Visualization Analysis for Tunnel Researches Based on CiteSpace

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Abstract. In order to find out the history, present situation and hot trend of tunnel research, this article is based on the literature data of tunnel study from 1997 to 2017 in CNKI database, using CiteSpace visual econometric analysis software to co-occurrence analysis and keyword co-word analysis and processing by citation data of authors and research institutions. The results showed that there is close cooperation among the authors of the main research groups, having a good cooperative relationship chain among the research institutions, and the keywords of hot research are diversion tunnel, deep buried tunnel, numerical simulation, water conveyance tunnel, lining, rock burst, rock mechanics, surrounding rock, river diversion tunnel, TBM and so on.

1. Introduction
Hydraulic tunnel is one of the main components of long distance water conveyance projects. It is a building built underground for the purpose of water conveyance and which occupies an important position in water conservancy projects [1]. Along with the development of our country’s national economy and technology, especially since the reform and opening, the emerging of the built of the Yuzixi first-class hydropower station’s diversion tunnel, Fengjiashan irrigation area’s diversion tunnel and water diversion project from Luanhe river to Tianjin city, and the development of the south-north water diversion project and the construction project of the supply tunnel from Songhua river, diversion project from Hanjiang river to Weihe river in recent years making researches in the field of tunnel have a long-term, stable and rapid development.

CiteSpace visualized metrological analysis software can explore the research foundation, research path, hot spots and frontiers of a research field. [2] Chen Chaomei et al. [3] used CitespaceII to identify and visualize new trends and trend in scientific literature. Morar, M et al. [4] analyzed the knowledge graph of chemical process and public industry problems, and obtained the research turning point and new trend of thermal integration and improvement. Small, H et al. [5] identified emerging scientific and technical topics through knowledge map. Xin Wei et al. [6] used CiteSpace to draw the knowledge map and summarized and analyzed the research status of military psychology in the Web of Science database. In the field of tunnel research, Chinese scholars have not yet made a systematic analysis of its development status and hot trends. In this paper, CiteSpace software was used to draw the scientific knowledge map of co-occurrence of authors, co-occurrence of institutions and co-occurrence of key words in the tunnel research field, and analysed the status, scientific research cooperation and research hot spots of tunnel research in China.
2. Data source and software selection

2.1. Date source
The data samples of this study were from the China National Knowledge Infrastructure database. In order to reflect the research situation of the tunnel research field more objectively, the periodical source categories were limited to SCI, EI and core journals. The time span was set from 1997 to 2017. "tunnel" was used as the noun for retrieval. Finally, 1680 literature were retrieved, and the entries that did not meet the analysis conditions were deleted. After sorting out, 1639 articles of relevant literature were obtained, and all literature data were downloaded and saved by Refworks format.

2.2. Software selection
CiteSpace was developed by Chen Chaomei professor of computer and information science at Drexel university based on the Java language platform [7]. As a powerful data analysis tool, CiteSpace provides not only the mining of citation space, but also the co-occurrence analysis of authors, institutions, countries or regions, as well as the co-occurrence analysis of keywords, subject words and categories, and can output the visual knowledge map. To some extent, it avoids the influence of researchers' subjective judgment on the analysis results, and then enhances the objectivity and reliability of the analysis results [8]. CiteSpace. V. 5.0.R7. SE. was selected as the analysis tool in this paper and the time division was set as one division every three years from 1997 to 2017, the author, institution and key words were selected as nodes respectively, the data were analyzed by software to form a visual co-occurrence map, and a comparative analysis was conducted on the basis of the co-occurrence map.

3. Result

3.1. Time analysis of output
As shown in fig.1, the statistical chart of the annual and cumulative output of the tunnel research from 1997 to 2017 shows that the average annual output articles of the tunnel area in the past 21 years were 78, and the overall output remains high level.

![Figure 1. Literature output trend in the field of tunnel research from 1997 to 2017.](image_url)

As can be seen from fig.1, the output volume of the tunnel field basically presents a stepped growth trend. Since China's development was still in its infancy at the end of the 20th century, the number of water diversion projects put into construction was limited, and the average annual output from 1997 to 2003 was only 27. From 2004 to 2007, the projects such as the diversion and water supply projects in Zhangjiu river etc have been designed so that the research into the tunnel field has been improved over the previous years, with an average of 64 articles published every year. Since 2008, with the construction of Liaoning Dahuofang water diversion project and the tunnel through the Yellow River on the middle line of the south-to-north water diversion project, the amount of research put into the tunnel field has also increased, and the amount of documents issued in the tunnel field has
been improved qualitatively. The average annual amount of documents issued has reached 114, and it has maintained a stable state every year.

