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# Visualization analysis of high-speed railway research based on CiteSpace

Xiaoyan Chen *, Yisheng Liu

School of Economics and Management, Beijing Jiaotong University, Beijing, 100044, China

A R T I C L E I N F O

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A B S T R A C T

With the rapid advancements of high-speed railway (HSR) in recent years, the results of HSR research are fruitful. This study aims to identify the research status quo and development trends of HSR using visualization analysis with CiteSpace. We retrieved published papers (1900–2019) from the Web of Science core collection with a topic search related to HSR. Next, we generated author, institution, and country co-authorship networks to identify the top productive authors, institutions, and countries, respectively, the journal co-citation network to determine the distribution of core journals, the document co-citation network to reveal the main research themes and explore the knowledge structure, the author co-citation network to identify the influential authors, and the keywords co-occurrence network to detect research hotspots and research frontiers. These analyses informed about the main contributing force of HSR research at three levels of authors, institutions, and countries, the knowledge sources and interdisciplinary characteristics of HSR, the major research domains and knowledge structures present status of HSR, and the orientations for further research. Furthermore, the case of China suggests that policy support is conducive to promote the development of HSR research.

## 1. Introduction

Lately, high-speed railway (HSR) has garnered considerable attention of scholars owing to its notable advantages such as safety, speed, punctuality, comfort, energy–saving and less pollution since the opening of the world's first HSR (Shinkansen) in 1964. To date, HSRs have been set up in succession to meet traffic demands in several countries, such as European Union (Vickerman, 1997), South Korea (Berton and Simonneau, 1998), France, Britain, Holland, Germany, Belgium (Norman and Vickerman, 1999), Taiwan (Chang and Chen, 2001), Spain (Chaker and Falero, 2001), China, and so on. After more than 50 years of development, the following three global development models of HSR were gradually formed: (i) exclusive corridors (e.g., Japan) (ii) hybrid networks both national (e.g., France and Germany); and international (e.g., European Union); and (iii) comprehensive national networks (e.g., China and Spain) (Perl and Goetz, 2015). Therein, HSR in China developed rapidly with operating mileage of 29,000 km, accounting for two-thirds of the world by the end of 2018.

The booming of HSR has allured researchers of different countries from various disciplines including civil engineering, economics, business & economics, mechanical engineering, electrical & electronic engineering, transportation, transportation science & technology, manufacturing engineering, composites, telecommunications, applied physics, biodiversity & conservation, automation & control systems, acoustics, information systems, and so on. Researchers from various disciplines have studied HSR from their own unique perspective from the range of line selection, foundation treatment, tunnel quake-proof, bridge stability, orbit placidity, electric traction system, investment benefit analysis, economic development, train monitoring system, environmental impact assessment, noise control, operation, and scheduling. However, efforts on the investigation of the comprehensive intellectual landscape of HSR have been seldom taken systematically about scientific studies mentioned above.

The intellectual landscape of a scientific field can be represented by a network of various entities such as cited references, collaborating authors and co-occurring keywords (Chen et al., 2014); such network can be visualized by knowledge mapping, an emerging approach for literature analysis providing holistic and comprehensive depictions of intellectual landscape of evolving scientific fields, with contributions to comprehend the knowledge structure, intellectual collaborations, novel developments, hot topics and developing trends which are essential to researchers, engineers, and business investors.

In this study, we used CiteSpace as an analysis software to make co-authorship, co-citation and keywords co-occurrence analysis of international HSR research references. The objectives of this study are as follows:

* Corresponding author. School of Economics and Management, Beijing Jiaotong University, No.3, Shangyuan Village, Hiandian District, Beijing, China.
*E-mail address:* c642333449@126.com (X. Chen).

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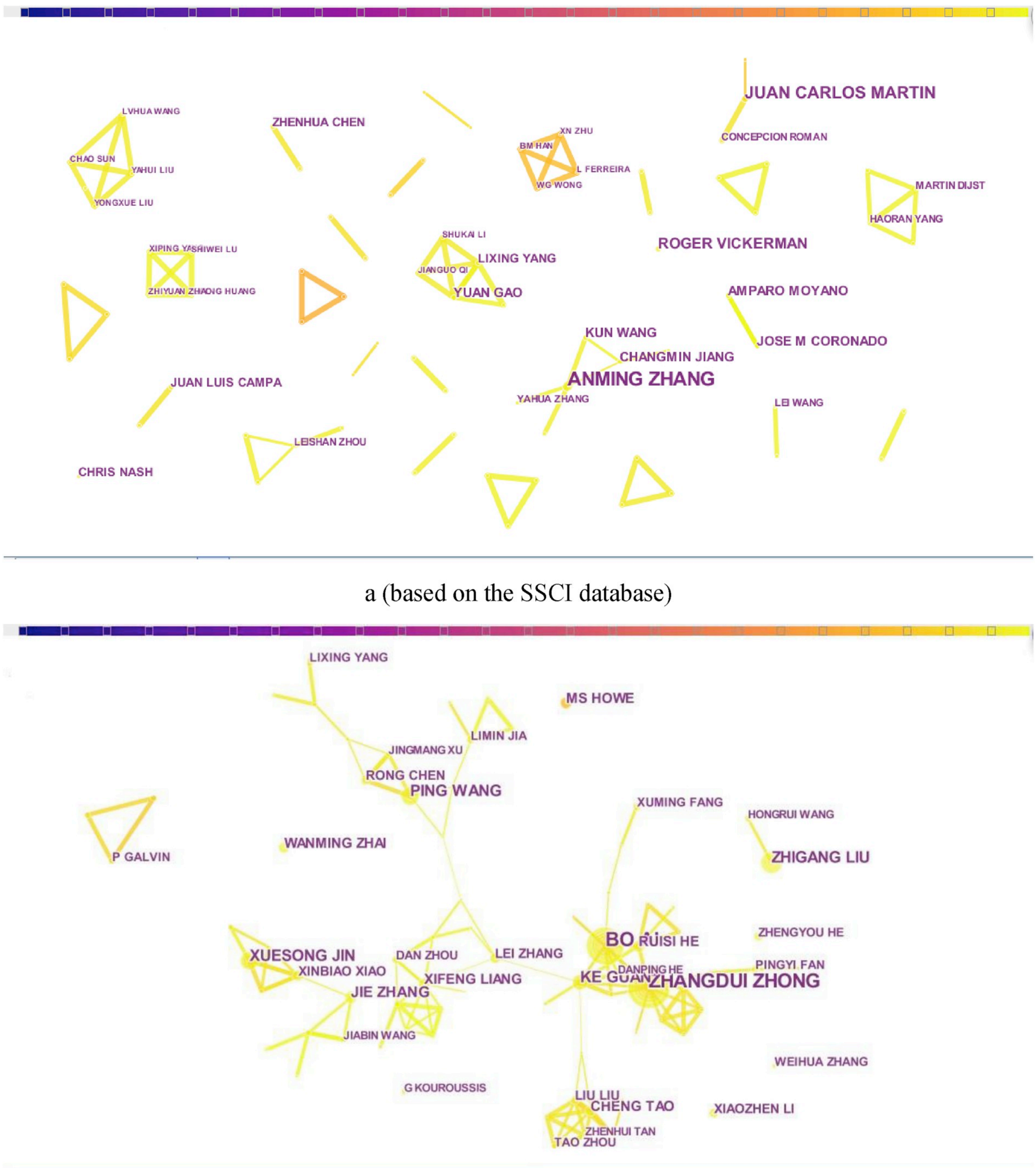



a (based on the SSCI database)

b (based on the SCIE database)

**Fig. 1.** Map of the author co-authorship network of HSR-related articles.

- to recognize the main research workforces in the field of HSR at the levels of individual, institute, and country
- to identify the distribution of core journals related to HSR research
- to distinguish the main research themes and explore the knowledge structure in the field of HSR; and
- to detect the research hotspots and research frontiers in the field of HSR.

## 2. Data collection and research methods

### 2.1. Data collection

Web of Science (WOS) has been long recognized as the most authoritative scientific and technical literature indexing tool that can provide the most crucial areas of science and technology research (Boyack et al., 2005) and is often considered to be an ideal data source for bibliometric investigations (Leeuwen, 2006). Our data sources were mainly from Citation Indexes known in print as Science Citation Index Expand (SCIE) and Social Science Citation Index (SSCI), of WOS Core

**Table 1**
Top 10 productive authors of HSR-related articles.

a (based on the SSCI database)

| Ranking | Counts | Centrality | Authors | Year | Field | From |
|---|---|---|---|---|---|---|
| 1 | 13 | 0.00 | Zhang AM | 2014 | TEP | Univ British Columbia, Canada. |
| 2 | 8 | 0.00 | Martin JC | 2007 | TTE | Univ Las Palmas Gran Canaria, Spain. |
| 3 | 6 | 0.00 | Vickerman R | 1999 | TE | Univ Kent, England. |
| 4 | 5 | 0.00 | Wang K | 2017 | TEP | Univ British Columbia, Canada. |
| 5 | 5 | 0.00 | Coronado JM | 2018 | ULP | Univ Castilla La Mancha, Spain. |
| 6 | 5 | 0.00 | Gao Y | 2016 | TNDOTS | Beijing Jiaotong Univ, P. R. China. |
| 7 | 5 | 0.00 | Jiang CM | 2016 | TEP | Univ Manitoba, Canada. |
| 8 | 5 | 0.00 | Moyano A | 2018 | ULP | Univ Castilla La Mancha, Spain. |
| 9 | 4 | 0.00 | Chen ZH | 2015 | IPP | Ohio State Univ, USA. |
| 10 | 4 | 0.00 | Yang LX | 2016 | TNDOTS | Beijing Jiaotong Univ, P. R. China. |

b (based on the SCIE database)

| Ranking | Counts | Centrality | Authors | Year | Field | From |
|---|---|---|---|---|---|---|
| 1 | 51 | 0.02 | Zhong ZD | 2012 | WMC | Beijing Jiaotong Univ, P. R. China. |
| 2 | 48 | 0.01 | Ai B | 2012 | WMC | Beijing Jiaotong Univ, P. R. China. |
| 3 | 26 | 0.00 | Liu ZG | 2016 | EPTDS | Southwest Jiaotong Univ, P. R. China. |
| 4 | 24 | 0.00 | Jin XS | 2007 | WRRVBR | Southwest Jiaotong Univ, P. R. China. |
| 5 | 23 | 0.01 | Wang P | 2012 | TSD | Southwest Jiaotong Univ, P. R. China. |
| 6 | 21 | 0.04 | Guan K | 2013 | WMC | Beijing Jiaotong Univ, P. R. China. |
| 7 | 20 | 0.00 | Howe MS | 1998 | TWC | Boston Univ, USA. |
| 8 | 17 | 0.02 | Zhang J | 2016 | GTA | Central S Univ, P. R. China. |
| 9 | 16 | 0.01 | Tao C | 2012 | WC | Beijing Jiaotong Univ,P. R. China. |
| 10 | 16 | 0.01 | He RS | 2013 | WMC | Beijing Jiaotong Univ, P. R. China. |

Source: Own elaboration-based data from output of author co-authorship analysis in CiteSpace, Web of Science.
TEP, transportation economy and policy; TTE, tourism and transportation economy; TE, transportation economics; ULP, urban and land planning; TNDOTS, traffic networks design and optimization for train scheduling; IPP, infrastructure planning and policy; WMC, wireless mobile communication; EPTDS, electric power transmission and distribution system; WRRVBR, high-speed wheel-rail relationship and vibration and noise reduction of high-speed trains; TSD, track structure and dynamics; GTA, ground traffic aerodynamics; TCW, tunnel compression wave; WC, wireless channels.

