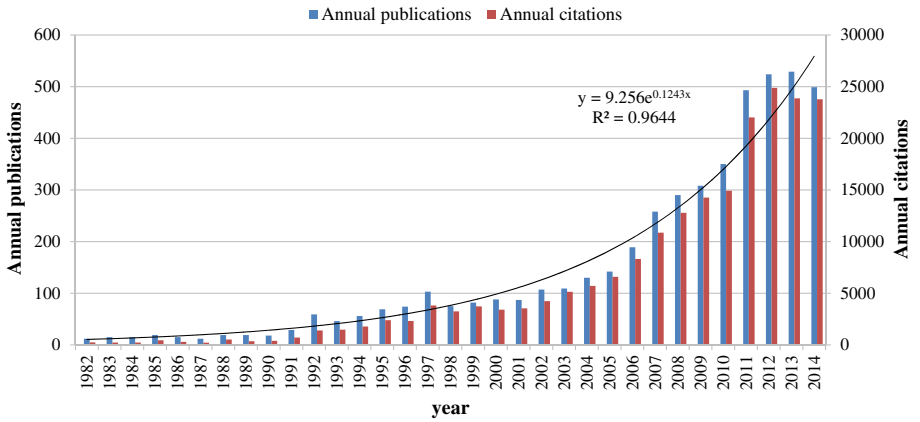

Fig. 1 Historical variations of transport geography publications and citations (1982–2014)

sharply and synchronously, multiplying by approximately 50 times and ranging from about 10 in the initial period to above 500 in the terminal period. At the same time, cited references have increased around 100 times, from 234 to 23,000. Accordingly, yearly average citations also have increased rapidly from less than 20 to 47 with rather large-level citations and high-speed growth. According to the chronological order, its historical changes have fluctuated and can be divided into four stages: a stagnant phase (1982–1990) where the number of and variations of documents were unstable and few; a takeoff phase (1991–2000) where figures climbed a bit more; a blooming phase (2000–2010) that presented an exponential mushroom growth and showed great scholarly concern; and finally a vibrant phase (2011–2014) showing stable and extensive development in scope (Fig. 1).

Using a technique integrated GoogleMap, BibExcel and ArcGIS, global distribution maps of co-authors and their institutes was generated (Fig. 2). Results suggest that there appears to be a core-peripheral structure. As clearly illustrated from images (1) and (2) in

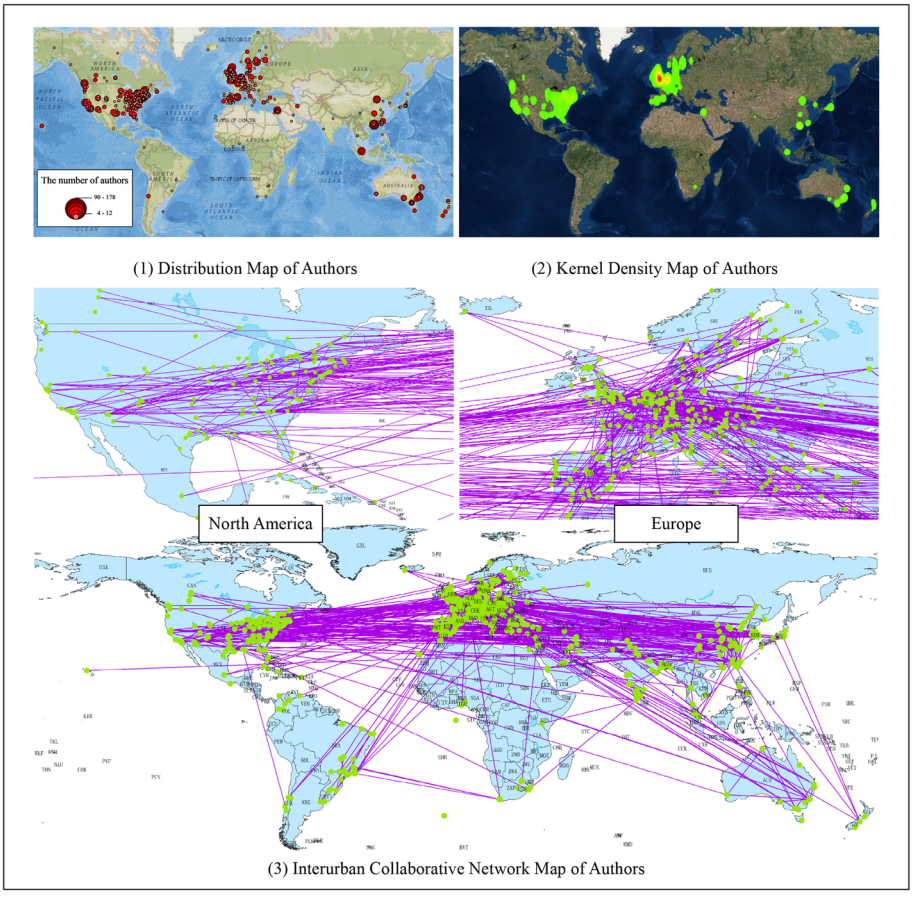

Fig. 2 Geographical distributions and networks of main authors and their organizations. **a** Global interurban distribution and collaborative network of main co-authors. **b** Global interurban distribution and collaborative network of main institutes

