Analysis of research frontier trend in transportation field based on knowledge mapping method

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Abstract—Identifying the research frontier trends in the field of transportation can provide researchers with new perspectives and innovation points, and provide information support for decision-making of scientific research planning managers. In this paper, the visual knowledge map analysis method is used to analyze the conference documents published by the Transportation Research Board of the United States from 2015 to 2019, and analyze in detail eight key areas, including aviation, highway, marine transportation, motor carriers, pedestrians and bicyclists, pipelines, public transportation and railroads. The above analysis reveals the research frontier trends of the whole and 8 key sub fields in the field of transportation.

1. INTRODUCTION
Transportation is a highly comprehensive and systematic science of complexity, sharing the characteristics of social sciences and natural sciences. Moreover, interdisciplinarity remains one of its striking features. Transportation engineering is increasingly closely interwoven with other engineering ranging over road, automotive, transportation (or logistics), human factors, electronic, communication, security and environment, which compounds the difficulty in distinguishing their boundaries. In consequence, transportation engineering is difficult to define in light of its objects, contents and methodology [1]. So far, academic circles have still lacked a systematic summary and review of the research frontier trends in the whole transportation field.

Literature, a crucial means used by modern researchers for result output and communication, serves as a pool of researcher’s study contents, whereas the special literature of conference documents prove superior to journal documents in meeting timeliness. In consequence, the research contents in conference documents are more effective in updating the research frontier trends facing researchers in their corresponding field.

This paper systematically summarizes and reviews the research frontier trends in the entire transportation field through visual knowledge map analysis of conference documents in this field from the perspective of bibliometrics, in the hope of providing references for scientific and technological innovation, and for planning and decision-making in such field.

2. DATA SOURCES AND SIZE

2.1. Data Sources
Data used for analysis in this paper are drawn from the annual meeting documents released by Transportation Research Board (TRB). All research fields of transportation have been covered by papers submitted during TRB’s annual meeting.

2.2. Data Size
Conference documents are sorted in accordance with the classification methods proposed by TRB [2]. Eight categories exist by the standard of transportation modes, namely aviation, highways, marine transportation, motor carriers, pedestrians and bicyclists, pipelines, public transportation and railroads. In contrast, as shown in Table 1, 29 categories exist in light of the research topics in the field of transportation.