Collection (WOSCC) databases. The data used in this study have been retrieved on March 23, 2019, from the online version of National Library of China, with the retrieval strategies as follows:

Topic = "high rail*" or "high-speed rail*" or "high speed rail*" or "rapid transit railway" or "high-speed train" or "high speed train" or ("HSR" and ("rail*" or "train?"')) or ("HST" and ("train?" or "rail*"')) or ("TGV" and ("train?" or "rail*"')) or ("ICE" and "German" and ("intercity express" or "inter city express" or "train?" or "rail*"')) or ("KTX" and ("Korea" or "train?" or "rail*"')) or "Shinkansen," which means that published documents with these words located in titles, abstracts or keywords will be collected.

Document type = article. Only data on original articles, which are peer-reviewed, represent original scientific development (Yao et al., 2014). Therefore, the article data were selected, considering the degree of completeness of the metadata of different document types in WOS meanwhile.

Timespan = All Years. We intended to collect all data related to HSR as long as possible because of not knowing the clear period of HSR publications in WOS.

Database = SSCI and SCIE databases that were retrieved individually to make the data obtained more comparable and the analysis results more reasonable, in the light of different discipline characteristics of documents from SSCI and SCIE databases, and considering economics papers taking longer time to be produced than engineering papers.

Based on the retrieval strategy described above, we extracted 717 and 3410 articles from SSCI and SCIE databases, respectively, and saved for other file formats with "record content" as full record and cited reference, and "file format" as plain text.

### 2.2. Research method

Visualizing of scientific knowledge based on social network analyses and graph theory is an emerging area of bibliometric methods. A total of nine representative software tools have been specifically developed to analyze scientific domain using of science mapping (Cobo et al., 2011). CiteSpace, one of which, a free available Java-based scientific visualization software package, developed by Dr. Chen Chaomei at Drexel University, United States (Liu et al., 2015), has gained extensive application and attention around the world because of its advanced and powerful functions (Hou and Hu, 2013). Thus, we used CiteSpace to visualize and analyze knowledge maps of the HSR research literature.

We visualized the obtained data with CiteSpace (5.3.R11), and the main analysis procedures were as follows.

First, we established two projects with the properties in default, such as "HSR SSCI" and "HSR SCIE", and input the data of 717 and 3410 studies with full record and cited reference in the plain text format to CiteSpace for the projects of "HSR SSCI" and "HSR SCIE", respectively.

Second, we established the parameters, including time slicing (year span from 1900 to 2019, years per slice of 1 year for co-authorship analysis and keywords co-occurrence analysis, while 5 years for co-citation analysis), term source (title, abstract, author keywords, and keywords plus), node type (author, institution, country, cited reference, cited author, cited journal, keyword, and grant), selection criteria (top 20%), pruning (pathfinder and pruning sliced networks), links (default), visualization (cluster view-static and show merged network).

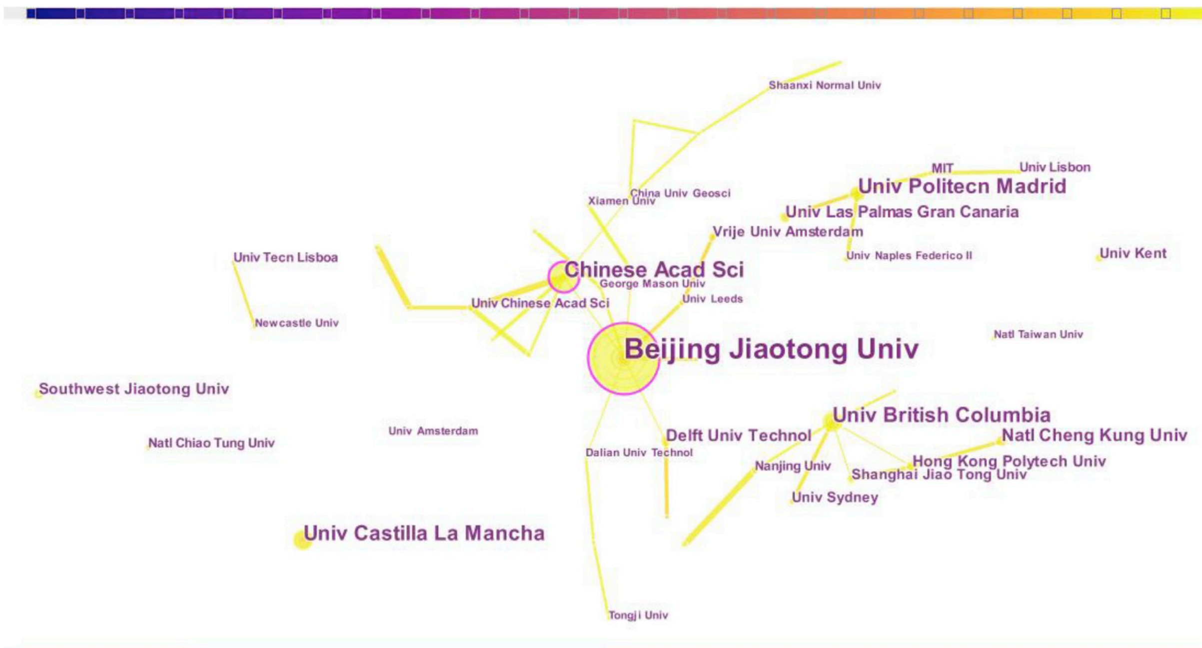
Third, we operated CiteSpace and obtained the networks and data, displaying the authors, institutions, and countries that have issued two or more articles, those journals, documents and authors that had been cited two or more times, and keywords that have occurred two or more times, respectively, for co-authorship analysis, co-citation analysis, and keywords co-occurrence analysis. Besides, the data of grants are obtained to assist the country co-authorship analysis for further analysis.

Finally, we studied the relevant networks and data, and presented the corresponding results of visualization analysis of the HSR research.

## 3. Results and discussion

### 3.1. Co-authorship analysis on HSR

Co-authorship is one of the most tangible and well-documented forms of scientific collaboration (Glänzel and Schubert, 2004), including three levels of cooperation namely individual, institutional,




a (based on the SSCI database)


b (based on the SCIE database)

**Fig. 2.** Map of the institute co-authorship network of HSR-related articles.

and national. Co-authorship analysis is beneficial to understand the collaborative network of various authors and detect the productive researchers on HSR around the world from microcosmic, meso, and macro perspectives.

### 3.1.1. *Author co-authorship analysis*

Fig. 1a and b shows the academic collaborations among authors, which are generated by selecting the unit of analysis, setting the appropriate thresholds, and excluding the isolated nodes. The size of nodes represents the number of papers that authors published. The distance between the nodes and the thickness of the links denote the level of cooperation among authors.

As shown in Fig. 1a, the authors of three or more papers were labeled. The whole network contained some isolated small sub-networks, implying that the authors in the field of social science (SS) tend to cooperate in small groups lacking communication among them. Herein, the sub-network with six nodes is the biggest research team headed by Zhang AM; the other five team members were Wang K, Xia WY, Jiang CM, Zhang YH, and D'Alfonso T. Besides, the second largest one comprised of five researchers, including Gao Y, Yang LX, Qi JG, Li SK, and Gao ZY.

As shown in Fig. 1b, the authors of eight or more papers were

**Table 2**
Top 10 productive institutions of HSR-related articles.

a (based on the SSCI database)

| Ranking | Counts | Centrality | Year | Institutions |
|---|---|---|---|---|
| 1 | 50 | 0.14 | 2011 | Beijing Jiaotong Univ, P. R. China. |
| 2 | 21 | 0.11 | 2014 | Chinese Acad Sci, P. R. China. |
| 3 | 18 | 0.00 | 2008 | Univ Castilla La Mancha, Spain. |
| 4 | 16 | 0.05 | 2014 | Univ British Columbia, Canada. |
| 5 | 15 | 0.00 | 2012 | Univ Politecn Madrid, Spain. |
| 6 | 10 | 0.01 | 2010 | Natl Cheng Kung Univ, China Taiwan. |
| 7 | 9 | 0.00 | 2012 | Univ Las Palmas Gran Canaria, Spain. |
| 8 | 9 | 0.02 | 2007 | Delft Univ Technol, Netherlands. |
| 9 | 8 | 0.00 | 2015 | Southwest Jiaotong Univ, P. R. China. |
| 10 | 8 | 0.03 | 2002 | Hong Kong Polytech Univ, China Hong Kong. |

b (based on the SCIE database)

| Ranking | Counts | Centrality | Year | Institutions |
|---|---|---|---|---|
| 1 | 365 | 0.21 | 2006 | Southwest Jiaotong Univ, P. R. China. |
| 2 | 355 | 0.14 | 2010 | Beijing Jiaotong Univ, P. R. China. |
| 3 | 158 | 0.12 | 2009 | Cent S Univ, P. R. China. |
| 4 | 103 | 0.11 | 2009 | Chinese Acad Sci, P. R. China. |
| 5 | 65 | 0.06 | 2008 | Tongji Univ, P. R. China. |
| 6 | 61 | 0.13 | 2012 | Southeast Univ, P. R. China. |
| 7 | 59 | 0.00 | 2003 | Korea Railrd Res Inst, Korea. |
| 8 | 55 | 0.04 | 2010 | Zhejiang Univ, P. R. China. |
| 9 | 54 | 0.01 | 1998 | Railway Tech Res Inst, Japan. |
| 10 | 39 | 0.06 | 2013 | Tsinghua Univ, P. R. China. |

Source: Own elaboration-based data from output of institution co-authorship analysis in CiteSpace.

labeled. The cooperation network comprised a slightly larger sub-network and other several isolated smaller sub-networks. The largest sub-network with 65 nodes comprised several obviously decentralized small subnets described briefly as follows. For example, one of them is the research team headed by Zhong ZD, with the team members including Ai B, He RS, Guan k, Fan PY et al. The next research team comprised Tao C, Liu L, Zhou T, and Tan ZH. The third one included Wang P, Chen R, Xu JM et al. The main members of fourth team were Jin XS and Xiao XB. The fifth comprised Zhang J, Wang JB, and so on. Further analysis revealed some communication to some extent but not much between aforementioned small research teams, in accordance with the number, distance, and thickness of the links between small subnets in the largest sub-network. From the overall perspective, the authors in the field of science and engineering (SE) also tended to work in small groups, with a lack of communication among them.

Appendix A provides the full names of authors in Fig. 1a and b and their corresponding abbreviations.

Regarding the prolific authors, sorted by the number of published papers, Table 1a and b lists the top 10 productive authors in both fields individually.

Table 1a shows that Zhang AM was the most productive author contributing 13 articles in transportation economy and policy. The remaining productive authors were as follows: Martin JC contributed eight articles in tourism and transportation economy; Vickerman R contributed six articles in transportation economics; Wang K contributed five articles in transportation economy and policy; Coronado JM contributed five articles in urban and land planning; Gao Y contributed five articles in traffic networks design and optimization for train scheduling; Jiang CM contributed five articles in transportation economy and policy; Moyano A contributed five articles in urban and land planning; Chen ZH contributed four articles in infrastructure planning and policy; and Yang LX contributed four articles in traffic networks design and optimization for train scheduling. In addition, three of them, such as Zhang AM, Wang K, and Jiang CM, are from the same team led by Zhang AM.

Table 1b shows that Zhong ZD was the most productive author contributing 51 articles in wireless mobile communication. The remaining productive authors were as follows: Ai B contributed 48 articles in wireless mobile communication; Liu ZG contributed 26 articles in electric power transmission and distribution system; Jin XS contributed 24 articles in high-speed wheel-rail relationship and vibration and noise reduction of high-speed trains; Wang P contributed 23 articles in track structure and dynamics; Guan K contributed 21 articles in wireless channels; Howe MS contributed 20 articles in tunnel compression wave; Zhang J contributed 17 articles in ground traffic aerodynamics; and Tao C and He RS contributed 16 articles individually in wireless mobile communication. Moreover, it is interesting to find that Zhong ZD, Ai B, Guan K, and He RS were affiliated to the same team headed by Zhong ZD.

In conclusion, the authors in both fields tended to cooperate in small groups, although the size of those research groups in SS is often smaller than that in SE. Meanwhile, it is also essential for researchers to select research teams and collaborators. However, the top 10 productive authors in both fields display different distributions in country. In SS, the top 10 productive authors came from five different countries, such as Canada, Spain, England, United States, and China, relatively scattered. In SE, however, nine of the top 10 productive authors came from China, except Howe MS from the United States, relatively centralized.