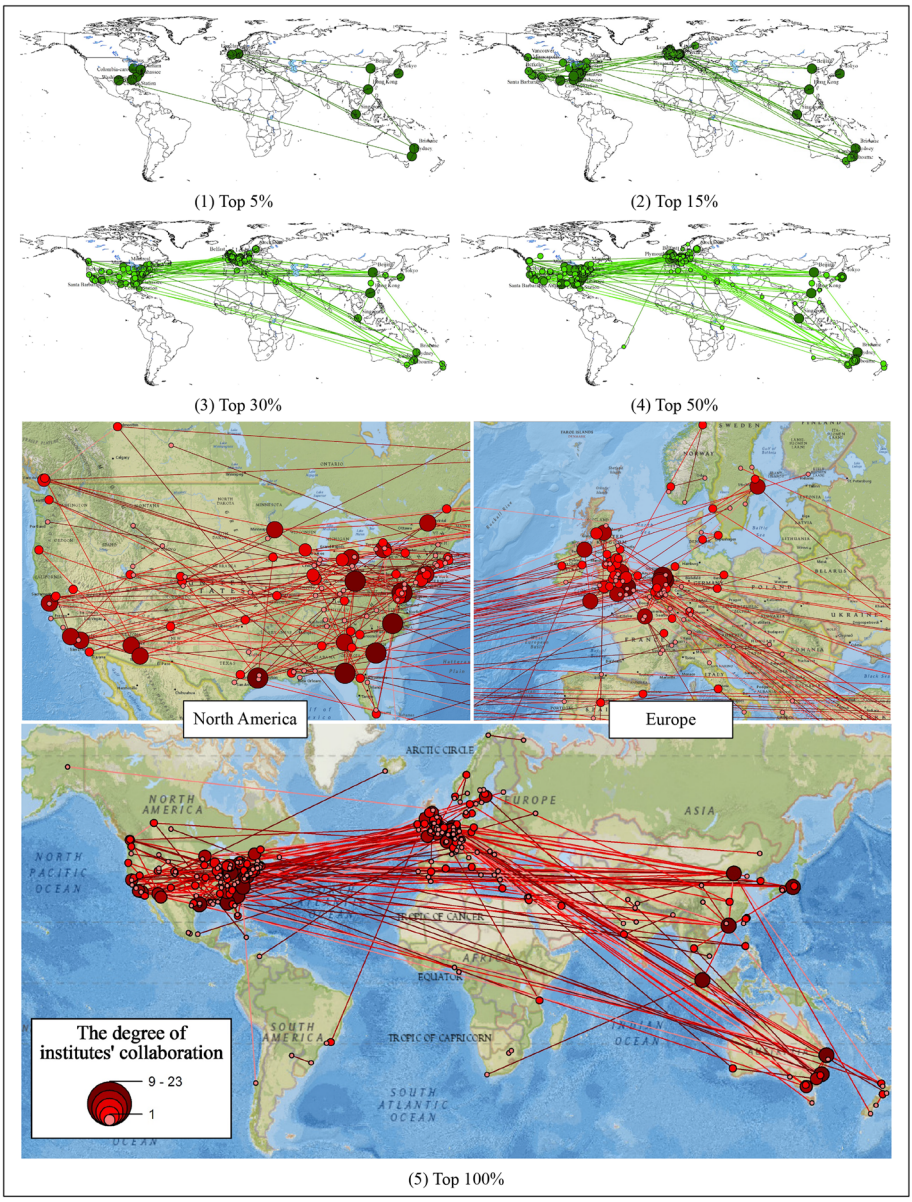

Fig. 2 continued

Fig. 2a, which were created with GoogleMap and BibExcel, major contributors (authors) of the total outputs come mainly from two core regions with high centrality and connectivity: West Europe (UK, Germany, Belgium, and France) and North America (USA and Canada), holding a dominate status in current scientific research domains. Meanwhile, most cities with a higher density of authors are distributed along coastal belts, over two-

third of which are located within buffer zones of 100 km from global coastlines. These have played a crucial role and acted as a communicating pivot in transport geographical research productions and authors, accounting for over one half of worldwide totals during this period. Similar findings are witnessed from the geolocations of its research institutes as seen in image (5) of Fig. 2b, a distributional map created by integrating GoogleMap and BibExcel. That is, the majority of research groups and their loci also are concentrated on the aforementioned regions: North America and Europe (the UK, Spain, Germany, Belgium, Sweden, etc.). All configurations were partially verified by looking at previous researches on relevant domains (i.e. innovation systems, urban geography, information science, etc.) (Liu et al. 2015; Batty 2003; Leydesdorff and Persson 2010). In addition, some newly or earlier industrialized countries in the West Pacific Rim (East Asia, Southeast Asia, and East Oceania) have higher-degree connectivity of scientific collaborations, centralizing in such transitional regions (or semi-core regions) as Southeast China, Taiwan of China, South Korea, Japan, Singapore, East Australia and East New Zealand (Fig. 2). At the same time, there is a lower level of international communication among underdeveloped, developing or recessionary industrial countries such as Africa, West Asia, North Asia, South America, and North Canada, which thus represent peripheral regions of global scientific collaboration networks (Fig. 2).

By means of ArcGIS network analysis and CiteSpace co-occurrence analysis, collaborative network maps of main authors and institutes (or groups) were generated as Fig. 2a image (3) and as Fig. 2b. Obviously, these interurban networks were organized by a hierarchical hub-and-spoke structure. On the one hand, nodal degree was introduced to outline the hierarchical structure in a global collaboration network by co-institutes analyses. Near 500 cities with almost 900 institutes in the general network were divided into five classes in a descending order: first-tier cities (that is hubs of global institute collaboration, nodal degree' top 5 %), second-tier cities (top 5–15 %), third-tier cities (top 15–30 %), fourth-tier cities (top 30–50 %), and fifth-tier cities (the remaining smaller-degree cities mainly concentrated on South America, Southern Africa, and Northern Europe) [Fig. 2b images (1)–(5)]. On the other hand, these top 15 % cities with denser authors and institutes can be recognized as several leading hubs centered in: the United States of America (along coastal belts), West Europe (aggregating in Great Britain, Belgium, Germany, Denmark), and the West Pacific Rim (Southeast China including Taiwan, Japan, South Korea, Singapore, and eastern shore of Australia) [Fig. 2a image (3), b image (5)], all of which have become pivotal regions of global-institute collaboration networks. They are surrounded by peripheral secondary cities with lower-size institutes agglomerated into them through some important spokes.

Academic communities

Co-citation of a paper is the major parameter used to measure its academic value. It is also the reflection of scientific achievements accepted by peers. Figure 3 is the network map of author co-citation analysis based on CiteSpace, its node or ring denotes main authors and their achievements, and edges express their co-citation relationships. Nodal size or ring thickness represents some co-cited degree of their works, and nodal or ring colors from colder tones to warmer tones illustrate interannual variabilities from early to late. The co-citied network not only reflects the cited-documental conditions but also reveals the academic community of a field. As shown in Fig. 3, nearly half of a century transport geography initially formed six academic communities (Fig. 3). First was the school of urban planning centered on R. Cervero, whose researches concerned sustainable