3.2. Authors' co-occurrence analysis

The authors' co-occurrence analysis can lead to the core authors in the field of tunnel research as well as their mutual cooperation and relations. In CiteSpace, the "Node Type" parameter was selected as Author; in "Time Slicing", the "#Years Per Slice" was selected as 3 Years; in each Time Slice, the "Selection Criteria" threshold was changed to Top50; and the network cutting was done with Pathfinder+Pruning sliced networks. The graph of cooperation network of scientific research institutions in the tunnel field obtained by running the software is shown in fig.2. There are a total of 370 nodes, 512 connections, and the network density is 0.0075. The size of the nodes in the figure represents the number of articles published by the author [9]. A total of 370 authors were included in the co-occurrence atlas, and the occurrence frequency was 1328 times.

After analysis by CiteSpace, as shown in table 1, 24 authors have published more than 7 papers. From the co-occurrence map of tunnel authors, it can be seen that there is a strong inter-citation relationship between the research teams represented by Feng Xiating, Lu Wenbo, Zhang Chunsheng and Liu Ning. However, the research team represented by Li Ning and Zheng Ying is basically independent, with weak connection and cooperation with other research teams.

![Figure 2. Co-occurrence of authors in tunnel research.](image)

**Table 1.** Authors and institutions with more than 6 papers published from 1997 to 2017.

| Number | Number of output | Author       | Institution                                                                 |
|--------|------------------|--------------|-----------------------------------------------------------------------------|
| 1      | 36               | Feng Xiating | State key laboratory of geotechnical mechanics and engineering, Wuhan institute of geotechnical mechanics, Chinese academy of sciences |
| 2      | 30               | Li Ning      | Institute of geotechnical engineering, Xi'an university of technology        |
| 3      | 27               | Lu Wenbo     | State key laboratory of water resources and hydropower engineering science, Wuhan university |
| 4      | 21               | Su Kai       | State key laboratory of water resources and hydropower engineering science, Wuhan university |
| 5      | 18               | Yan Peng     | State key laboratory of water resources and hydropower engineering science, Wuhan university |
3.3. Mechanism co-occurrence analysis

In CiteSpace, the parameter of "Node Type" was selected as Institution, in time Slice "#Years Per Slice" was selected as 3 years, the threshold of "Selection Criteria" of each time Slice was changed to Top50, and Pathfinder+Pruning sliced networks was used for network cutting. Running software get tunnel research institutions cooperation network graph as shown in fig.3. A total of 213 institutional nodes and 154 institutional cooperative link lines are generated in the figure, the thickness of the link line represents the amount of literature produced jointly by the two agencies, the thicker the line is, the more the literature is produced, and the size of "annual ring" node represents the number of articles published by the mechanism. The more the number of articles published, the larger the node in the mechanism co-occurrence map will be [10].
Figure 3. Co-occurrence of tunnel research institutions.

Institutions co-occurrence graph growth tree branches plump, formed state key laboratory of water resources and hydropower engineering science, Wuhan university and Chinese academy of sciences, Wuhan institute of rock and soil mechanics in geotechnical mechanics and engineering state key laboratory as important output node, Xi’an university of technology institute of geotechnical engineering, the Yellow River survey planning and design limited company and Ertan hydropower development limited liability company, China’s hydropower consulting group east China survey design institute and other institutions for important media join points of complete cooperative ecological tree. The research institutions in the tunnel field are mainly research institutes, university laboratories and some design and development companies. Table 2 shows the key outputs of the tunnel research and high centrality structures. The cooperation between various agencies is frequent and makes great contribution to the tunnel research field.