### Table 1: Trends of Released Papers on Different Research Topics

| Topics                              | 2015 | 2016 | 2017 | 2018 | 2019 | Quantity Trend | Proportion Trend |
|-------------------------------------|------|------|------|------|------|----------------|------------------|
| Administration and Management       | 70   | 33   | 43   | 19   | 13   | **↓**           | **↓**             |
| Bridges and other structures        | 105  | 80   | 52   | 107  | 21   | **↑**           | **↑**             |
| Construction                        | 57   | 56   | 35   | 76   | 24   | **↑**           | **↑**             |
| Data and Information Technology     | 256  | 259  | 300  | 183  | 211  | **↑**           | **↑**             |
| Design                              | 186  | 135  | 97   | 139  | 45   | **↑**           | **↑**             |
| Economics                           | 78   | 68   | 70   | 127  | 67   | **↑**           | **↑**             |
| Education and Training              | 16   | 13   | 11   | 17   | 6    | **↑**           | **↑**             |
| Energy                              | 42   | 64   | 37   | 106  | 47   | **↑**           | **↑**             |
| Environment                         | 131  | 139  | 132  | 164  | 75   | **↑**           | **↑**             |
| Finance                             | 71   | 56   | 67   | 82   | 46   | **↑**           | **↑**             |
| Freight Transportation              | 92   | 88   | 101  | 130  | 63   | **↑**           | **↑**             |
| Geotechnology                       | 36   | 29   | 28   | 55   | 24   | **↑**           | **↑**             |
| History                             | 4    | 4    | 3    | 9    | 1    | **↑**           | **↑**             |
| Hydraulics and Hydrology            | 10   | 6    | 5    | 21   | 5    | **↑**           | **↑**             |
| Law                                 | 10   | 8    | 16   | 9    | 12   | **↑**           | **↑**             |
| Maintenance and preservation        | 139  | 96   | 128  | 118  | 43   | **↑**           | **↑**             |
| Materials                           | 135  | 129  | 120  | 259  | 106  | **↑**           | **↑**             |
| Operations and Traffic Management   | 395  | 359  | 331  | 740  | 588  | **↑**           | **↑**             |
| Passenger Transportation             | 46   | 24   | 35   | 121  | 38   | **↑**           | **↑**             |
| Pavements                           | 196  | 175  | 213  | 394  | 123  | **↑**           | **↑**             |
| Planning and Forecasting            | 721  | 648  | 755  | 1008 | 492  | **↑**           | **↑**             |
| Policy                              | 58   | 52   | 40   | 106  | 57   | **↑**           | **↑**             |
| Research                            | 3    | 3    | 3    | 4    | 4    | **↑**           | **↑**             |
| Safety and Human Factors            | 273  | 234  | 301  | 481  | 277  | **↑**           | **↑**             |
| Security and Emergencies            | 26   | 29   | 47   | 60   | 31   | **↑**           | **↑**             |
| Society                             | 72   | 60   | 82   | 148  | 109  | **↑**           | **↑**             |
| Terminals and Facilities            | 54   | 46   | 41   | 97   | 39   | **↑**           | **↑**             |
| Transportation (General)            | 139  | 120  | 120  | 148  | 94   | **↑**           | **↑**             |
| Vehicles and Equipment              | 77   | 118  | 120  | 329  | 213  | **↑**           | **↑**             |

Documents themed on administration and management, design, and maintenance and preservation reached their peak both in quantity and proportion in 2015, which, to a certain extent, reveals recent years’ decline in attention on the three topics paid by researchers involved.

The earlier peak in document proportion than in quantity, covering research topics including environment, finance, freight transportation, and planning and forecasting, reflects that recent years have seen a slower rate of increase in relevant researchers’ attention on the four topics.

On the contrary, in regard to the research topics of data and information technology, economics, law, operations and management, policy, security and emergencies, society, transportation (general), and vehicles and equipment, their documents’ quantity and proportion peaked in 2018 and 2019 respectively, which implies that these topics have received closer attention from relevant researchers in the past two years.

3. Methodology
As the data on TRB’s documents feature merely five fields, namely author, title, keywords, abstract and publication year, the research frontiers in the field of transportation can be fully revealed should the analysis method of knowledge maps be adopted. Specifically, this paper conducts a visualization map analysis of the keyword co-occurrence in the documents released by TRB through the knowledge map tool, VOSviewer (visualization of similarities). Three types of visualization maps are produced, namely network visualization, overlay visualization, and cluster regularized overlay visualization, which are used to reveal the research frontiers of transportation.
3.1. Network visualization

In network visualization, an element composed of a node (round spot in the Fig.1) and a text label represents a keyword, whose frequency of co-occurring with other keywords is signified by the size of this node, meaning that a larger node stands for a higher frequency of co-occurrence. The color of a node represents what cluster it belongs to. Different clusters are displayed in different colors. Nodes in the same color represents the documents with the same or similar research orientation. The clustering algorithm applied to VOSviewer is an algorithm for modularity-based community detection in large networks, an optimal version of the community detection algorithm proposed by Newman and Girvan, through modularized function weight and parameterized variables [3]. On that basis, Ludo Waltman and Nees Jan van Eck, developers of VOSviewer, have had the clustering function of VOSviewer further optimized by utilizing a smart local moving algorithm (SML) [4], endowing VOSviewer’s local clustering with a higher precision.

Network visualization analysis of the literature keywords in certain field can highlight the current distribution of research directions in that field.