transportation policy and planning, focusing on the nexus between urban transportation and land-use systems or the built environment. R. Cervero paid great attention to the transport effects of the built environment, urban form, balance of jobs and housing, transit-oriented planning, and sustainable transport policy. The second, the school of Marxist geography, was led by D. Harvey, who enriched the geographical theoretical basis, promoting it from positivism geography to Marxist geography and then on to post-modernism geography. He established a sound theoretical basis for the positivism and criticism turns in transport geography. The third, the school of new mobility (or mobility turn), took the two sociologists J. Urry and T. Cresswell as leading contributors. This led to the 'mobility turn' of transport geography and concentrated upon the physical and virtual movements (or flows) of people and networks organizing social life. The fourth, the school of time geography, was originally developed by T. Hägerstrand (Lenntorp 1999). It contributed largely to strides in spatiotemporal processes and visualization over recent decades, especially in the efforts of M. Kwan and H. Miller. These researches mainly were interested in ontological features, space–time behavior, GIS/GPS-based 3D visualization, and the dynamic mechanisms of individual daily activity (social, economic, political and environmental influences). The fifth, the school of new economic geography as represented by P. Krugman and M. Fujita, introduced such crucial items as general equilibrium, increasing returns or indivisibilities, imperfect competition, locational movement, and transport costs into the new economics models (Fujita and Krugman 2004), and illustrated spatial agglomeration, regional growth, and international trade and economic globalization. The sixth, the school of port geography, was steered by J. Rodrigue as well as B. Slake, T. Notteboom, A. Ng, and C. Ducruet among others. It explored freight logistics and supply-chain management, maritime shipping and port evolution, and multimodal transport under globalization. These schools are characterized in Table 1.

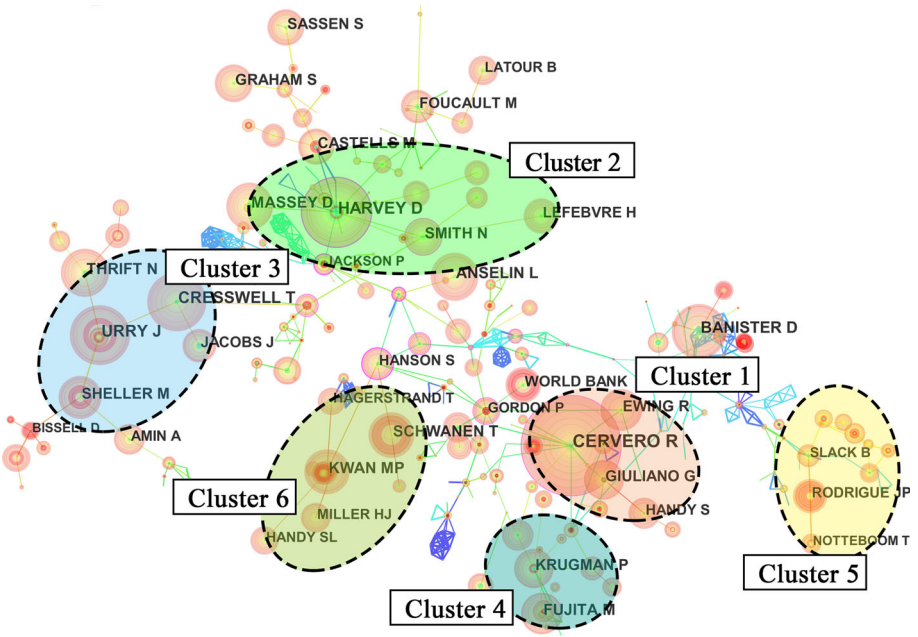

Fig. 3 Networks of co-cited authors

Table 1 Academic communities in transport geography

Academic communities	Leading scholars	Representative works	Research contents	Personnel bibliographies
Urban planning school	Cervero R.	Travel demand and the 3Ds: density, diversity, and design; Transforming cities with transit	Transport planning and land use	http://ced.berkeley.edu/ced/faculty-staff/robert-cervero
	Ewing R.	Travel and the built environment: a meta-analysis; Relationship between urban sprawl and physical activity, obesity, and morbidity	Built environment and travel	https://faculty.utah.edu/u0646355-REID_EWING/
	Handy S.	Urban form and pedestrian choices: study of Austin neighborhoods; Methodologies for exploring the link between urban form and travel behavior	Built environment and physical activity	https://www.des.ucdavis.edu/faculty/handy/
	Giuliano G.	Land use and transportation: why we won't get there from here; Car ownership, travel and land use: the US and Great Britain	Land use and transport policy	https://priceschool.usc.edu/genevieve-giuliano/
Marxist geography school	Harvey D.	Explanation in geography; Social justice and the city; Limits to capital; The condition of postmodernity	Marxist geography, critical geography	https://en.wikipedia.org/wiki/David_Harvey
	Massey D.	Capital and land: landownership by capital in Great Britain; Spatial divisions of labour: social structures and the geography of production	Marxist, feminist and cultural geography	https://en.wikipedia.org/wiki/Doreen_Massey_(geographer)
	Castells M.	The urban question: a Marxist approach	Marxist urban sociology	http://annenberg.usc.edu/faculty/communication/manuel-castells
	Lefebvre H.	The production of space; Critique of everyday life	Dialectical materialism	https://en.wikipedia.org/wiki/Henri_Lefebvre
New mobility school	Cresswell T.	On the move: mobility in the modern western world; Geographies of mobilities: practices, spaces, subjects	Mobilities and place	http://www.northeastern.edu/cssh/faculty/tim-cresswell
	Urry J.	Mobilities; Mobilities: new perspectives on transport and society	New mobilities paradigm	http://www.lancaster.ac.uk/sociology/about-us/people/john-urry
	Sheller M.	The new mobilities paradigm; Mobile technologies of the city	Mobility sustainability and justice	http://drexel.edu/now/experts/Overview/sheller-mimi/
New economic geography school	Krugman P.	Increasing returns and economic geography; The age of diminished expectations	Agglomeration economics	http://web.mit.edu/krugman/www/