### 3.1.2. *Institution co-authorship analysis*

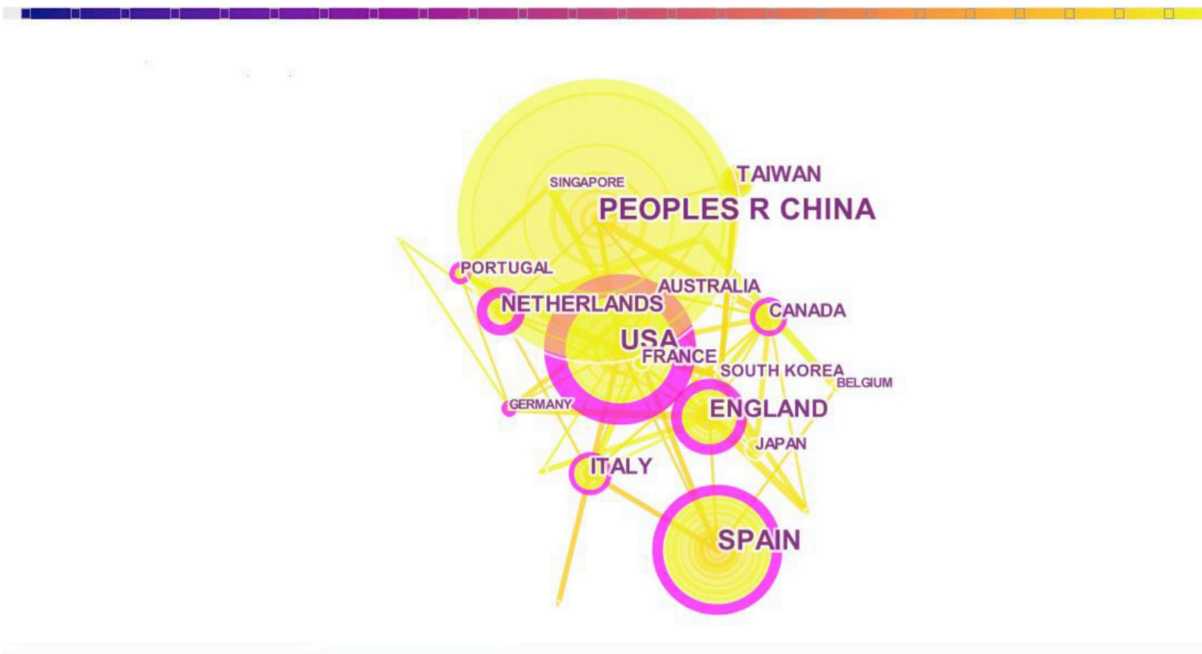
Fig. 2a and b shows the academic collaborations among institutions of HSR research, generated using the same way to form the network of author co-authorship. The size of nodes represents the number of papers that institutions published, and the distance between the nodes and the thickness of the links denote the level of cooperation among institutions.

As shown in Fig. 2a, in SS, the institutions of four or more papers were labeled, and three major scatted sub-networks and other sporadic institutions prop up the whole cooperative network. The biggest sub-network comprised 24 institutions. As far as a single institution was concerned, only a few institutions cooperated more with other units such as Beijing Jiaotong Univ, Chinese Acad Sci, and Univ British Columbia. In addition, the maximum number of institutions with which Beijing Jiaotong Univ cooperated was seven; however, the seven cooperated units were not connected to each other. Together with the number of links in each sub-network and the entire network for further analysis, it shows that the cooperation between different organizations inter and internal sub-networks is insufficient. Nevertheless, much room remains for improvement. Moreover, within the organizational collaboration network of 76 institutions, there are 73 universities (accounting for 96.05%) and three research institutions (accounting for 3.95%).

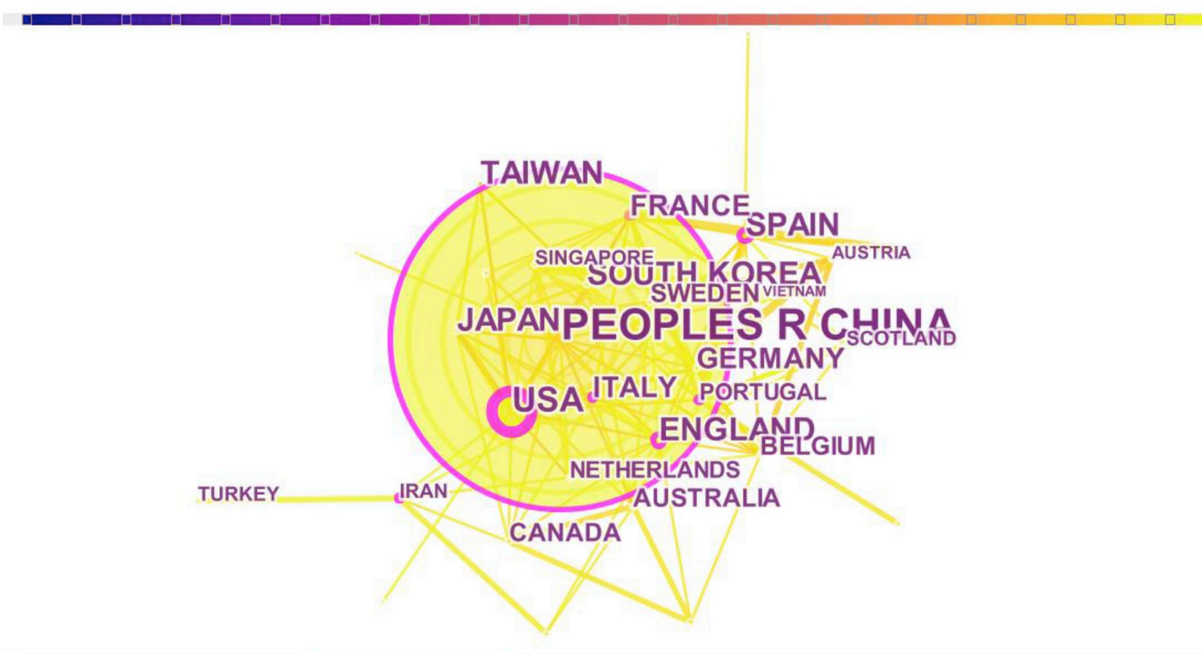
As shown in Fig. 2b, in SE, the institutions of 15 or more papers were labeled, and three sub-networks were far apart from each other, suggesting limited communication between different sub-networks. While the biggest one contained 90 nodes, occupying an absolute dominant position in the whole collaboration network. As shown in the largest sub-network, most of the 90 nodes were relatively concentrated considering the distribution of the nodes, and the cooperation between most of them was comparatively extensive considering the number of links. However, the intensity of inter-cooperation among most of those nodes was generally not sufficiently high based on the thickness of the links. Consequently, the partnership between those various institutions still needs to be strengthened unceasingly. Furthermore, within the organizational collaboration network of 166 institutions, there are 124 universities (accounting for 74.70%), 22 research institutions (accounting for 13.25%), 2 administrative institutions (accounting for 1.21%), and 18 enterprises (accounting for 10.84%).

Table 2a and b summarizes the top 10 prolific institutions sorted by the quantities of their published articles in both fields individually.

Table 2a shows that Beijing Jiaotong Univ performed well and ranked in the first position with 50 articles published, followed by Chinese Acad Sci (21), Univ Castilla La Mancha (18), Univ British Columbia (16), Univ Politecn Madrid (15), Natl Cheng Kung Univ (10), Univ Las Palmas Gran Canaria (9), Delft Univ Technol (9), Southwest Jiaotong Univ (8), and Hong Kong Polytech Univ (8). Regarding the




a (based on the SSCI database)




b (based on the SCIE database)

**Fig. 3.** Map of the country co-authorship network of HSR-related articles.

nature of these institutions, nine institutions were universities, while one was an academic institution. All of them contributed 164 articles, and nine universities issued 143 articles, accounting for 22.87% and 19.94% of the total number of articles (717) on HSR research in SS, respectively.

While Table 2b demonstrates that Southwest Jiaotong Univ performed better than Beijing Jiaotong Univ and ranked in the first position with 365 articles published, followed by Beijing Jiaotong Univ (355), Cent S Univ (158), Chinese Acad Sci (103), Tongji Univ (65), Southeast Univ (61), Korea Railrd Res Inst (59), Zhejiang Univ (55), Railway Tech Res Inst (54), and Tsinghua Univ (39). Slightly different from the results in Table 2a, seven institutions were universities, and three were academic institutions. All contributed 1314 articles, and seven universities issued 1098 articles, accounting for 38.09% and 31.83% of the total number of articles (3450) on HSR research in SE, individually. In addition, regarding the number of published articles on HSR, Beijing Jiaotong Univ, Southwest Jiaotong Univ, and Chinese Acad Sci appear in Table 2a and b at the same time.

As mentioned above, the nature of those top 10 productive institutions in both fields has strong homogeneity, and most of them were universities. The core research forces were mainly from universities. Besides, three institutions from PR China, including Beijing Jiaotong

**Table 3**
Top 10 productive countries of HSR-related articles.

| Ranking | Counts | Centrality | Year | Countries |
|---|---|---|---|---|
| a (based on the SSCI database) | | | | |
| 1 | 215 | 0.04 | 2002 | P. R. China |
| 2 | 104 | 0.79 | 2002 | USA |
| 3 | 103 | 0.21 | 2004 | Spain |
| 4 | 64 | 0.39 | 1999 | England |
| 5 | 47 | 0.00 | 2007 | China Taiwan |
| 6 | 43 | 0.12 | 2007 | Italy |
| 07 | 39 | 0.27 | 2003 | Netherlands |
| 8 | 29 | 0.12 | 2012 | Canada |
| 9 | 26 | 0.06 | 2002 | Australia |
| 10 | 21 | 0.08 | 2009 | France |
| b (based on the SCIE database) | | | | |
| Ranking | Counts | Centrality | Year | Countries |
| 1 | 1603 | 0.21 | 2002 | P. R. China |
| 2 | 358 | 0.32 | 1996 | USA |
| 3 | 207 | 0.02 | 1998 | South Korea |
| 4 | 203 | 0.04 | 1975 | Japan |
| 5 | 179 | 0.19 | 2004 | Spain |
| 6 | 163 | 0.18 | 1992 | England |
| 7 | 149 | 0.00 | 1998 | China Taiwan |
| 8 | 126 | 0.16 | 1998 | Italy |
| 9 | 110 | 0.08 | 1994 | Germany |
| 10 | 91 | 0.17 | 1996 | France |

Source: Own elaboration-based data from output of country co-authorship analysis in CiteSpace.

Univ, Southwest Jiaotong Univ, and Chinese Acad Sci, have shown strong scientific research strength in HSR research in both fields. Furthermore, PR China on the overall has significant HSR research capabilities and profound R&D expertise.

### 3.1.3. Country co-authorship analysis

Fig. 3a and b shows the country co-authorship networks of HSR-related articles in both fields, presenting an analysis of the spread of research on HSR between various countries. The nodes stand for countries, the size of which denotes the number of papers originated from different countries. The distance between the nodes and the thickness of the links represent the level of cooperation among countries. The purple rings of nodes depict the high betweenness centralities, which means such nodes are a pivotal point connecting different parts of the network. The thicker the purple ring is, the higher betweenness centralities the node has. In Fig. 3a and b, the countries of eight or more articles are labeled.

Fig. 3a consists of 22 nodes and 54 links (density: 0.2338). The 22 countries are primarily distributed in four continents, two in North America (United States and Canada), seven in Asia (PR China, Japan, South Korea, China Taiwan, and so on), 12 in Europe (Spain, England, Italy, France, Germany, Portugal, and so on), and one in Oceania (Australia). As shown in Fig. 3a, the cooperation network includes all 22 relatively centralized countries that work closely. There are eight nodes with purple rings, including the United States, Canada, Spain, England, Italy, Germany, the Netherlands, and Portugal; that is to say these eight countries play key roles in cooperation among 22 countries on HSR research in SS.