| Number | Frequency | Centrality | Output institutions |
|--------|-----------|------------|---------------------|
| 1      | 84        | 0.16       | State key laboratory of water resources and hydropower engineering science, Wuhan university |
| 2      | 49        | 0.19       | State key laboratory of geotechnical mechanics and engineering, Wuhan institute of geotechnical mechanics, Chinese academy of sciences |
| 3      | 27        | 0.02       | Institute of geotechnical engineering, Xi’an university of technology |
| 4      | 26        | 0          | The first hydropower corps of the Chinese people’s armed police force |
| 5      | 25        | 0.02       | Yellow River survey planning and design limited company |
| 6      | 21        | 0.1        | Ertan hydropower development limited liability company |
| No. | Year | Contribution | Institution/Department |
|-----|------|--------------|------------------------|
| 7   | 19   | 0            | Shanxi province Wanjiazhai Yellow River diversion project administration bureau |
| 8   | 18   | 0.01         | East China investigation and design institute of sinohydro consulting group |
| 9   | 17   | 0.06         | College of water resources and hydropower, Sichuan university |
| 10  | 17   | 0            | Beijing water conservancy planning and design institute |
| 11  | 17   | 0.01         | Key laboratory of hydraulic rock mechanics, ministry of education, Wuhan university |
| 12  | 17   | 0.09         | Key laboratory of geotechnical mechanics and engineering, ministry of water resources, Changjiang academy of sciences |
| 13  | 17   | 0            | Liaoning Runzhong water supply limited liability company |
| 14  | 16   | 0.04         | Yunnan water conservancy and hydropower survey and design institute |
| 15  | 16   | 0.02         | School of resources and civil engineering, Northeastern University |
| 16  | 14   | 0.01         | School of architecture and engineering, Tianjin university |
| 17  | 13   | 0.07         | Institute of geotechnical engineering, Hohai university |
| 18  | 13   | 0            | School of water resources and hydropower, Hohai university |
| 19  | 13   | 0.02         | China power construction group east China survey design research institute limited company |
| 20  | 13   | 0.02         | School of water conservancy and hydropower engineering, Hohai university |
| 21  | 13   | 0.04         | School of civil engineering Hohai university |
| 22  | 13   | 0            | China railway first survey and design institute group limited company |
| 23  | 12   | 0.01         | School of water resources and hydropower, Wuhan university |
| 24  | 12   | 0            | College of water conservancy and architectural engineering, northwest a&f university |
| 25  | 12   | 0.02         | State key laboratory of hydraulics and mountain river development and protection, Sichuan university |
| 26  | 11   | 0            | China institute of water resources and hydropower research |
| 27  | 11   | 0            | Yangtze river water conservancy commission design institute |
| 28  | 11   | 0.06         | Yalong river hydropower development limited company |
| 29  | 11   | 0            | State key laboratory of water and sediment science and water conservancy and hydropower engineering, Tsinghua university |
| 30  | 11   | 0            | School of science, Qingdao university of technology |
| 31  | 10   | 0.04         | Key laboratory of geological hazards, ministry of education, three gorges reservoir area, three gorges university |
| 32  | 10   | 0            | Liaoning hydraulic and civil engineering consulting limited company |

3.4. **Analysis of keywords co-word**

Keywords are the summary of the main content of the scientific literature. Through the co-occurrence analysis of the keywords in the tunnel field, this paper understands the main focus and development trend of the tunnel research. Firstly, the parameter "Node Type" was selected as the keyword in the software, and the time slice "#Years Per Slice" was selected as 3 years. The threshold of "Selection Criteria" for each time slice was changed to Top50, and Pathfinder+Pruning sliced networks was used for network cutting. Run the software to get the keyword common word map, as shown in figure 4.
The network map has 247 nodes, 512 connections, and the network density is 0.0169.

Figure 4. Co-word map of keywords in tunnel research.

There are 247 key words co-existing in the map, apart from the keywords with the same meaning, the most frequent keywords are "diversion tunnel", "hydraulic tunnel", "deep tunnel", "numerical simulation", "water conveyance tunnel", "lining", "rock burst", "rock mechanics", "surrounding rock", "diversion tunnel", "TBM", "high ground stress" and etc.

In this paper, used the Find clusters tool in the software for keyword clustering, and formed 10 clusters as shown in figure 5. The Modularity Q=0.5807 in the figure above indicates good clustering results and the Mean Silhouette coefficient=0.4193, indicating general Silhouette of the network.

Figure 5. Co-occurrence word cluster diagram of tunnel research.

Along with the implementation of the "national 172 water diversion project construction plan", the number of new hydraulic tunnel continue to increase in recent years, such as the water diversion tunnel in Lanzhou water source area, the Geshuang tunnel in the north Sinkiang water supply project, the diversion tunnel in the northeast from the Songhua river water supply tunnel and other hydraulic tunnels have started construction [11], combined with the tunnel research co-occurrence word clustering figure out that in recent years, the main research direction in the field of tunnel have: (1) Study on rock engineering problems such as stress, strain, stability and failure mechanism of rock mass under the action of water flow, temperature and load changes [12]. (2) Exploration of various construction methods and research of construction technology in tunnel construction [13]. (3) Research on rock burst, a common dynamic failure phenomenon in the construction process of hydraulic tunnel [14]. (4) Study on numerical calculation method for stability analysis of surrounding rock by discrete element method; (5) Research on the diversion tunnel from the water source in the tunnel field.
Table 3. Main keywords and centrality of tunnel research