Table 1 continued

Academic communities	Leading scholars	Representative works	Research contents	Personnel bibliographies
	Fujita M.	The spatial economy: cities, regions, and international trade; Economics of agglomeration	Spatial economy and globalization	https://ideas.repec.org/e/pfu109.html
Port geography school	Rodrigue J.	The geography of transport systems; The global economic space: advanced economies and globalization	Maritime systems and logistics	https://people.hofstra.edu/jean-paul_rodrigue/jpr_publications.html
	Slack B.	Containerization, inter-port competition, and port selection; Ocean transport in the twenty-first century	Maritime transport and intermodality	https://www.concordia.ca/faculty/brian-slack.html
	Notteboom T.	Port regionalization: towards a new phase in port development; An economic analysis of the Rhine–Scheldt delta port region	Port logistics and evolutions	https://www.uantwerpen.be/en/staff/theo-notteboom/
Time geography school	Kwan M.	Space–time and integral measures of individual accessibility; Gender and individual access to urban opportunities; Time, information technologies and the geographies of everyday life	Time geography, GIS and transport	http://meipokwan.org/
	Hägerstrand T.	What about people in regional science?; Innovation diffusion as a spatial process	Migration, time geography	https://en.wikipedia.org/wiki/Torsten_H%C3%A4gerstrand
	Schwanen T.	The Internet, changing mobilities and urban dynamics; The Internet, mobile phone and space–time constraints	ICT and transport	http://www.tsu.ox.ac.uk/people/tschwanen.html
	Miller H.	Geographic information systems for transportation: principals and applications; Societies and cities in the age of instant access	Transport-GIS	https://geography.osu.edu/people/miller.81

Flagship journals

Journal co-citation, meaning that two journals are cited in one paper, can reflect the relations among all kinds of periodicals and disciplines, as well as the distribution of knowledge basis. Figure 4 shows the co-citation network of most-cited journals in transport geography research. Its nodes represent different journals, and the edges denote some co-cited relations among academic journals. The strength of co-cited relations is expressed by edge thickness, and the co-cited duration is indicated by nodal colors ranging from inner colder tones to external warmer tones meaning temporal variations (Chen et al. 2014).

In general, the majority and mainstream of transport research networks are comprised of geography journals (i.e. *Environment and Planning A*, *Annals of AAG*, *Journal of*

Transport Geography, *Urban Studies*, and *Progress in Human Geography*). Transportation and planning science journals (e.g. *Transport Research A*, *Transport Research Record*, *Transport Reviews*, *Transport Policy*, *Environment and Planning D*, *Journal of the American Planning Association*, and *Landscape and Urban Planning*) are auxiliary and secondary. This implies that geography is a central theme to the study of transportation, which corresponds with the judgment of Goetz et al. (2009). Interestingly, transport geography research also cites some multidisciplinary journals, including *Science*, *Nature* and *PNAS*.

Statistically, as seen in Table 2, it is evident that related top journals are mainly centered on the two English-native countries: the United States of America (USA) and Great Britain (GB), which is similar to the distributions of authors and institutes noted above. The largest absolute number of cited journals from 1982 to 2014 was *Environment and Planning A*, with a citation count of 1230 (Fig. 4; Table 2), which published the most articles about transport research (Goetz et al. 2009) as well as the highest-cited paper 'The new mobilities paradigm' in 2006. The *Journal of Transport Geography*, a leading geography journal specializing in transportation, cited 998 times, closely follows the most-cited journal despite its later launch (in 1996). The journals and proceedings of *The Association of American Geographers* (AAG) and of *The Institute of British Geographers* (RGS-IBG) are the third-most-important knowledge sources for transport geography. It is

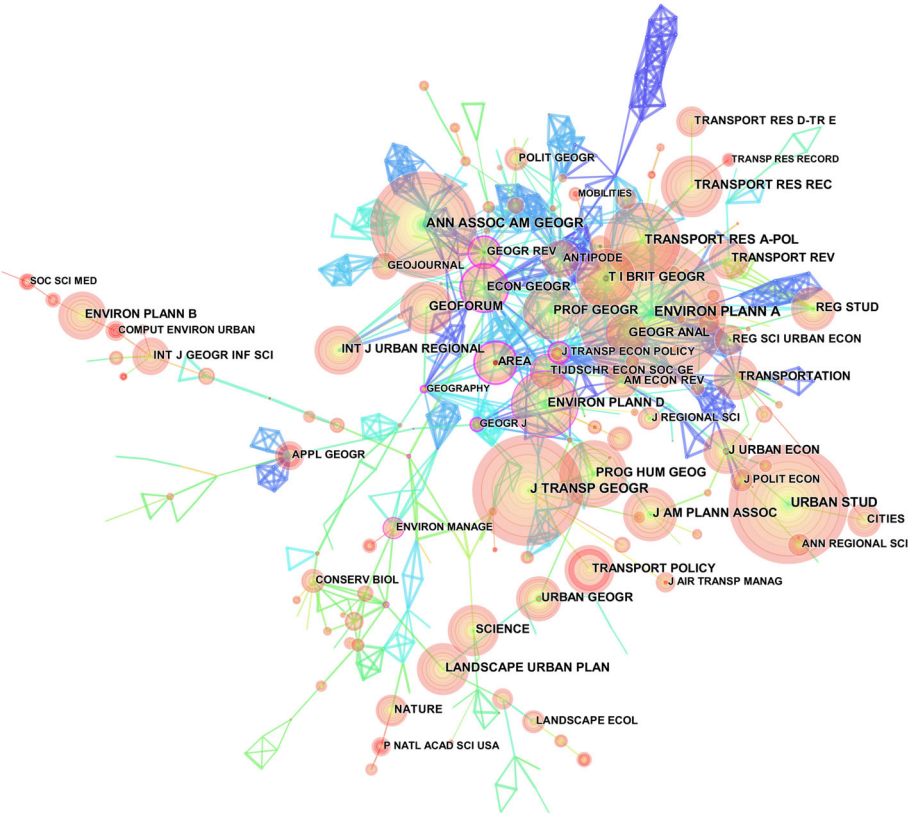

Fig. 4 Network of co-cited journals

obvious that *Transportation Research Part A: Policy and Practice* and *Transport Policy* have more citation counts, implying that transport geography turns toward applied orientation and policymaking. To sum up, the citation resources of transport geography have ranged from human geography to more specialized works in various fields (environment and ecology, business and economics, transportation engineering, transport policy and planning, urban studies and regional science, etc.), which may blur its "geographicalness", or property of geography.