Fig. 3b comprises 32 nodes and 119 links (density: 0.2399). These 32 countries are mainly spread in five continents, two in North America (United States and Canada), 11 in Asia (PR China, Japan, South Korea, China Taiwan, Singapore, Iran, and so on), 16 in Europe (Spain, England, Italy, France, Germany, Portugal, the Netherlands, and so on), two in Oceania (Australia and New Zealand), and one in South America (Columbia). As shown in Fig. 3b, the cooperation network comprises 30 countries accounting for 93% of the whole 32 countries. The dense links between these 30 countries show that they cooperates intensively. The eight nodes with purple rings, such as the United States, Spain, England,

**Table 4**
Top 10 productive grants of HSR-related articles.

| Ranking | Counts | Centrality | Year | Grants |
|---|---|---|---|---|
| a (based on the SSCI database) | | | | |
| 1 | 88 | 0.41 | 2012 | National Natural Science Foundation of China |
| 2 | 20 | 0.15 | 2015 | Fundamental Research Funds for the Central Universities |
| 3 | 7 | 0.00 | 2016 | Spanish Ministry of Economy and Competitiveness |
| 4 | 7 | 0.00 | 2016 | Research Foundation of State Key Laboratory of Rail Traffic Control and Safety Beijing Jiaotong University China |
| 5 | 6 | 0.15 | 2018 | China Postdoctoral Science Foundation |
| 6 | 6 | 0.00 | 2017 | National Science Foundation of China |
| 7 | 6 | 0.00 | 2016 | National Social Science Foundation of China |
| 8 | 5 | 0.00 | 2018 | National Key Research and Development Program of China |
| 9 | 3 | 0.08 | 2018 | China Scholarship Council |
| 10 | 3 | 0.00 | 2018 | JSPS KAKENHI |
| b (based on the SCIE database) | | | | |
| Ranking | Counts | Centrality | Year | Grants |
| 1 | 948 | 0.07 | 2010 | National Natural Science Foundation of China |
| 2 | 228 | 0.19 | 2011 | Fundamental Research Funds for the Central Universities |
| 3 | 145 | 0.21 | 2010 | National Basic Research Program of China (973 program) |
| 4 | 87 | 0.07 | 2017 | National Key Research and Development Program of China |
| 5 | 68 | 0.05 | 2011 | Research Foundation of State Key Laboratory of Rail Traffic Control and Safety Beijing Jiaotong University China |
| 6 | 61 | 0.08 | 2011 | China Postdoctoral Science Foundation |
| 7 | 44 | 0.06 | 2012 | Beijing Municipal NSF |
| 8 | 39 | 0.16 | 2012 | National Science Foundation of China |
| 9 | 30 | 0.10 | 2011 | National High-Tech R&D Program of China (863program) |
| 10 | 30 | 0.08 | 2011 | National Key Technology RD Program |

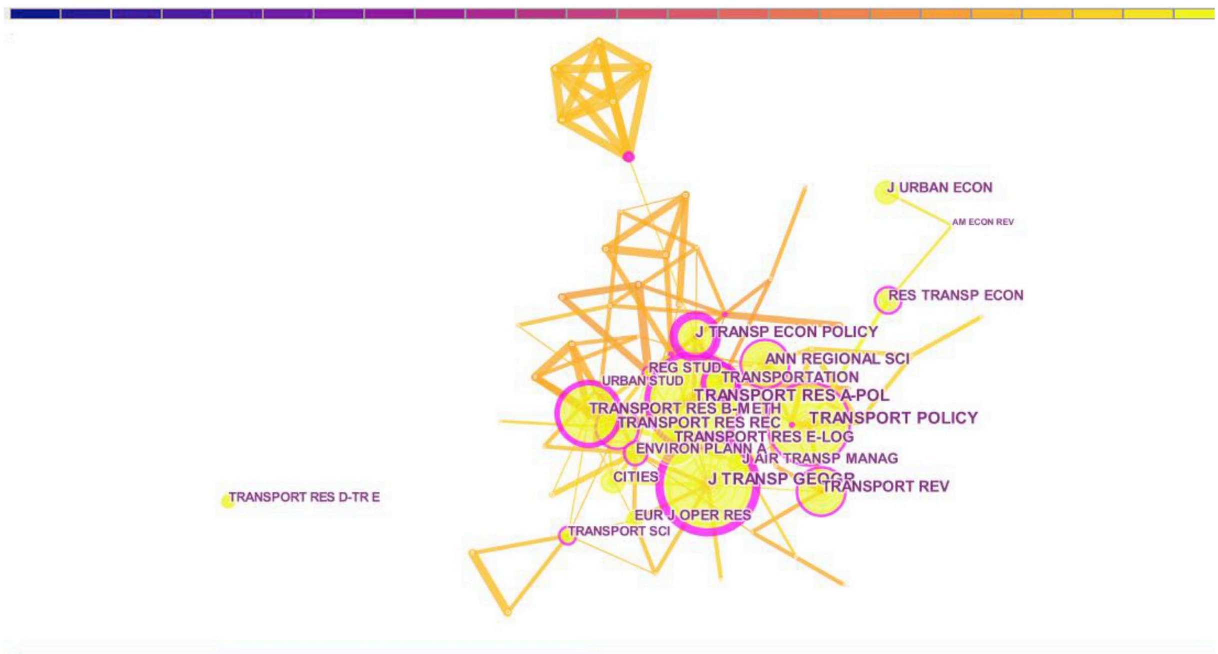
Source: Own elaboration-based data from output of grant analysis in CiteSpace. Owing to the data limitation of WOS, only the fund subsidies in 2008 and subsequent years are counted.

Italy, France, Portugal, PR China, and Iran, suggest their pivotal roles in the collaboration network on HSR research in SE at the country level.

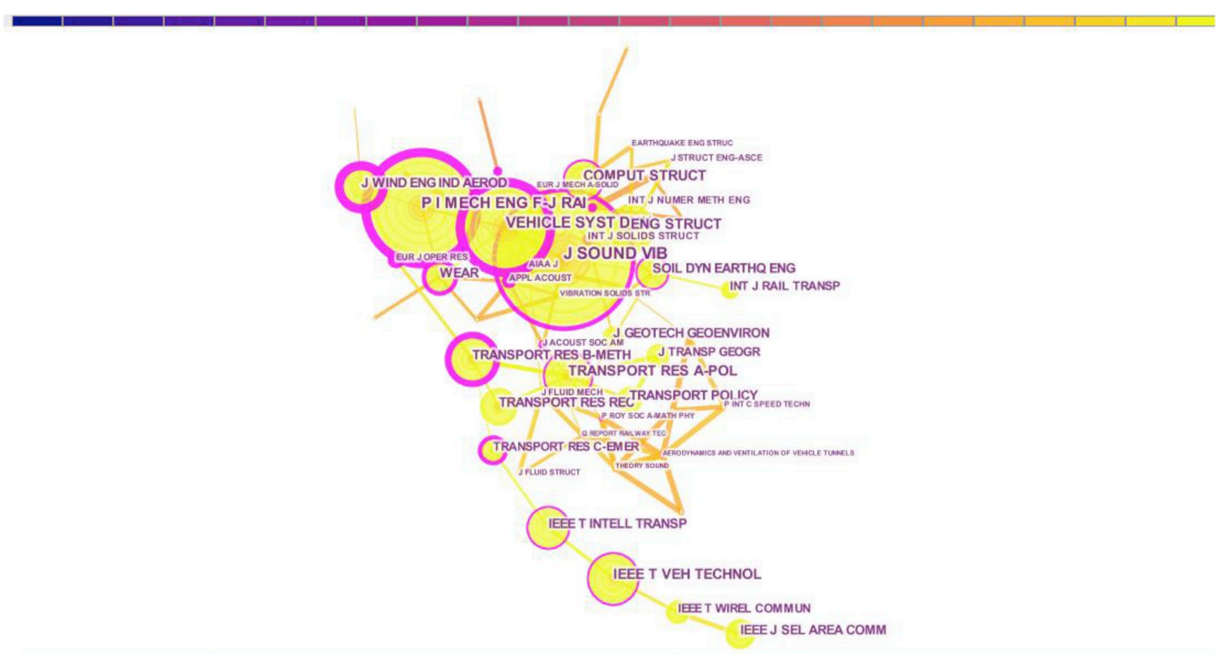
Table 3a and b shows the top ten productive countries sorted by the quantities of their published articles in the descending order in both fields individually. In SS, PR China contributed 215 papers, followed by the United States (104), Spain (103), England (64), China Taiwan (67), Italy (43), the Netherlands (39), Canada (29), Australia (26), and France (21), as shown in Table 3a. In SE, PR China contributed 1603 papers, followed by the United States (358), South Korea (207), Japan (203), Spain (179), England (163), China Taiwan (149), Italy (126), Germany (110), and France (91), as shown in Table 3b.

Further analysis revealed that the number of HSR-related articles from PR China in both fields, especially in SE, is much higher than other countries, even prolific countries like the United States and Spain without exception; the primary reason for this is that PR China has made great efforts to promote HSR research throughout the country.

The Chinese government proposed plans and objectives for the development of HSR, and the developing strategy in science and technology for railways. Policy objectives can be achieved through policy tools, which serves as a bridge between goals and outcomes, and the path and mechanism for translating policy objectives into concrete actions. With the policy tools categories proposed by McDonnell and Elmore (1987), the main measures taken by the Chinese government for




a (based on the SSCI database)




b (based on the SCIE database)

**Fig. 4.** Map of the journal co-citation network of HSR-related articles.

the development of HSR research can be grouped into the following four types.

The first is the type of command, which means the specific objectives of HSR research set out by the government provided its ruling authority must be followed such as People's Republic of China Railway Law, Ten-year Plan for Railway Science and Technology "Ninth Five-Year Plan (1996–2000)" for Railway Science and Technology Development and Outline of Long-term Plan for 2010, "Tenth Five-Year Plan (2001–2005)" for Railway Science and Technology Development and Outline of Long-term Plan for 2015, "Eleventh Five-Year Plan (2006–2010)" for Railway Science and Technology Development, "Twelfth Five-Year Special Plan (2011–2015)" for High-speed Train Science and Technology Development, Special Plan for Science and Technology Innovation in the Field of Transportation during the "13th Five-Year Plan (2016–2020)," Joint Action Plan for Independent Innovation of High-speed Trains in China, and so on.