3.2. Overlay visualization

In overlay visualization, color mapping is used to map corresponding colors onto each node of keyword in accordance with the mean of years when the keyword occurs. The annual change in node color can reflect the research trends in particular field. For instance, the occurrence of the keyword “ridesharing”, once in 2016 and 2017, thrice in 2018 and four times in 2019, implies that its mean of years is \((2016*1+2017*2+2018*3+2019*4)/(1+1+3+4)=2018.11\).

Overlay visualization analysis of the literature keywords in certain field can reveal the keyword cluster that has a mean of years closest to the present time, a situation in which the research contents represented by this keyword cluster signify the research frontiers of this field.
3.3. Cluster regularized overlay visualization

In cluster regularized overlay visualization, keywords have their x- and y-coordinates adjusted respectively based on the clusters (colors) that the keywords belong to in network visualization, and the mean of years in overlay visualization, leaving those keywords arranged in time order in their respective columns that are shaped in light of the clusters the keywords belong to, which facilitates the discovery of research frontiers from densely distributed overlay visualization.

4. OVERALL TRENDS IN RESEARCH FRONTIERS

Clustering of research on 9013 documents released by TRB (2015-2019) helps produce a graph as shown in the following figure. The clustering result in the graph demonstrates that five major research directions exist in the field of transportation, namely traffic safety and risk management, pavement materials and engineering, mode choices based on travel behavior, global optimization of traffic flows, and travel demand and route planning of different transportation modes.
Research frontiers of the five directions in transportation are analyzed as shown in Fig. 5 and Fig. 6.

Research frontiers involving pavement materials and engineering (displayed by red dotted line circle) contain: performance tests of various pavement under repeated loads, disaster resilience of various pavement, and studies on bitumen modifications through asphalt additives;

Research frontiers in the area of mode choices based on travel behavior (green dotted line circle) include: studies on the impacts that demand responsive transportation, such as ridesourcing and ridesharing, impose on travelers’ choices of transportation modes;

Research frontiers pertaining to demand management and forecasting, and route planning (blue dotted line circle) comprise: the application of nonlinear programming and time domain analysis to travel demand forecasting and route planning;

Research frontiers concerning global optimization of traffic flows (yellow dotted line circle) are oriented towards: market penetration of autonomous and connected vehicles (CVs); highway traffic control based on macroscopic fundamental diagrams; communication modes, vehicle following strategies, eco-driving strategies at intersections, and vehicle crashes of autonomous and connected vehicles; the application of deep learning algorithm to the training of autonomous vehicles’ control strategies and to vehicle tracing;

Research frontiers regarding traffic (in particular highways) safety and risk management (purple dotted line circle) include: the impacts that the driving behavior exhibited by automobile drivers exert on traffic safety; the transferability of safety performance functions (SPFs), including SPFs’ standardization and calibration; the application of lane occupancy detection to highway design and driving safety alerting.

A holistic knowledge map analysis of the transportation field can reveal its panorama to a certain extent. Despite that, the extensive research scope in the transportation field and the enormous number of the documents released by TRB render it unlikely to detailedly display the research frontier trends in each sub-fields of transportation through such analysis. In consequence, knowledge map analysis is conducted hereinafter regarding the key transportation modes in the field of transportation, in the hope of revealing the research frontiers in this field from as multiple dimensions and facets as possible.

5. RESEARCH TRENDS IN KEY FIELDS

A deep analysis is conducted centering on the eight types of transportation modes classified by TRB. The clustering, intensity, and timing of the keyword co-occurrence serve as the basis for analyzing and exploring the research status and development tendencies in each transportation mode.

5.1. Aviation

The following figure shows the cluster analysis of TRB’s documents regarding the transportation mode of aviation. Six major research directions exist in this field, including: studies on airport runway
pavement, aviation risk management, competition games between airlines, the application of drones and aircrafts to traffic surveillance, airport environment impacts, and flight planning.

The research frontiers in the six major directions of aviation are analyzed as shown in Fig. 7, in the past two years including: the application of neural network and back calculation to studies on pavement performance and flexible pavement; emergency management; electric vehicles; the application of integer programming in operations research to aeronautical operational control (AOC); studies pertaining to airlines’ willingness to pay.