Table 2 The top 20 most-cited journals

Frequency	Journal	Country	Research domains
1230	Environment and Planning A	GB	Human geography, environmental studies, urban and regional research
998	Journal of Transport Geography	GB	Geographical dimensions of transport, travel and mobility
985	Urban Studies	GB	Urban conditions and changes
836	Annals of the Association of American Geographers	USA	Environmental or physical geography, Geo-computation and GIS, social-natural relationship, human geography
776	Transportation Research Part A	GB	Transportation policy, planning, design, and evaluation
624	Transportation Research Record	USA	Transportation engineering
564	Progress in Human Geography	GB	Human geography research- philosophical, theoretical, thematic, methodological or empirical
549	Environment and Planning D	GB	Spatial analysis of political and social actives
534	Transportation	USA	Transportation and civil engineering
502	The Professional Geographer	USA	Empirical and methodologies studies in academic or applied geography
500	Transactions of the Institute of British Geographers	GB	Theoretical, conceptual or empirical geography; stimulate and shape research
500	Transport Policy	GB	Policy concerns in transport
499	Journal of the American Planning Association	GB	Public policies and administration, urban and regional planning, infrastructure design
480	Geoforum	GB	Global political economy, urban and regional development, environmental justice and resources management
454	Economic Geography	USA	Theoretically-based empirical research in economic geography
437	Environment and Planning B	GB	Method application and spatial problems in built environments
433	Transport Reviews	GB	Research-based reviews of transport
429	Journal of Urban Economics	USA	Theoretical or empirical, positive or normative research in urban economics
423	International Journal of Urban and Regional Research	USA	Critical, comparative and geographic perspectives in urban and regional studies
421	Landscape and Urban Planning	Netherlands	Landscape change and planning, design, urban ecology

Table 3 Burst terms in transport geography

Year	Burst	Centrality	Burst term	Frequency	Year	Burst	Centrality	Burst term	Frequency
1991	3.89	0.25	Deregulation	30	1999	2.95	0	Agglomeration economies	24
1992	5.64	0	Channel tunnel	11	1999	2.54	0.02	Competition	64
1992	3.4	0.09	Air pollution	63	1999	2	0.01	Gender	85
1992	2.69	0.01	Air transport	50	2000	4.39	0	Planning	31
1994	3.7	0.01	Services	51	2000	3.57	0.03	Public transport	169
1995	4.76	0.08	Landscape	138	2000	2.89	0	Social exclusion	46
1995	4.25	0	Private sector	23	2002	4.03	0.02	Case study	65
1996	5.28	0.04	Metropolitan area	156	2003	4.92	0	Regional development	31
1996	4.41	0.01	Ports	22	2003	1.98	0	Quality	47
1996	2.49	0	Congestion	41	2004	4.31	0.01	Globalization	85
1996	2.29	0.06	Policy	122	2004	4.17	0.01	Climate change	137
1996	2.17	0.03	Public space	103	2005	4.57	0.01	Transport costs	66
1996	2.11	0.02	Impact	111	2005	4.52	0	Identity	59
1997	4.64	0.04	Economic development	78	2005	3.43	0	New economic geography	23
1997	3.59	0.01	Tourism	64	2006	1.98	0.01	Transport geography	37
1997	2.8	0	High-speed rail	27	2007	2.63	0.01	Conservation planning	13
1998	3.41	0.01	Employment	66	2010	1.95	0	Walking	78
1998	3	0	Spatial mismatch	28	2012	4.44	0	Time geography	25

Intellectual dynamics

Research fronts

Research front, originating from an emergent and transient grouping of concepts (Price 1965), means the emerging thematic trends and surges of new topics, namely abrupt frequency increase of terms from titles, abstracts, and descriptors (Chen 2006). The sample data, after being imported into CiteSpace software and subjected to term co-occurrence analysis, generated 36 burst terms.

As shown in Table 3, the research trajectories of transport geography followed contemporary social hot issues during each period. This represents a strong policy, or problems-oriented, tendency. Since the end of the 1970s, neo-liberalism, which centers on deregulation and privatization, has arisen. European and North American countries carried out a policy of deregulation and liberalization of transportation industry, which became the major development tendency of worldwide transportation industry. For example, *The Airline Deregulation Act of 1978*, *The Staggers Rail Act of 1980* and *The Motor Carrier Act of 1980* were gradually promulgated by the United States. In the early 1990s, studies on the spatial effects of transportation deregulation became a research mainstream, particularly focusing on the air transport industry (Borenstein 1992; Goetz and Sutton 1997) and on air pollution (Lieu and Treyz 1992; Shukla and Parikh 1992). In the middle of the 90s, with the further development of deregulation, the transportation infrastructure as a kind of public service began changing from public to private sector ownership (Bowen and Leinbach 1995; Forrest and Murie 1995; Gibb et al. 1996). At the same time, transport capacity (or loading) gradually increased, and related topics, such as transport and regional development, were continually expanding. These topics included port volumes (Slack 1993), urban traffic congestion (Hodge 1992; Yang 1996), transport policy and impact (Owens 1995), employment (Holloway 1998), high-speed rail (Vickerman 1997), spatial mismatch (Wyly 1998), regional economic development (Linneker and Spence 1996), tourism (Lumsdon 2000), and climate change (Chapman 2007) as well as other frontiers. Later, the new field of economic geography hosted ground-breaking contributions in agglomeration economies, competition and globalization topics. At the coming of the twentyfirst century, the topics 'social turn', 'cultural turn' and 'mobility turn' emerged in transport geography and transport-related social exclusion, and gender mobility and accessibility became new focuses (Church et al. 2000; Kwan 1999; Law 1999). After the year 2000, research methods and scales in transport geography tended to be diversified, as in this case study, critical analysis and qualitative methodologies were gradually adopting, while traditional quantitative analyses were being integrated with interdisciplinary geocomputation (or geoinformatics) (Kim and Kwan 2003; Ivan et al. 2015), GIS/GPS and geovisualization (Kwan 2000; Miller and Shaw 2001; Buliung and Kanaroglou 2006), and the structural fractal and complex network (Zhang and Li 2012; Lin and Bai 2013; Ducruet and Lugo 2013), as well as other quantitative methods (i.e. statistical economics, big data, computation social science). Since 2010, the use of 'behavior turn' in transport geography has been enhanced, which is largely based on the framework of time geography. What's more, transport geography has developed strong humanistic tendencies, increasingly converting from a macroscale to a microscale perspective (i.e. individual behavior, community, or neighborhood scale).

Research hotspots

As keywords of documents are reflections of main content, to a large degree the frequency at which keywords are used can identify research hotspots in a specific field. It is necessary to merge synonyms or singular and plural nouns in CiteSpace. For example, the words 'city' and 'cities' are both overlapped to 'city'. As shown in Fig. 5, a node represents one keyword. More frequently the keyword appears, the bigger the nodal size. Similar to the mappings of journal co-citations in Fig. 4, lines in Fig. 5 show co-occurrence relationships, line thickness represents the intensity of co-occurrence, and ring color and radius indicate temporal variations and duration.