The second is the type of incentive, a kind of short-term incentives, which means the rewards of giving individual and institutional funds for certain actions and achievements such as Zhan Tianyou Railway Science and Technology Award (including Zhan Tianyou Award, Zhan Tianyou Achievement Award, Zhan Tianyou Contribution Award, Zhan Tianyou Youth Award, and Zhan Tianyou Special Fund Award), the National

**Table 5**
The distribution of ten "core journals'' on HSR study.

a (based on the SSCI database)

| Ranking | Counts | Centrality | Cited Journals | IF in 2018 | Subject Coverage |
|---|---|---|---|---|---|
| 1 | 327 | 0.23 | TRANSPORT RES A-POL | 3.693 | B&E, T |
| 2 | 304 | 0.41 | J TRANSP GEROGR | 3.56 | B&E, G, T |
| 3 | 273 | 0.16 | TRANSPORT POLICY | 3.19 | B&E,T |
| 4 | 230 | 0.21 | TRANSPORT RES B-METH | 4.574 | B&E, E, OR&MS, T |
| 5 | 193 | 0.14 | TRANSPORT REV | 6.648 | T |
| 6 | 183 | 0.12 | ANN REGIONAL SCI | 1.075 | B&E, ES&E,G,PA |
| 7 | 172 | 0.05 | TRANSPORT RES E-LOG | 4.253 | B&E, E, OR&MS, T |
| 8 | 158 | 0.52 | J TRANSP ECON POLICY | 1.027 | B&E,T |
| 9 | 155 | 0.13 | TRANSPORT RES REC | 0.748 | E, T |
| 10 | 150 | 0.20 | TRANSPORTATION | 3.457 | E, T |

b (based on the SCIE database)

| Ranking | Counts | Centrality | Cited Journals | IF in 2018 | Subject Coverage |
|---|---|---|---|---|---|
| 1 | 714 | 0.31 | J SOUND VIB | 3.123 | A, E, M |
| 2 | 518 | 0.67 | P I MECH ENG F-J RAI | 1.54 | E, T |
| 3 | 432 | 0.68 | VEHICLE SYST DYN | 2.613 | E |
| 4 | 275 | 0.02 | ENG STRUCT | 3.084 | E |
| 5 | 263 | 0.14 | COMPUT STRUCT | 3.354 | CS, E |
| 6 | 251 | 0.12 | TRANSPORT RES A-POL | 3.693 | B&E, T |
| 7 | 251 | 0.12 | IEEE T VEH TECHNOL | 5.339 | E, Tele, T |
| 8 | 236 | 0.67 | J WIND ENG IND AEROD | 3.01 | E, M |
| 9 | 234 | 0.00 | TRANSPORT RES REC | 0.748 | E, T |
| 10 | 224 | 0.51 | TRANSPORT RES B-METH | 4.574 | B&E, E, OR&MS, T |

Source: Own elaboration-based data from output of co-cited journals analysis in CiteSpace, Web of Science and Journal Citation Reports 2018.
A, acoustics; E, engineering; M, mechanics; B&E, business & economics; T, transportation; G, geography; Tele, telecommunications; OR&MS, operations research & management science; CS, computer science; ES&E, environmental science & ecology; PA, public administration; IF, impact factor.

Science and Technology Award (including the National Supreme Science and Technology Award, the National Natural Science Award, the National Technology Invention Award, the National Science and Technology Progress Award, and the International Science and Technology Cooperation Award of the People's Republic of China), and so on.

The third is the type of capacity building, a kind of long-term incentives, which means that the government invests funds to individuals and institutions in scientific research for long-term results such as National Natural Science Foundation of China, National Science and Technology Major Special Fund, National Key R&D Program, Joint Fund for Basic Research of High-Speed Railways, Foundation and talent specialization for State Key Laboratory of Traction Power, National Engineering Laboratory of High Speed Railway Construction Technology, National Engineering Research Center of Rail Transit Operational Control System, National Research Center for Electrification and Automation Engineering Technology of Rail Transit, State Key Laboratory of High Speed Railway Track Technology, National Engineering Laboratory of High Speed Railway System Test, National Key Laboratory of Rail Transit Control and Safety, State Key Lab of Rail Traffic Control & Safety, and so on.

The fourth is the type of system change, a redistribution of power and responsibility, which implies the changes of mechanism and system. For example, the reform of the Ministry of Railways in 2013, assigned its administrative responsibilities in formulating railway development plans and policies to the Ministry of Transport, established the National Railway Bureau managed by the Ministry of Transport to shoulder other administrative responsibilities, established the China Railway Corporation to undertake its enterprise responsibilities, and abolished itself meanwhile.

Among them, the relationship between capacity–building tools and HSR research outputs is more direct than the other three tools, because they directly invest government funds in the HSR research, laboratory construction, and talent cultivation. Accordingly, the more the government funds invest, the more HSR research outputs are, and vice versa. Table 4a and b lists the top 10 productive grants of HSR-related articles in SS and SE, respectively, where most of the top 10 productive grants in both fields are from China, and the most prolific grant in both fields is the National Natural Science Foundation of China; this result elucidates the phenomenon mentioned above.

As analyzed above, with the rapid development of HSR in recent years, a growing number of countries have been attracted toward its research. Overall, most of them are closely tied in each field, and five countries, the United States, Spain, England, Italy, and Portugal, synchronously play critical connecting roles to the cross-country collaborations in both fields. Moreover, the outputs of HSR research in PR China are the most abundant in both fields owing to the policy support from the Chinese government.

### 3.2. Co-citation analysis on HSR

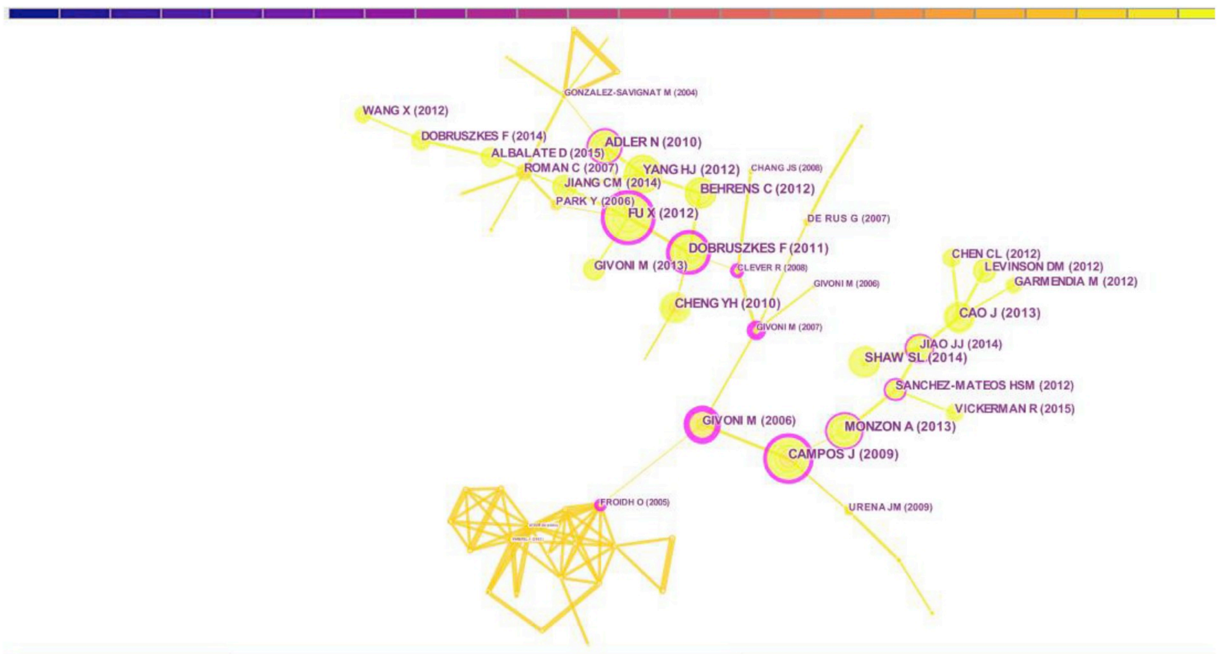
When two or more journals, documents and authors appear in the reference list of a third document simultaneously, they have a co-citation relationship (Osareh, 1996). The co-citation analysis provides a tool for establishing a structure or a map of specialty, monitoring the development of scientific fields and assessing the degree of interrelationship among specialties (Small, 1973). Accordingly, three main forms of co-citation analysis reveal the structure and relationship of journals, documents, and authors.

#### 3.2.1. Journal co-citation analysis

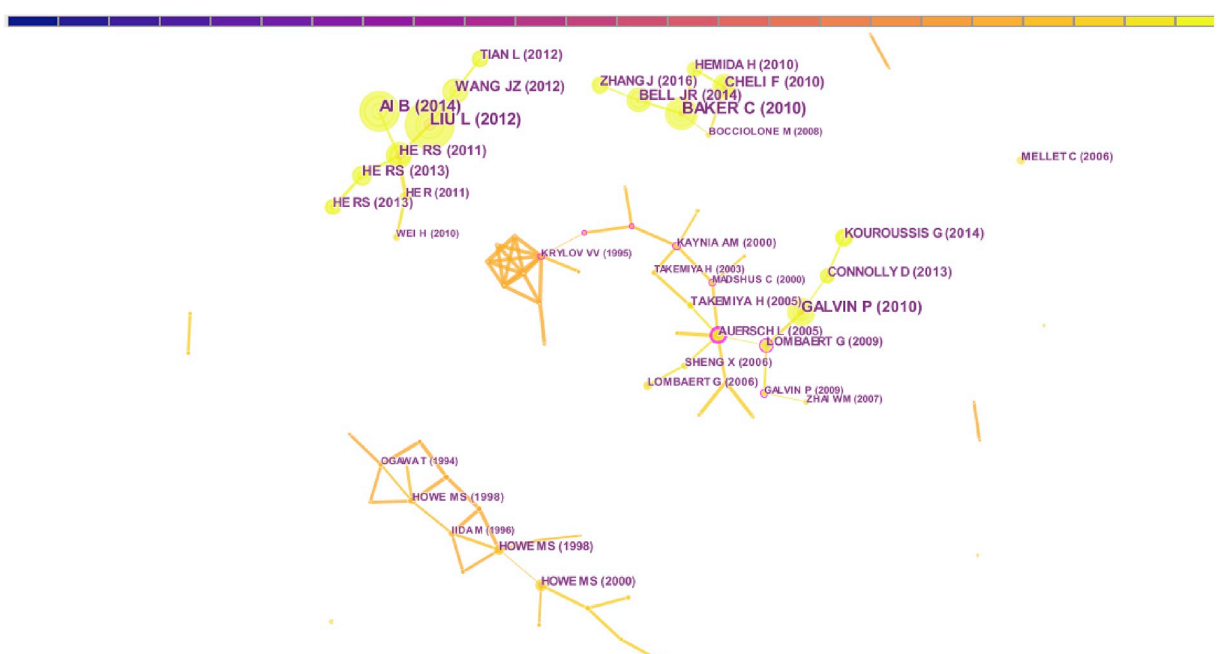
Two journals would be co-cited when, at least, one article from each journal is listed in a citing article's reference list (McCain, 1991). A journal co-citation analysis is conducive to study the structure of an academic field in which scholarly journals are cardinal means of communication (Hu et al., 2011). By using CiteSpace, we potted Fig. 4a and b, where the nodes represent journals and the links represent co-citation relationship between these journals. In addition, the size of a node represents the number of citations a journal has received, and the distance between two nodes represents the journal co-citation frequency. Usually, the bigger the node is, the more crucial a journal is; the smaller the distance between two nodes is, the higher the journals' co-citation frequency is. In Fig. 4a and b, the journals of 10 or more citation counts are labeled.

Fig. 4a comprises 69 nodes and 126 links, and the biggest sub-network includes 64 nodes accounting for 92% of the whole. Fig. 4b comprises 60 nodes and 89 links, with the largest sub-network of 56 nodes accounting for 93% of the whole. Comparison of Fig. 4a and b shows that the journals are linked more closely in Fig. 4a than that in Fig. 4b, which means that the co-citation relationship between journals in SS is stronger than that in SE; the main reason for this could be that the disciplines related to HSR research involved in SS are less extensive than that in SE.

Usually, "Core journals" refer to the most important journals with higher citation counts. Table 5a and b lists top ten journals with higher citation count and illustrates the distribution of core journals in HSR study with counts, centrality, cited journals, IF in 2018, subject coverage, and ranked by counts in both fields. Comparison of Table 5a and b revealed that three cited journals, such as TRANSPORT RES A-POL, TRANSPORT RES B-METH, and TRANSPORT RES REC, appear in




a (based on the SSCI database)




b (based on the SCIE database)

**Fig. 5.** Map of the document co-citation network of HSR-related articles.

Table 5a and b at the same time, suggesting they are the core journals in both fields. Moreover, seven cited journals had the impact factor of >3 in Table 5a and b, suggesting that the qualities of core journals in both fields were high to some extent on the overall.

As analyzed above, the co-citation analysis of journals offered the distribution of key knowledge sources of HSR research in both fields, which could help us determine which journals were cited and identify the core journals, as well as the links between these journals. Meanwhile, the results revealed the characteristics of strong interdisciplinary nature of HSR research, not only in SS but also in SE. Thus, none of the individual subject areas would fully reflect HSR research with extensive discipline distribution.