5.2. Highways

The following figure displays the cluster analysis of TRB’s documents concerning the transportation mode of highways. Four major research directions exist in highways, namely: studies on highway pavement design, mix design of pavement materials, and pavement performance; planning and forecasting of highway traffic behavior, and the environment impacts imposed by highway traffic; studies on risk management and assessment of highway safety; global optimization of traffic flows.
Figure 10: Research trends in the field of highways

Figure 11: Research trends in the field of highways (cluster regularized overlay visualization)

The research trends in highways is as shown in Fig. Figure 10 and Fig. Figure 11, in which yellow spots represent the keywords that have occurred frequently in recent years. An analysis of the above map demonstrates that research frontiers in 2018 and 2019 included:

Concerning the research directions of highway pavement design, mix design of pavement materials, and pavement performance (red dotted line circle), the past two years’ research frontiers respectively concentrated in the first aspect on construction of pavement base course, lateral restraint mechanism of geogrids and relevant mechanical stability; in the second on performance tests of various materials, for instance, the impacts that fiber’s absorptive property, anti-stripping performance, and rutting-resistant performance impose on pavement performance; in the last aspect on self-healing of bituminous materials.

In terms of studies on risk management and assessment of highway safety (yellow dotted line circle), the past two years’ research frontiers centered on the transferability of safety performance functions (SPFs), including SPFs’ standardization and calibration; the application of lane occupancy detection to highway design and driving safety alerting; modeling vehicle-bicycle crashes and pedestrian-bicycles crashes to analyze crash causes, frequency and severity; the stability and efficiency of vehicles’ crash avoidance systems, including forward collision warning (FCW), pedestrian collision warning (PCW), blind spot warning (BSW) or lane change warning (LCW), and intersection movement assist (IMA); factors affecting the crash risks facing teenage drivers; human factors in crashes, for instance, the impacts that the driving behavior exhibited by automobile drivers (including degree of concentration) exert on crash incidence; factors resulting in pedestrian-vehicle crashes, for instance, pedestrian exposure and the impacts that the proportion of vehicle types on the road impose on pedestrian-vehicle crashes.
Research frontiers regarding global optimization of traffic flows (blue dotted line circle) in the past two years focused on communication modes, vehicle following strategies, eco-driving strategies at intersections, and vehicle crashes of autonomous and connected vehicles; the application of deep learning algorithm to the training of autonomous vehicles’ control strategies and vehicle tracing, the estimation of bicyclists’ travel destinations and traffic flow transferability of shared bicycles across traffic zones, the optimization of traffic assignment theory on user equilibrium (UE), the forecasting of traffic crashes by utilizing convolutional neural networks, the detection of safety problems at intersections and traffic incidents based on traffic data accessed from various channels, and the classification of pavement conditions; the optimization of connected and autonomous vehicles’ trajectories, traffic signal timing, coordinated signal control and the measurement of traffic volume in neighboring areas, design of coordinated traffic signal control over CVs, shared mobility and departure interval, frequency scheduling of bus services, and strategies for autonomous vehicles’ speed control.

In regard to studies on the planning and forecasting of highway traffic behavior, and the environment impacts imposed by highway traffic (green dotted line circle), research frontiers in the past two years were oriented to ridesourcing’s algorithms for route and time planning and management, marginal strip exploitation, competition with taxis, and its impacts on traffic congestion and on mode choices of travel behavior; the impacts that demand responsive transportation have on traffic congestion, and route optimization; traffic issues pertaining to school children, for instance, safe route to school (SRTS), and the impacts on traffic imposed by the time interval between office hours and school hours and on pupils’ health imposed by traffic pollution.

5.3. Marine Transportation

The following figure displays the cluster analysis of TRB’s documents referring to the transportation mode of marine transportation. Eight major research directions exist in this field: optimization of container terminals’ efficiency; port operations; freight transportation modes and planning; inland waterway traffic; economic analysis and demand forecasting of marine transportation; mode choices of marine transportation; marine safety; environment impacts imposed by marine transportation.