As this image of keyword co-occurrence in Fig. 5 has illustrated, 'transport', 'city' and 'geography' can be seen to be the most significant hubs, having the largest three frequencies as well as centralities in the whole network. Other high-frequency keywords abundantly cover its thematic contents, from the initial 'space' (i.e. 'accessibility', 'patterns' or 'structure', 'location'), 'landscape' (i.e. 'land-use' or 'land-use change', 'built environment', and 'urban form'), and 'impact' (i.e. 'environment', 'conversation', 'sustainable development') researches to such emerging turns as 'mobility turn' (i.e. 'mobility'), critical or cultural return (i.e. 'women'/'gender', 'race', 'inequality') and behavior turn (i.e. 'time', 'travel behavior', 'behavior'). However, far more extensive attention was paid to traditional former (traditional topics) rather than the latter (newly emerging hotspots), and focus was more intensively on macro-economic and environmental aspects (e.g. 'impact' and 'accessibility') than on political or social-cultural viewpoints (i.e. 'privatization', 'deregulation', 'behavior', 'health', 'time', 'walking', etc.). In this vein, little concern was given to dynamic process (i.e. 'dynamics') or to influencing mechanisms of the physical environment ('built environment', 'urban form', 'physical activity'), policy and management (i.e. 'privatization', 'deregulation'), urbanization and

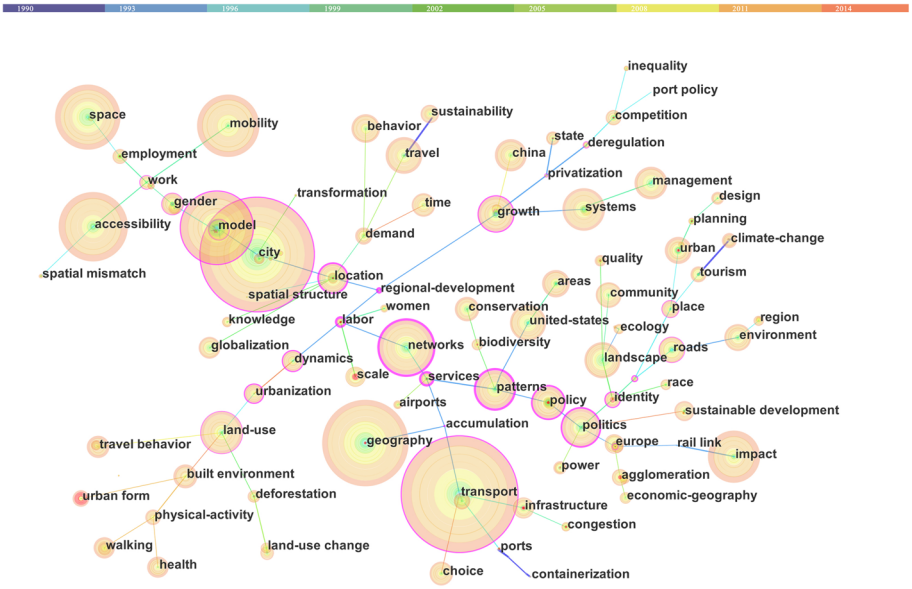

Fig. 5 Map of co-occurring keywords

globalization, social-culture and behavior (i.e. 'inequality', 'race', 'identity', 'travel behavior', 'health', 'time', 'walking'). Meanwhile, differences existed among transport sectors as well, with more researches oriented to road transport rather than air, port or rail transport. Moreover, some research methods, e.g. 'model', 'accessibility' and 'networks' analyses and case studies of some typical areas (i.e. USA, Europe and China) were most prevalent in the quantitative and positivist perspectives. Also, its research scales were full of diversity, from global or national to urban or local, and yet mainly concentrated on such small and medium scales as 'city' ('urban') and 'community'. Far larger or smaller scales (such as global, neighborhood and individual scales) need to be significantly strengthened.

In general, it is found that transport geography has main trajectories and trends as follows. First, according to the three highest-frequency keywords, it is evident that urban transport has become a leading field of transport geography in over the past two decades. Second, 'model', 'network' and case studies, with higher frequency and centrality, have become the current highlighted methodologies and still maintain the methodological framework of the 1960s. Third, such words as 'location', 'pattern', 'structure', 'scale', 'space' and 'place' indicate that 'geography' still holds the center of transport research, which makes the key of transport geography different from other transport sciences. Fourth, some recent alto frequent words are meaningful for identifying new directions in the field: 'behavior or humanism turn', 'critical or cultural turn' and 'mobility turn', which is same as found with some qualitative reviews (Kwan and Schwanen 1999; Attoh 2014; Merriman 2015a, b). And fifth, sustainability of transport (i.e. 'environmental impact', 'sustainable development', 'sustainability', 'conversation', 'congestion', 'climate change', 'inequality' and transport 'policy', etc.) increasingly are hotspots of transport geography research.

Landmark references

An analysis of co-cited references can effectively identify the intellectual structure, dynamics, emerging trends and paradigm shifts within a certain subject (Chen et al. 2012). Based on a CiteSpace time-zone analysis, we obtained a time-zone view of main influential works (Fig. 6). As shown in Fig. 6, their co-citations are depicted by nodal size or ring width, their co-cited years from early to late are indicated by series of tone variations from cool to warm. In a sight, the top 23 co-cited references were extracted, and then became disciplinary landmarks in the fluctuating and periodic evolution of transport geography knowledge, which is divided into four peaks and three intervals (two short-term and one long-term periods) (Fig. 6). Specifically, dissatisfaction with the empirical analysis framework of regional geography promoted new positivist thoughts and caused a quantitative revolution in human geography, leading to the first boom in transport geography research in the late 1950s and early 1960s (the first peak). From there, quantitative and empirical geography research played the core role in growing into its heyday (in the late 1960s) (Shaw and Sidaway 2011). However, during the 1970 and 1980s, positivist geographic research was criticized widely for numerous shortcomings from humanist, radical, feminist, and other philosophical positions (Goetz et al. 2009). Transport geography failed to follow the social and humanistic turns of human geography thought because of its policy tendency (Røe 2000), resulting in the first stagnation period of its academic research. From the late 1980s to the early 1990s (the second peak), it began to revive once again due to space theory [i.e. spatial economics/econometrics of Anselin (1988) and Krugman (1991), social space production of Lefebvre (1991)], geo-computation [i.e. geospatial and geo-data analysis of Anselin (1988), transport-GIS of Miller (1991)] and infrastructure economic