### 3.2.2. *Document co-citation analysis*

Documents represent a critical repository of knowledge. The document co-citation analysis, by selecting some representative studies as the analysis subject to form a document co-citation network, can be a crucial mean to detect the structure and evolution path of a specific domain (Liao et al., 2018). By running CiteSpace, Fig. 5a and b were plotted, where the nodes represent different cited documents, and those of 10 or more cited counts were labeled with the first author and the year of publication. In addition, the links represent the co-citation relationship

**Table 6**
Top 10 cited documents related to HSR research.

| Ranking | Counts | Centrality | Year | Documents |
|---|---|---|---|---|
| a (based on the SSCI database) | | | | |
| 1 | 57 | 0.29 | 2012 | Fu X, 2012, RES TRANSP ECON, V35, 13. |
| 2 | 51 | 0.25 | 2009 | Campos J, 2009, TRANSPORT POLICY, V16, 19. |
| 3 | 45 | 0.35 | 2011 | Dobruszkes, 2011, TRANSPORT POLICY, V18, 870. |
| 4 | 43 | 0.01 | 2012 | Yang HJ, 2012, TRANSPORT RES B-METH, V46, 1322. |
| 5 | 41 | 0.18 | 2013 | Monzon A, 2013, CITIES, V30, 18. |
| 6 | 41 | 0.11 | 2010 | Adler N, 2010, TRANSPORT RES B-METH, V44, 812. |
| 7 | 40 | 0.02 | 2010 | Cheng YH, 2010, TRANSPORT POLICY, V17, 51. |
| 8 | 39 | 0.02 | 2012 | Behrens C, 2012, J URBAN ECON, V71, 278. |
| 9 | 36 | 0.07 | 2013 | Cao J, 2013, J TRANSP GEOGR, V28, 12. |
| 10 | 35 | 0.00 | 2014 | Shaw SL, 2014, J TRANSP GEOGR, V40, 112. |
| b (based on the SCIE database) | | | | |
| Ranking | Counts | Centrality | Year | Documents |
| 1 | 69 | 0.01 | 2012 | Liu L, 2012, IEEE J SEL AREA COMM, V30, 834. |
| 2 | 58 | 0.00 | 2014 | Ai B, 2014, IEEE T INTELL TRANSP, V15, 2143. |
| 3 | 51 | 0.00 | 2010 | Baker, 2010, J WIND ENG IND AEROD, V98, 277. |
| 4 | 42 | 0.03 | 2010 | Galvin P, 2010, J SOUND VIB, V329, 5147. |
| 5 | 40 | 0.01 | 2011 | He RS, 2011, IEEE ANTENN WIREL PR, V10, 808. |
| 6 | 38 | 0.00 | 2010 | Cheli F, 2010, J WIND ENG IND AEROD, V98, 189. |
| 7 | 37 | 0.00 | 2012 | Wang JZ, 2012, IEEE J SEL AREA COMM, V30, 675. |
| 8 | 34 | 0.00 | 2014 | Bell JR, 2014, J WIND ENG IND AEROD, V134, 122. |
| 9 | 30 | 0.00 | 2013 | He RS, 2013, IEEE T WIREL COMMUN, V12, 794. |
| 10 | 26 | 0.00 | 2016 | Zhang J, 2016, J FLUID STRUCT, V61, 249. |

Source: Own elaboration-based data from output of co-cited documents analysis in CiteSpace.

between these documents. The bigger the node is, the more important the document is; the smaller the distance between two nodes is, the higher the documents' co-citation frequency is, and the more similar their research themes is.

As shown in Fig. 5a, the node with a purple ring implies that the document centrality is more than 0.1. The thicker the purple ring is, the more important the role of node is. The node corresponding to Givoni (2006) with the highest centrality of 0.48 is the center of the document co-citation network in SS, which reviewed the development status and impacts of HSR from seven aspects, including technological evolution, main models, routes network development, a mode of transport, socio-economic impacts, environmental impact, infrastructure cost, and suggested the definition of HSR service. Then, it created three main research areas, such as interaction of HSR and air transport including competition (Clever and Hansen, 2008; Dobruszkes, 2011; Fu et al., 2012) and cooperation (Givoni and Banister, 2006; Jiang and Zhang, 2014), impacts of HSR on space-economy including urban and regional development (Urena et al., 2009) and accessibility of cities (Sanchez-Mateos and Givoni, 2012; Monzon et al., 2013), and impacts of HSR on tourism (Froidh, 2005); these co-citation documents provides the knowledge bases of aforementioned three research areas for us.

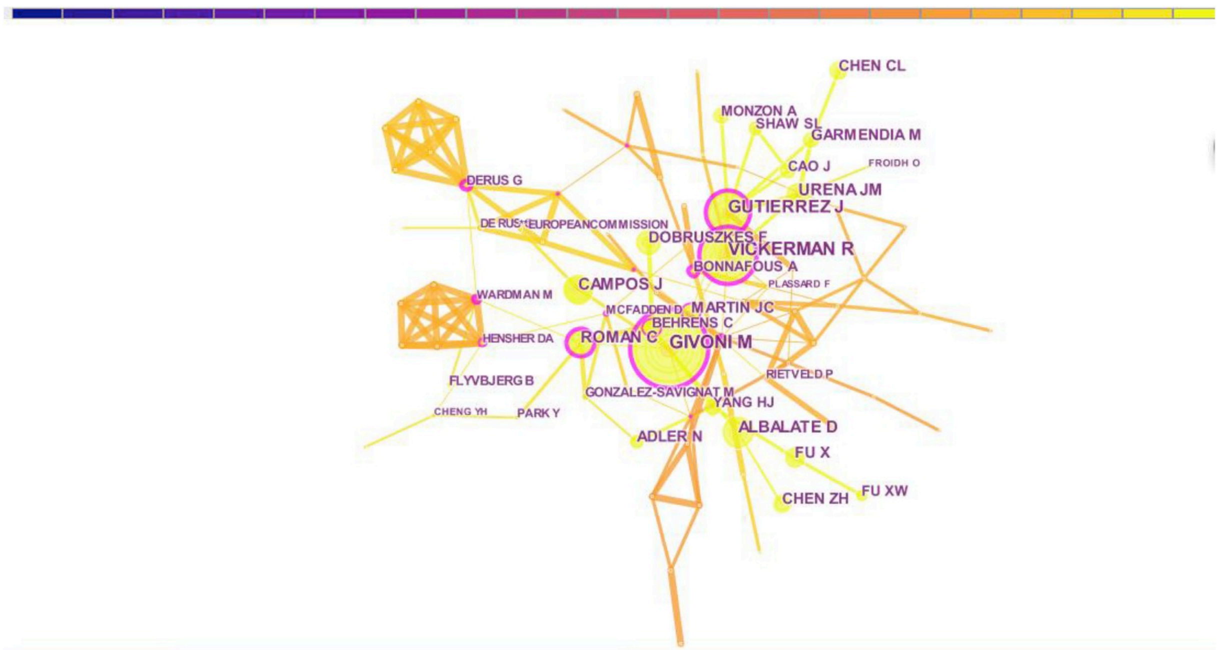
As shown in Fig. 5b, four obvious sub-network, and each represents a distinct specialty or a thematic concentration. From the lens of the average size of nodes in each sub-network, the largest sub-network is represented by its biggest node (Liu et al., 2012), which proposed a statistical position-based wireless channel model for HSR under a viaduct at 2.35 GHz in China, significantly promoting the evaluation technology of the radio interface and development of wireless communications system on the HSR. Likewise, the second large one is represented by Backer (2010), which described different flow fields causing the issues in train aerodynamics around high-speed trains in still air conditions and crosswind conditions. The third one is represented by Galvin et al. (2010), which presented a general and fully three dimensional multi-body-finite element-boundary element model to predict vibrations because of train passage at the vehicle, track and free field, assessing the vibrations induced by high-speed train passage for a ballasted track and analyzing the dynamic behavior of a transition zone between a ballast track and a slab track. The fourth one is represented by Howe et al. (2000), which studied the compression wave generated by a high-speed train entering a tunnel theoretically and experimentally, obtaining the ideal experimental results. Thus, combined with other co-citation documents in each sub-network, they lay the knowledge bases, respectively, for the research of HSR wireless mobile communication, high-speed train aerodynamics, HSR train–track–ground dynamic interaction, and the tunnel compression wave when high-speed train passing by.

Table 6a and b lists the top 10 most cited documents together with citation count, centrality, author, the year of publication, and journal information in both fields. As shown in Table 6a, five studies (Fu et al., 2012; Dobruszkes, 2011; Yang and Zhang, 2012; Adler et al., 2010; Behrens and Pels, 2012) were frequently cited in the research of competition of HSR and air transport, Cheng (2010) was cited 40 times in the research of integration of HSR and air transport; three documents (Monzon et al., 2013; Cao et al., 2013; Shaw et al., 2014) were cited more often in the research of HSR impacts on accessibility of cities, Campos and Ginés de Rus. (2009) was cited 51 times in the impacts research of HSR on urban and regional development. Likewise, Table 6b, five documents (Liu et al., 2012; Ai et al., 2014; He et al., 2011; Wang et al., 2012; He, 2013), four documents (Baker, 2010; Cheli et al., 2010; Bell et al., 2014; Zhang et al., 2016), and Galvin et al. (2010) were frequently cited, respectively, in the research of wireless mobile communication, high-speed train aerodynamics, and train–track–-ground dynamic interaction, suggesting that these highly cited documents are the knowledge root of their each corresponding research area.

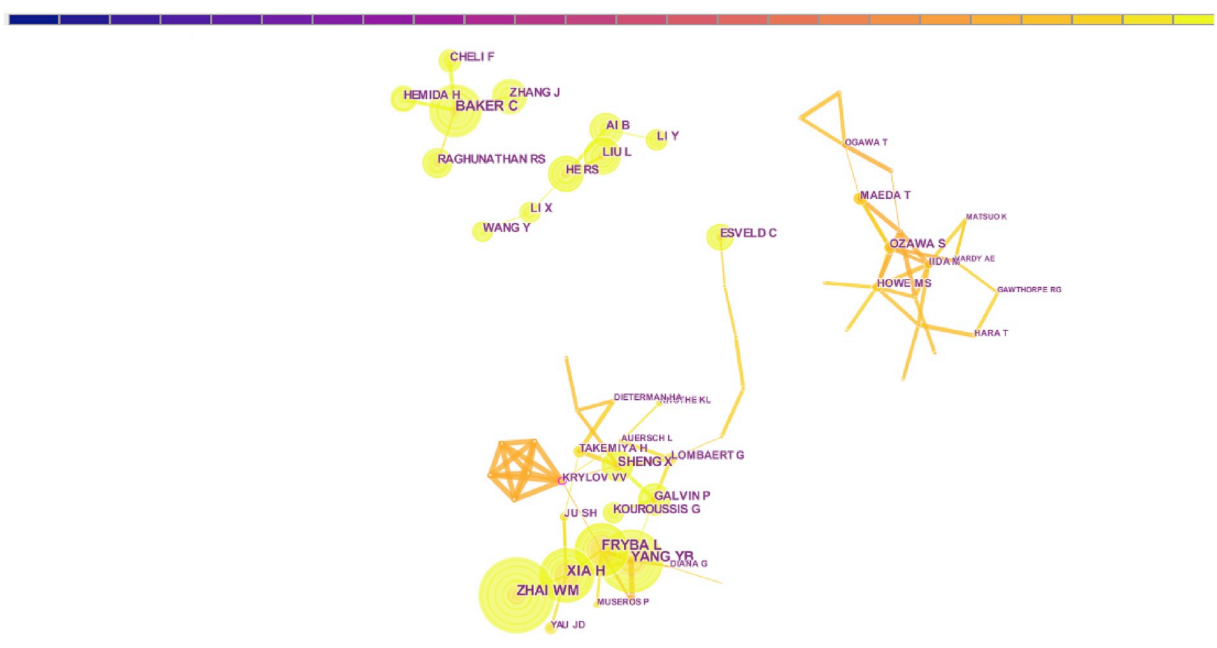
As analyzed above, the knowledge structure of HSR is taking shape continuously. The document co-citation analysis helps us not only identify the highly cited and influential research documents but also learn about the intellectual bases of such research domains as interaction of HSR and air transport, impacts of HSR on space-economy, impacts of HSR on tourism, HSR wireless mobile communication, high-speed train aerodynamics, HSR train–track–ground dynamic interaction, and the tunnel compression wave when high-speed train passing by, especially competition of HSR and air transport, impacts on accessibility of cities, wireless mobile communication, and high-speed train aerodynamics.