| Number | Frequency | Centrality | Key-world                  | Co-occurrence year |
|--------|-----------|------------|---------------------------|--------------------|
| 1      | 192       | 0.13       | Tunnel                    | 1998               |
| 2      | 188       | 0.19       | Diversion tunnel          | 1998               |
| 3      | 96        | 0.13       | Hydraulic tunnel          | 1998               |
| 4      | 92        | 0.08       | Tunnel engineering        | 2003               |
| 5      | 82        | 0.04       | Deep-buried tunnel        | 2004               |
| 6      | 78        | 0.05       | Numerical simulation      | 2004               |
| 7      | 73        | 0.09       | Water conveyance tunnel   | 1998               |
| 8      | 66        | 0.15       | Lining                    | 1998               |
| 9      | 56        | 0.02       | Rock burst                | 2006               |
| 10     | 55        | 0.07       | Rock mechanics            | 2004               |
| 11     | 54        | 0.12       | Surrounding rock          | 1998               |
| 12     | 52        | 0.07       | River diversion tunnel    | 1997               |
| 13     | 47        | 0.05       | Jinping-II hydropower Station | 2006         |
| 14     | 46        | 0.06       | TBM                       | 2001               |
| 15     | 31        | 0.06       | High ground stress        | 2006               |
| 16     | 31        | 0.06       | Tunnel excavation         | 2000               |
| 17     | 30        | 0.15       | Tunnel construction       | 1997               |
| 18     | 28        | 0.04       | Tunnel engineering        | 2003               |
| 19     | 27        | 0.12       | Finite element            | 2003               |
| 20     | 27        | 0.15       | Pressure tunnel           | 1997               |
| 21     | 27        | 0.12       | Stability                 | 2004               |
| 22     | 26        | 0.09       | Circular tunnel           | 2004               |
| 23     | 26        | 0.08       | Construction technique    | 2000               |
| 24     | 24        | 0.02       | Tunnel crossing yellow river | 2003         |
| 25     | 23        | 0.04       | Adjoining rock stability  | 2004               |
| 26     | 23        | 0.09       | Construction              | 1999               |

It can be concluded from the list of the main keywords and the centrality of the tunnel study that the "diversion tunnel" has the highest centrality value and is the decisive hub connecting the key words. The research on the tunnel is mainly based on the diversion tunnel, and the research on "lining", "tunnel construction", "pressure tunnel", "surrounding rock", "finite element", "stability" and other key words are derived successively.
In CiteSpace software with Keywords in running condition, in the column of Bursts tunnel research keywords dash forward show in the graph, dash forward show strength strongest keywords is "Wanjiazhai Yellow River diversion project", dash forward show strength of 6.8705. The first phase of the Yellow River diversion project in Wanjiazhai has 25 tunnels, and the Number 7 tunnel in the south main line is 43.5 kilometers long. The construction difficulty is unprecedented. On the premise of the emergence of "Wanjiazhai Yellow River diversion project", representative keywords such as "crack", "smooth blasting", "deep buried long tunnel", "surrounding rock classification" and "TBM" also emerged one after another.

From 2006 to 2008, "Dahuofang reservoir water transfer project", "Middle route of south-to-north water diversion project" and "Jinping secondary hydropower station" have emerged one after another. Due to the construction of these projects, some new analysis methods such as "elastoplastic analysis", "finite element strength reduction method", "numerical simulation" have been widely used in the field of tunnel. In terms of tunnel diseases, researches on "crack width", "rock burst", "seepage" and "high ground temperature" also begin to emerge.

4. Conclusion and Prospect
In this paper, CiteSpace visualized metrological analysis software was used to compare and analysis the scientific and technological documents on tunnel research collected by CNKI from 1997 to 2017. The analysis results showed that:

(1) Research literature output. Basically, the output volume in the tunnel field presents a stepped growth trend. After 2008, with the construction of many new water conveyance projects, more and more researches have been put into the field of tunnel, with an average annual output of 114 papers. The research on China's investment in the field of tunnel will increase gradually with the construction of national key construction projects such as long-distance water supply tunnel engineering.

(2) Co-occurrence analysis. The research teams represented by Feng Xiating, Lu Wenbo, Zhang Chunsheng and Liu Ning have a strong mutual citation relationship, which basically accounts for 40% of the output in the tunnel field. However, the research team represented by Li Ning and Zheng Ying is basically independent, with weak connection and cooperation with other research teams.

(3) Institutional research cooperation. The state key laboratory of water resources and hydropower engineering science of Wuhan university and the state key laboratory of rock and soil mechanics and engineering of Wuhan institute of rock and soil mechanics, Chinese academy of sciences are the main research institutions, which have cooperated frequently with other agencies and made great contributions in the field of tunnel research.

(4) Research in hot areas. With the construction of the north Sinkiang water supply project, the northeast water supply project and the upcoming construction of the west route of the south-to-north water transfer project, the main directions of the tunnel research are diversion tunnel, deep-buried tunnel, water conveyance tunnel, water diversion tunnel and pressure tunnel. With the deepening of relevant studies in the field of tunnel, new construction methods, new technologies and new structures have gradually become research hot spots. For example, the current mainstream TBM construction technology, smooth blasting technology in the process of tunnel excavation, etc. It is used in numerical simulation, finite element analysis and lining structure research. It is also the key to study the rock burst failure phenomenon and the stability of surrounding rock during tunnel construction.

Acknowledgement
This work was supported by the National Natural Science Foundation of China (51669010, 51969011).

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