Figure 12: Clustering of research on marine transportation

Figure 13: Research trends in the field of marine transportation
As shown in Fig. 13, research frontiers regarding the eight directions in this field during the past two years contained: the application of cranes and trucks to the optimization of container terminals’ efficiency; vessel operations in inland waterway traffic; schedules of liner shipping; the application of crash avoidance systems to marine safety; optimization of automatic vehicle detection and identification systems on the basis of spatio-temporal network and neural network analysis.

5.4. Motor Carriers
The following figure displays the cluster analysis of TRB’s documents involving the transportation mode of motor carriers. Five major research directions exist in this field: economic and environmental analysis of freight transportation; cause analysis of truck crashes; energy consumption of heavy-duty trucks; demand forecasting and route planning of truck traffic; studies on the weighing of heavy-duty vehicles.

As shown in Figure 15, research frontiers concerning the five directions in this field during the past two years focused on: choice of truck routes and scheduling optimization of container handling based on simulation; the application of regression analysis to trucking safety and highway design; the application of intelligent vehicles and traffic platooning to the reduction of energy consumption; the impacts imposed by policies on traffic volume and freight transportation; methodology of weighing tractor trailer combinations in motion.

5.5. Pedestrians and bicyclists
The following figure displays the cluster analysis of TRB’s documents concerning the transportation mode of pedestrians and bicyclists. Five major research directions exist in this field: the impacts that urban environment and social factors impose on bicyclists’ mode choices; pedestrian flow and route choices; crash severity and risk assessment; factors influencing street crossing behavior and relevant models; bicycle sharing.
Research frontiers in the five major directions of pedestrians and bicyclists are as shown in Fig. 17, which demonstrates that the past two years’ research concentrated on: factors affecting travel by shared bicycles, and modeling, namely building models to forecast the traffic flow transferability of shared bicycles based on analysis of traffic accessibility, travel demand, relationships between neighbors, and travel time; building analysis models of traffic crashes involving pedestrians and pedestrian collision warning (PCW) system based on factors affecting injury severity ranging from weather conditions to pedestrian jaywalking.

5.6. Pipelines

As shown in Table 2, 13 documents published by TRB concentrate on the transportation mode of pipelines. The steady increase of documents in this field from 2016 to 2019 corroborates that studies on pipelines have been drawing closer attention.

| Number | Author | Title | Year |
|--------|--------|-------|------|
| 1      | FARRAG K., GONG J., | TRANSPORTATION RESEARCH B. Risk Analysis of Natural Gas Distribution Lines Subjected to Natural Forces | 2016 |
| 2      | MAGHSOUDI R., AMADOR-JIMENEZ L., SHAHROKHI SHAHRAKI H., ALECSANDRU C., | A Capacity-Based Optimal Allocation of Storm Pipes’ Replacements: Considering the Effects of Climate Change and Urbanization | 2016 |
| 3      | DUSYK N., AXSEN J., DULLEMOND K., | TRANSPORTATION RESEARCH B. Media Framing of Unconventional Fossil Fuels: The Absence of Climate Dialogue In Canada’s Northern Gateway Project | 2017 |
| 4      | MEEGODA J. N., TANG C., JULIANO T. M., POTTS L., AGBAKEF M., | A Drainage Identification Analysis and Mapping Database | 2017 |
| 5      | YANG Y., YU X., | Computer Vision System for Real-Time Dynamic Response Measurement of Arch-Truss and Rising Pipeline Structure | 2017 |
5.7. Public Transportation

Figure 18 shows the cluster analysis of TRB’s documents centering on the transportation mode of public transportation. Among the four major research directions of public transportation are: optimization of public traffic flows through mathematical approaches; service quality of shared mobility; collection and analysis of data on public transportation; travel behavior of public transportation.