#### *3.2.3. Author co-citation analysis*

The author co-citation analysis can not only obtain the distribution of highly cited authors in a certain field and identify influential authors in this field but also understand the research topics of similar authors in a certain field and the distribution of their subject areas through the co-citation network. We plotted Fig. 6a and b by running CiteSpace, where each node represents one author, the link between two authors represents their co-citation relationship. In addition, the size of each node represents the author's citation counts, the distance between two nodes represents the two author co-citation frequency. The bigger the node is, the more important the author is; the smaller the distance between two nodes is, the higher the authors' co-citation frequency is, and the closer their research directions is. In both Fig. 6a and b, the authors of 15 or




a (based on the SSCI database)




b (based on the SCIE database)

**Fig. 6.** Map of the author co-citation network of HSR-related articles.

more citation counts are labeled.

As shown in Fig. 6a, in SS, the biggest node corresponds to Givoni M, co-cited with Roman C and other authors (Dobruszkes F, Albalate D, Adler N, Behrens C, Yang HJ, Fu X, and so on), who focused on the correlation between HSR and air transport. The second large node is represented by Vickerman R, with the co-citation relationship of Gutierrez J and other authors (Bonnafous A, Urena JM, Garmendia M, and so on), who focused on the impacts of HSR on space-economy, such as urban and regional development, and accessibility of cities. Besides, there are two other co-citation groups represented by Derus G and Hensher DA, respectively. The research direction of each is cost-beneficial analysis and social impacts of HSR individually.

As shown in Fig. 6b, several isolated sub-networks exist, which means the research areas of different sub-networks are far apart, although there are similar research directions within each sub-network. In SE, based on the average size of nodes in each sub-network, the first large co-citation group is represented by Zhai WM (Fig. 6b). Further analysis of the distances between these connected nodes revealed that there are three main research directions; one is the train–track–bridge dynamic interaction (Zhai WM, Yang YB, Fryba L, and Xia H), the other is train–track–ground dynamic interaction (Galvin P and Sheng X), and the third is wave propagation in the train-track-ground system (Esveld

**Table 7**
Top 10 cited authors of HSR-related articles.

| a (based on the SSCI database) | | | | | |
|---|---|---|---|---|---|
| Ranking | Counts | Centrality | Authors | Year | From |
| 1 | 171 | 0.15 | Givoni M | 2006 | Tel Aviv Univ, Israel. |
| 2 | 141 | 0.40 | Vickerman R | 2004 | Univ Kent, England. |
| 3 | 104 | 0.19 | Gutierrez J | 1997 | Univ Complutense Madrid, Spain. |
| 4 | 78 | 0.00 | Albalate D | 2015 | Univ Barcelona, Spain. |
| 5 | 73 | 0.25 | Roman C | 2010 | Univ Las Palmas Gran Canaria, Spain. |
| 6 | 73 | 0.03 | Campos J | 2011 | Univ Las Palmas Gran Canaria, Spain. |
| 7 | 72 | 0.05 | Urena JM | 2010 | Univ Castilla La Mancha, Spain. |
| 8 | 60 | 0.00 | Dobruszkes F | 2015 | Univ Libre Bruxelles, Belgium. |
| 9 | 60 | 0.09 | Martin JC | 2010 | Univ Las Palmas Gran Canaria, Spain. |
| 10 | 52 | 0.03 | Fu X | 2015 | Hong Kong Polytech Univ, China Hong Kong. |
| b (based on the SCIE database) | | | | | |
| Ranking | Counts | Centrality | Authors | Year | From |
| 1 | 173 | 0.01 | Zhai WM | 2010 | Southwest Jiaotong Univ, P. R. China. |
| 2 | 162 | 0.18 | Yang YB | 1997 | Natl Taiwan Univ, China Taiwan |
| 3 | 152 | 0.19 | Fryba L | 1997 | Czech R Acad Sci, Czech R. |
| 4 | 134 | 0.06 | Xia H | 2005 | Beijing Jiaotong Univ, P. R. China. |
| 5 | 126 | 0.07 | Baker C | 2010 | Univ Birmingham, England. |
| 6 | 106 | 0.21 | Sheng X | 2000 | East China Jiaotong Univ, P. R. China. |
| 7 | 89 | 0.00 | Liu L | 2012 | Beijing Jiaotong Univ, P. R. China. |
| 8 | 88 | 0.01 | Esveld C | 2005 | Delft Univ Technol, Netherlands. |
| 9 | 82 | 0.02 | He RS | 2012 | Beijing Jiaotong Univ, P. R. China. |
| 10 | 81 | 0.02 | Zhang J | 2015 | Central S Univ, P. R. China. |

Source: Own elaboration-based data from Output of author co-cited analysis in CiteSpace, Web of Science.

C). Backer C is at the center of the second large group focusing on high-speed train aerodynamics research. The third group is represented by Liu L on the research of wireless mobile communication. The fourth group concentrating on the research of tunnel compression waves when high-speed train passing by, is represented by Howe MS.

Table 7a and b lists the top ten cited authors by the citation counts of their published articles in the descending order in both fields, respectively. As shown in Table 7a, in SS, the most cited author is Givoni M (171), the other top nine cited authors are Vickerman R (141), Gutierrez J (104), Albalate D (78), Roman C (73), Campos J (73), Urena JM (72), Dobruszkes F (60), Martin JC (60), and Fu X (52). As shown in Table 7b, in SE, the most cited author is Zhai WM (173), followed by Yang YB (162), Fryba L (152), Xia H (134), Baker C (126), Sheng X (106), Liu L (89), Esveld C (88), He RS (82), and Zhang J (81). These results suggested that these authors' research played critical roles in contributing the HSR research and its future development, and they are influential authors.

As analyzed above, the results of author co-citation analysis in both fields, on the one hand, elucidates the intellectual structure of HSR research, on the other hand, help us identify the influential authors of HSR research, in each field.

### 3.3. Keywords co-occurrence analysis on HSR

Keywords can provide information about the core content of articles. Over time, a knowledge map of keyword co-occurrence could reflect hot topics, and burst keywords (keywords that are cited frequently over a period of time) could indicate frontier topics (Yu et al., 2017). Using by running CiteSpace, we plotted Fig. 7a and b, where each node represents one keyword, and its size is proportional to the co-occurrence frequencies. Table 8a and b lists the top 10 keywords in terms of counts and centrality in both fields. Table 9a and b lists the top 10 burst keywords with the most robust citation bursts in both fields.

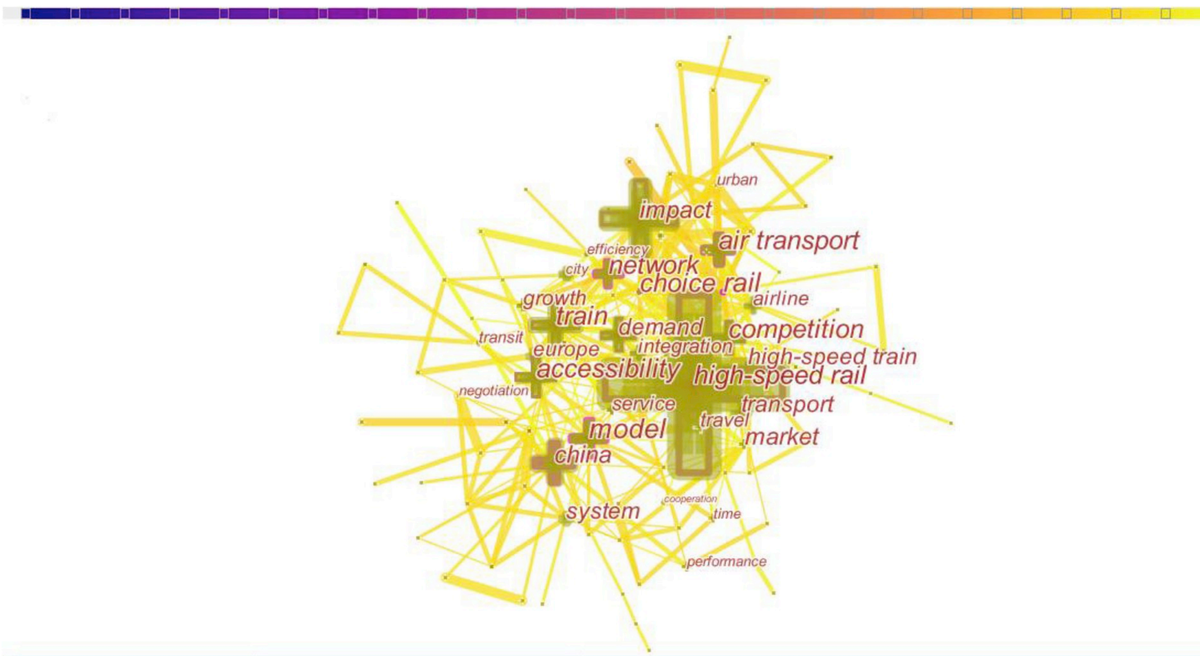
#### 3.3.1. Hot research topics

In SS, with the information provided in Fig. 7a and Table 8a, the three main hot research topics of HSR research are as follows:

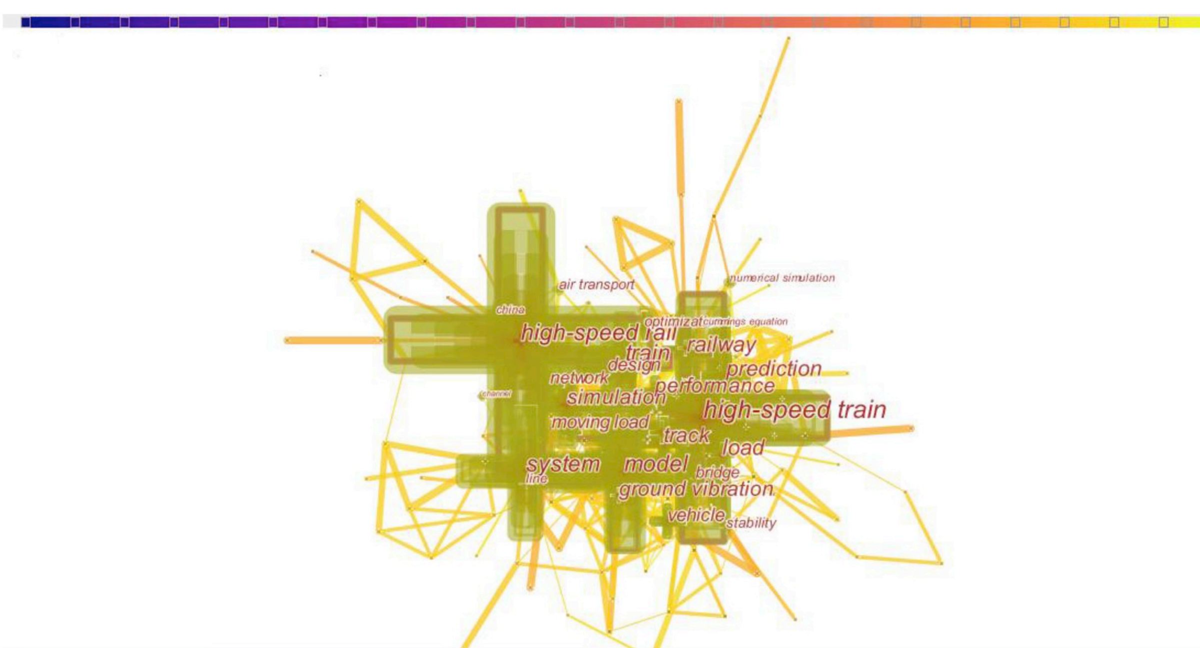
(1) *Research method*: Modeling is a commonly used research method. Researchers often analyze and solve problems by modifying existing models or building new models, including theoretical models and mathematical models.
(2) *HSR network*: These topics, such as the demand analysis of HSR network development, its planning and construction, the development modes in different countries, hierarchical structure of the built HSR network, and the competition between HSR network transport service and air transport service, have garnered more attention from researchers.
(3) *Various impacts*: The multiple influences of HSR (network) are mainly concentrated in three areas of social, economic, and environmental. Therein, social impacts primarily manifest in social cohesion, rural livelihood, labor migration, passenger's behavior choice, and population distribution; and economic impacts are principally reflected in the following facets, such as air transport demand, tourism, household income, manufacturing agglomeration, urban service industry agglomeration, land development, accessibility improvement, regions' economic fortunes, and so on. Regarding environmental impacts, there are potential mitigation of $CO_2$ emissions, combined effects of HSR noise, and ground vibrations.