effect [i.e. transport investment and economic growth of Aschauer (1989)]. Since the mid-to-late 1990s (the third peak), the new economy [i.e. *The Spatial Economy: Cities, Regions, and International Trade* edited by Fujita et al. (1999)], sustainable cities [i.e. the transport metabolism model of Newman (1999)], urbanization and globalization (i.e. *The New Urban Frontier: Gentrification and the Revanchist City* by Smith 1996 and the land-use and travel pattern researches of Handy 1996 and of Cervero and Kockelman 1997) caused extensive concern. Accordingly, urban commute, transport model, space–time accessibility, sustainable transport, travel patterns, and international travel and trade became the highest frequency keywords. Since 2005 (the fourth peak), there has been an evident mobility turn in geographical movements by drawing rich nutrition from social sciences [cf. Cresswell (2006), Urry (2007) and Sheller and Urry (2006)]. In the meantime, global port regionalization entered also a new phase that had garnered significant attention [i.e. *Port regionalization: Towards a new phase in port development* by Notteboom and Rodrigue (2005)].

As listed in Table 4, the top 10 cited references from 1982 to 2014 includes four journal articles and six books. The most-cited article is M. Sheller and J. Urry's "*The new mobilities paradigm*" (2006), written in response to those ignoring or trivializing the importance of the systematic movements of people for daily work and family life, like commuting, leisure and pleasure in social science (Keeling 2008). This drove development of the new "mobility turn" in transport geography. Next, Hansen's 1959 paper "*How accessibility shapes land use*" initially proposed the concept and algorithm of accessibility. Since then, accessibility has gained much attention from many disciplines including urban planning, transport geography and regional development. The third-most-cited article was authored by Krugman (1991), and is regarded as one of the theoretical bases of the new economic geography. Its economies of scale, core-periphery model and general-equilibrium analysis have laid the

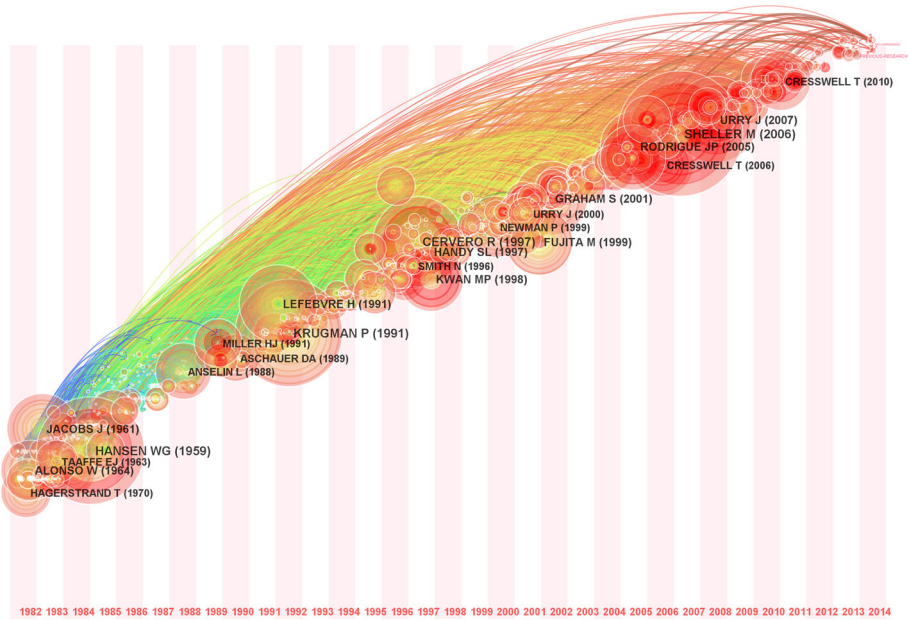

Fig. 6 TimeZone view of co-cited references

micro-foundation for location selection and space analysis of moving activity. R. Cervero and K. Kockelman's paper "*Travel demand and the 3Ds: Density, diversity, and design*" published in 1997 holds the fourth place. It illustrated how the urban built environment influenced travel demand along three principal dimensions: density, diversity, and design. The remaining six books focus on issues almost similar with the four aforementioned papers, concentrating on 'new mobilities' and social space, land use and urban planning, and geographical economics, which is consistent with the academic community analysis above. In Table 4, both books edited by Graham and Marvin (2001) and Urry (2007) and the 2006 article of M. Sheller and J. Urry have gone into a deeper discussion of "the mobilities" of social space. Also, Lefebvre's 1991 book, the representative of neo-Marxism, emphasized "space is the product of society" and "social-history-space" features as well. Furthermore, there are some highlights in urban geography and planning researches including J. Jacobs's book (a critique of urban planning policy and urban renewal) and W. Alonso's book (urban land use and location) (Jacobs 1961; Alonso 1964), as well as the two articles related to urban transport and land use and conducted by Cervero and Kockelman (1997) and Hansen (1959). And the last but not least some earlier works from Fujita et al. (1999) and Krugman (1991) are recognized as classic works in the economic geography.

Bursting references

Citation bursts, or abrupt increases of citation, provide a useful method for tracing the development of research focus (Chen et al. 2012). In Fig. 7, the top 18 references with the strongest citation bursts during the period are shown. Citation lines in red indicate the interval period in which these citation bursts were detected by citing burst analysis from

Table 4 The top 10 cited references

Freq.	Author	Title	Source	Year
83	Sheller M. and Urry J.	The new mobilities paradigm	Journal, Environment and Planning A	2006
78	Hansen W. G.	How accessibility shapes land use	Journal, Journal of the American Institute of Planners	1959
76	Krugman P.	Increasing returns and economic geography	Journal, The Journal of Political Economy	1991
65	Cervero R. and Kockelman K.	Travel demand and the 3Ds: density, diversity, and design	Journal, Transportation Research Part D	1997
62	Lefebvre H.	The production of space	Book, Basil Blackwell	1991
60	Jacobs J.	The death and life of Great American cities	Book, Random House, Inc.	1961
55	Urry J.	Mobilities	Book, Polity Press	2007
53	Graham S. and Marvin S.	Splintering urbanism: networked infrastructures, technological mobilities and the urban condition	Book, Routledge	2001
53	Alonso W.	Location and land use: toward a general theory of land rent	Book, Harvard University Press	1964
49	Fujita M., Krugman P., and Venables A.	The spatial economy: cities, regions, and international trade	Book, The MIT Press	1999