Figure 18: Clustering of research on public transportation

Figure 19: Research trends in the field of public transportation
As shown in Figure 19, research frontiers pertaining to the four directions in this field during the past two years centered on: optimizing bus route networks through mathematical models which are built by using the data analysis approaches of spatial analysis and shortest path algorithms; exploring social hot-spot issues varying from ride sharing to Uber, shared-use vehicle system and equity, and designing a framework for demand responsive public transportation systems; applying new technologies and new forms of business to public transportation, such as electric buses and electric vehicle charging.

5.8. Railroads
The cluster analysis of TRB’s documents concentrating on the transportation mode of railroads is as shown in Figure 20. Research in this field has four major directions, namely: railroad travel surveys and management; railroad transportation planning and forecasting; railroad maintenance; multimodal transportation involving railroads.

![Figure 20: Clustering of research on railroads](image1)

The past two years’ research frontiers in the four major directions of railroads are as shown in Fig. Figure 21, focusing on two aspects. One is studies on the disaster resilience of railroad transportation. The other covers studies on rapid transit of high population density, with subways included. For instance, mathematical models built on the basis of traffic are used to estimate the trends of traffic volume and passenger traffic, so that the prevention of emergencies during railway operation, such as traffic crashes and terrorism, can contribute to the reinforcement of railroad traffic safety.

6. Conclusion
In light of the data on the documents released by TRB (2015-2019), this paper detailedly analyzes the research frontier trends in eight key fields, namely aviation, highways, marine transportation, motor carriers, pedestrians and bicyclists, pipelines, public transportation and railroads. The above analysis reveals that the research frontier trends in the field of transportation are oriented to the following aspects:
6.1. Studies on green transportation

Studies on green transportation aim to minimize energy consumption and pollutant emissions in the process of transportation, mainly including:

- Green pavement materials and green pavement construction technologies; optimization of passenger and freight transportation structure, green travel, for instance, the application of such technologies as Internet and sharing mobility to public transportation; improvement of utilization efficiency of port shoreline, land and channel resources; application of clean and efficient transportation facilities; reductions of greenhouse gas emissions, such as carbon dioxide; transportation planning under the concept of green traffic.

6.2. Studies on intelligent transportation

Studies in this regard concentrate on the application of modern electronic and information technologies, including Internet of Things, cloud computing, artificial intelligence, automatic control (cybernation), and mobile Internet, to the field of transportation, mainly containing the following aspects:

- Digitalization and networking of transportation infrastructure and transport facilities, for instance, intelligent connected vehicles (ICVs), and intelligent traffic surveillance systems; informatization and intelligentization of traffic operation data; the application of artificial intelligence and Internet to autonomous vehicles, ICVs, intelligent traffic surveillance, and intelligent travel decisions; cooperative vehicle infrastructure systems (CVIS) and vehicle platooning techniques used for autonomous vehicles or ICVs; automation and intelligentization enhancement of heavy-duty transportation; demand responsive transportation based on modern information technologies; intelligent monitoring and control that work to ensure traffic safety; intelligent monitoring and guidance that can alleviate traffic congestion.

6.3. Studies on transportation sharing

Studies in this respect focus on the exploration of ridesharing modes with the aid of modern information technologies, mainly including:

- Social acceptability of shared driverless vehicles; service systems relying on shared applications (apps) on mobile intelligent devices; improvement of shared transportation vehicles by harnessing clean energy; demand generation, passenger-vehicle matching, and route planning of shared driverless vehicles.

6.4. Studies on efficient transportation

Studies concerning this aspect work on improving transportation efficiency, principally containing:

- Layout and construction of logistics hubs, in particular the layout of multimodal hubs; traffic efficiency improvement contributed by freight vehicle platooning; traffic route planning; enhancement of port collection and distribution capacity, for instance, the optimization of handling facility operation and the application of new handling facilities.

Worldwide transportation is ushering in a new developmental stage in history, in which new forms of business, new technologies and new models continually replace the previous ones. The research frontier trends in the field of transportation presented by this paper can equip researchers with novel perspectives, and furnish personnel responsible for scientific research planning and management with information support for their decision-making.

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