While in SE, in Fig. 7b and Table 8b, there are also three main hot research topics:

(1) *Research method*: Modeling is the most common and effective research method, followed by simulation. Both these methods are sometimes used separately, and sometimes simultaneously. In addition, other methods include design and prediction, which at times are cross-used with modeling and simulation.
(2) *HSR operation*: The safe, stable and comfortable operation of HSR cannot be separated from the efficient operation of many systems, such as high-speed train (controlling and warning for collisions), track (including track-subgrade and train-track), tunnel, communication (including wireless), and power supply (including traction and catenary), where the systems of communication and traction power supply attract more attentions of researchers than others.
(3) *Various vibrations*: It includes ground vibration, track vibration, train body vibration, bridge vibration, bogie frames vibration, and so on, caused by HSR operation under different conditions; the research on these vibrations is primarily embodied in three aspects, one is the prediction, measurement and performance analysis of these vibrations, the other is the adverse effects of these vibrations on the surrounding environment, buildings, and equipment, and the third is the effective measures and materials to control and reduce these vibrations.




a (based on the SSCI database)




b (based on the SCIE database)

**Fig. 7.** Map of the keywords co-occurrence network of HSR-related articles.

### 3.3.2. *Research frontiers*

As shown in Table 9a, besides the burst strength, considering the top 10 burst keywords together with their corresponding red lines, the three research frontiers of HSR research in SS are as follows:

(1) *City*: Different types of HSR city-to-city links, connectivity and accessibility of city network, and development of cluster-cities.
(2) *Growth*: Tourism growth and urban and regional economic growth.
(3) *Integration*: The integration of different modes of transportation, such as HSR, air transport, urban public traffic, and so on, giving full play to their respective advantages, to meet the passengers different travel demands; the metropolitan integration and regional integration promoted by the development of HSR.

As shown in Table 9b, similarly, the three research frontiers of HSR research in SE are as follows:

(1) *China*: More cases or research data from China used for research.
(2) *Performance*: Aerodynamic performance of high-speed train in different conditions, and effects of influencing factors on aerodynamic performance of high-speed train such as bogie positions,

**Table 8**
Top 10 keywords in terms of counts and centrality.

a (based on the SSCI database)

| Ranking | Counts | Year | Keywords | Centrality | Year | Keywords |
|---|---|---|---|---|---|---|
| 1 | 309 | 2000 | high-speed rail | 0.31 | 2012 | China |
| 2 | 135 | 2009 | impact | 0.29 | 2007 | model |
| 3 | 99 | 2009 | Train | 0.28 | 2007 | network |
| 4 | 88 | 2012 | China | 0.23 | 2004 | rail |
| 5 | 83 | 2007 | Model | 0.21 | 2000 | high-speed rail |
| 6 | 75 | 2011 | accessibility | 0.19 | 2010 | air transport |
| 7 | 72 | 2012 | competition | 0.15 | 2012 | competition |
| 8 | 67 | 2010 | air transport | 0.15 | 1998 | high-speed train |
| 9 | 65 | 2007 | Demand | 0.14 | 2009 | impact |
| 10 | 62 | 2007 | Network | 0.13 | 2011 | accessibility |

b (based on the SCIE database)

| Ranking | Counts | Year | Keywords | Centrality | Year | Keywords |
|---|---|---|---|---|---|---|
| 1 | 551 | 1996 | high-speed rail | 0.22 | 1996 | high-speed rail |
| 2 | 546 | 1994 | high-speed train | 0.20 | 1994 | high-speed train |
| 3 | 342 | 2005 | model | 0.16 | 2005 | model |
| 4 | 279 | 2004 | system | 0.16 | 2000 | railway |
| 5 | 212 | 2000 | train | 0.11 | 2000 | train |
| 6 | 191 | 2000 | simulation | 0.11 | 2000 | vibration |
| 7 | 137 | 2000 | railway | 0.09 | 2004 | system |
| 8 | 133 | 2004 | design | 0.09 | 2001 | behavior |
| 9 | 118 | 2005 | prediction | 0.07 | 2005 | prediction |
| 10 | 108 | 2006 | track | 0.07 | 1998 | tunnel |

Source: Own elaboration-based data from output of keywords analysis in CiteSpace.

**Table 9**
Top 10 Keywords with the strongest citation burst.

| Keywords | Strength | Begin | End | 1900-2019 |
|---|---|---|---|---|
| high-speed train | 10.3996 | 1998 | 2014 | |
| high-speed rail | 3.9400 | 2000 | 2002 | |
| cost | 4.3032 | 2004 | 2011 | |
| rail | 6.0185 | 2004 | 2015 | |
| railway | 4.5821 | 2012 | 2013 | |
| Spain | 3.7945 | 2015 | 2016 | |
| land use | 4.9250 | 2015 | 2017 | |
| city | 4.4226 | 2017 | 2019 | |
| growth | 3.5603 | 2017 | 2019 | |
| integration | 5.6820 | 2017 | 2019 | |

b (based on the SCIE database)

| Keywords | Strength | Begin | End | 1900-2019 |
|---|---|---|---|---|
| moving load | 9.6285 | 1999 | 2011 | |
| bridge | 7.5190 | 1999 | 2014 | |
| beam | 9.2069 | 1999 | 2014 | |
| ground vibration | 8.5352 | 2001 | 2013 | |
| viaduct | 9.0728 | 2014 | 2015 | |
| line | 9.1118 | 2015 | 2016 | |
| numerical simulation | 9.5507 | 2015 | 2016 | |
| China | 12.3984 | 2016 | 2019 | |
| performance | 12.5803 | 2017 | 2019 | |
| flow | 15.4848 | 2017 | 2019 | |

Source: Own elaboration-based data from output of burst keywords analysis in CiteSpace.

inter-car gap length, wind speed variation, lateral wind, different ground conditions, and so on.

(3) *Flow*: The flow field and structure around high speed trains, for example, around the nose, side, roof, wake, and under body of high speed trains, and effects on the flow field of different parts of

high speed trains, such as the effects of bogies on the wake flow of high speed trains, and so forth.

## 4. Conclusions

Based on the analyses of co-authorship, co-citation, and keywords co-occurrence in the preceding part of the text, the following conclusions can be drawn.

As far as the main contributing forces of HSR research is concerned, at the micro (authors) level, the prolific authors in SS are Zhang AM, Martin JC, Vickerman R, and others, and in SE as Zhong ZD, Ai B, Zhang J, He RS, and so on. While the highly cited authors in SS are Givoni M, Vickerman R, Martin JC et al., in SE are Zhai WM, Fryba L, Zhang J, He RS et al. Where Martin JC, Vickerman R, Zhang J, and He RS are both prolific and highly cited authors. At the meso (institutions) level, the core research forces were mainly from universities, and Beijing Jiaotong Univ, Southwest Jiaotong Univ, and Chinese Acad Sci are prolific institutions in both fields. At the macro (countries) level, PR China, the United States, Spain, England, Italy, France, China Taiwan are prolific in both fields, and the number of articles in PR China is much more than other countries', the main reason for this is the policy support from Chinese government stronger than other countries to some extent.

Regarding the core journals, most of them with high qualities, such as TRANSPORT RES A-POL and TRANSPORT RES B-METH, their distribution not only provides important knowledge sources of HSR research in both fields but also indicates the characteristics of strong interdisciplinary nature of HSR research.

Regarding the main research themes, they are primarily embodied in the following areas, such as the interaction of HSR and air transport, impacts of HSR on space-economy, and so on in SS, HSR wireless mobile communication, high-speed train aerodynamics, HSR train–track–-ground dynamic interaction, the tunnel compression wave when high-speed train passing by, and so on in SE. In these research domains the regular intellectual bases have been established. Overall, the knowledge structure of HSR begins to take shape.

Regarding research hot topics, there are "research method," "HSR network," and "various impacts" in SS and "research method," "HSR operation," and "various vibrations" in SE. Regarding the latest research frontiers, there are "city," "growth," and "integration" in SS and "China," "performance," and "flow" in SE. Where "research method" is the common research hotspot in both fields.

All of these research findings provide an insight into HSR and valuable information for HSR researchers to understand the research status and trends in the HSR analysis. Follow-up evolvement of HSR research is inseparable from a series of sustained supportive policies from China and other countries. However, some deficiencies exist in this study despite some meaningful results obtained through the visualization on HSR-related publications. The input data for CiteSpace were all downloaded from SCIE and SSCI of WOSCC databases with >99% of the articles written in English, resulting in a linguistic bias of articles in other languages and neglect other data sources.

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## Declarations of competing interest

None.

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## Appendix A

Owing to built-in setups in the version of CiteSpace (5.3.R11), when conducting author co-authorship analysis, the authors' names are labeled in full names as shown in Fig. 1a and b. While conducting documents co-citation analysis and author co-citation analysis, the authors' names are both labeled in short names as shown in Fig. 5a and b and Fig. 6a and b. Owing to the unmodifiable built-in setups, to keep the authors' names consistent in context and avoid confusion, the authors' names are also used in short names in author co-authorship analysis. Table Alists the authors' full names involved in author co-authorship analysis in Fig. 1a and b and their corresponding abbreviations.

**Table A**
The authors' full names in Fig. 1a and b and their corresponding abbreviations involved in section 3.1.1

| Full names in Fig. 1a | Abbreviations | Full names in Fig. 1b | Abbreviations |
|---|---|---|---|
| ANMING ZHANG | Zhang AM | ZHANGDUI ZHONG | Zhong ZD |
| KUN WANG | Wang K | BO AI | Ai B |
| WENYI XIA | Xia WY | RUISI HE | He RS |
| CHANGMIN JIANG | Jiang CM | KE GUAN | Guan k |
| YAHUA ZHANG | Zhang YH | PINGYI FAN | Fan PY |
| TIZIANA D'ALFONSO | D'Alfonso T | CHENG TAO | Tao C |
| YUAN GAO | Gao Y | LIU LIU | Liu L |
| LIXING YANG | Yang LX | TAO ZHOU | Zhou T |
| JIANGUO QI | Qi JG | ZHENHUI TAN | Tan ZH |
| SHUKAI LI | Li SK | PING WANG | Wang P |
| ZIYOU GAO | Gao ZY | RONG CHEN | Chen R |
| JUAN CARLOS MARTIN | Martin JC | JINGMANG XU | Xu JM |
| ROGER VICKERMAN | Vickerman R | XUESONG JIN | Jin XS |
| JOSE M CORONADO | Coronado JM | XINBIAO XIAO | Xiao XB |
| AMPARO MOYANO | Moyano A | JIE ZHANG | Zhang J |
| ZHENHUA CHEN | Chen ZH | JIABIN WANG | Wang JB |
| | | ZHIGANG LIU | Liu ZG |
| | | MS HOWE | Howe MS |

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