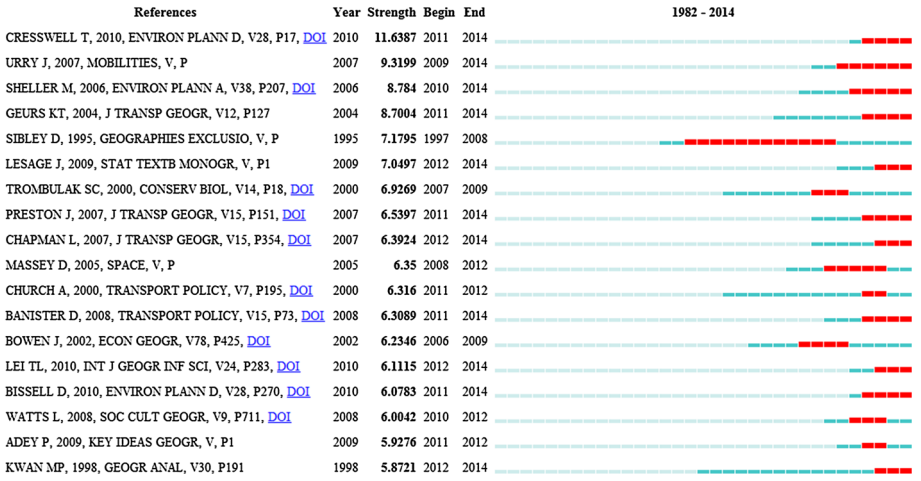

Fig. 7 Top 18 references with strongest citation bursts during the period 1982–2014

running CiteSpace. These are, therefore, references which may have had a profound influence on the development of transport geography.

Specifically, the three articles having the highest burst strength (written by Cresswell 2010; Urry 2007; Sheller and Urry 2006, respectively) are devoted to moving forward with some of the insights of the "mobility turn" (or "new mobilities paradigm") in the social sciences (Birtchnell and Urry 2015), meaning that transport geography should better engage with "mobility turns" within geography and related disciplines (Hall 2010). The fourth-ranked article, a review written by Geurs and van Wee (2004), focuses on advanced accessibility evaluation of land-use and feedback mechanisms between accessibility, land use and travel behavior. The book by Sibley (1995) and the articles by Preston and Rajé (2007) as well as Church et al. (2000) all concern on transport-related social exclusion which highlights power and knowledge intertwined to produce geographies of exclusion. Lesage and Pace's book (2009) "*Introduction to Spatial Econometrics*", ranked in fifth place, is one of the classic textbooks and monographs on spatial statistics and geo-computations, indicating that quantitative methods retain a dominant position in methodology. Articles by Trombulak and Frissell (2000), Banister (2008) and Chapman (2007) concentrated on such environmental issues in transport as carbon emissions, energy consumption and environmental effects, and pointed out that the transportation sector was a dominant source of pollutant discharges leading to multiple environmental impacts. For example, an increasing amount of energy consumption and greenhouse gas emissions result in climate change, which must be measured to develop the sustainable mobility. It is interesting that the last article on individual accessibility has recently drawn much concern after a long term of quiet (Kwan 1998).

Conclusions

Despite being a vibrant subfield within human geography, a lack of the intellectual structure and evolution analysis of transport geography research has been identified. To correct this, big-data literature mining and scientometric mapping have been used in this research to depict the spatial distribution of affiliations, academic community structures,

and flagship journals as well as to detect the key fronts, hotspots, landmark references, and bursting references relevant to reviewing transport geography from 1982 to 2014.

Existing reviews of a half century of transport geography progress, its research subjects and objects are full of polarizing inequality and structural gaps. Overall, global distributions of outputs, authors and institutes show uneven patterns within a core-peripheral structure. Major cores are concentrated in cities with higher centrality or greater connectivity of "big three" world-class core regions: Western Europe, North America and the West Pacific Rim. Accordingly, their interurban collaboration networks are hierarchically organized as multiple hub-and-spoke modes. Those higher-degree cities with a larger number of authors and groups, recognized as hubs, are centralized in the "big three" and dominate their surrounding cities by exocentric spokes as well. Beyond the spatial differences, the networks of co-authors and journals are provided with some structural heterogeneities. For one thing, those co-author networks with strong linkages have played a leading role in the dynamics of transport geography. These networks have been divided into "big-six" communities and named based on their research interests as: Urban Planning School, Marxist Geography School, New Mobility School, New Economic Geography School, Port Geography School, and Time Geography School. In addition, the field's main co-cited journals exhibited a 'geographical' preference and spatial agglomeration. They are not only attributed as geography and related transport and planning sciences, but also located in the two countries of the United States of America and Great Britain. This means that geography is a central theme to the study of transportation and English-native countries are still the main fronts to transport geography research.

Meanwhile, the research perspectives of transport geography are increasingly full of vibrancy and diversity. After the exponential ascensions of its outputs, its field is in an "active phase" with diverse emerging publications, social orientations and theoretical trends. Beyond being centralized in 'geographicalness', its emerging trajectories are close to topic- or problem-oriented debates (Schwanen 2016), from initial deregulation/liberalization to sustainable transport, from supply strategies (TOD) to demand (or behavior)-driven planning, from local challenge to globalization/regionalization, from economic effect to social equality and cultural turn. They evidently are also boosted by interdisciplinary integrations (i.e. economics, management, environmental science, urban and regional science, transportation science, and so on). Furthermore, transport geography has been driven by numerous landmark references originating from humanist theoretical reforms, from initial positivism, to behaviorism, to new regionalism, to post-modernism, and then to recent social and cultural turns ('new mobility' turn, behavior turn). One of the most important of these is the social turn in transport inequality and transport "social exclusion", taking the mobility turn as a representation. Another is space–time behavior return focusing on the exploration of "individuals in region" based on their spatiotemporal behavior. Although transport geography is full of various perspectives and multi-discipline crossovers, it still not only maintains strong path-dependence on quantitative and positivist approaches, but also retains a fixed center of geographical analysis. Similarly, it adheres strongly to an urban (or city) scale rather than more macro or micro scales such as global, national, regional, local, neighborhood-level, and individual.

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