# ITS-Frame: A Framework for Multi-Aspect Analysis in the Field of Intelligent Transportation Systems

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***Abstract*— Intelligent transportation systems (ITS) have been developed rapidly over the last few decades because of global urbanization and industrialization. ITS involve a wide range of different technologies and applications such as automatic road enforcement, dynamic traffic light sequence, and as a result, a significant number of scientific papers have been published in the field of ITS. In this paper, we present a useful insight into the development of ITS area by systematically analyzing the publications over the period of 20 years. First, we identify the most cited papers and most impactful authors in the field. Second, in the aspect of topic analysis, we identify some active keywords. To do so, we develop a keyword co-occurrence network to find topics in the ITS field. Finally, for the collaboration pattern analysis, we construct two networks to interpret collaboration patterns, including a co-authorship network, and an author co-keyword network to show the development and research tendency of ITS. Some most interesting findings from our investigation include the following: 1) Besides the USA, China and Europe have begun to play an increasingly significant role in this field and 2) *GPS*, *traffic control*, and *road safety* show an upward trend from the analysis of the evolution of ITS research topics, given the rise of new research areas such as autonomous vehicles. Our first-hand investigation and analysis of the literature provides a valuable reference to research activities in the development of ITS field and presents worthy insights on the current status and future technical trends.**

***Index Terms*— Impact analysis, topic analysis, collaboration patterns, intelligent transportation systems (ITS).**

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## I. Introduction

INTELLIGENT Transportation Systems (ITS) are defined as the systems that utilize synergistic technologies and system engineering concepts to develop and improve transportation systems of all kinds [1]. ITS play a critical role in the modern society and the field involves a wide range of technologies and applications such as automatic road enforcement, dynamic traffic light sequence, and autonomous vehicles. Nowadays, top-ranked journals such as IEEE Transactions on Intelligent Transportation Systems have published a large number of papers in the field of ITS research. Recognizing the importance of scientific research in the ITS field, many scientists have analyzed the development of ITS through the published papers [2]–[6]. Clearly, such analyses are valuable and have the potential to help research community assess the impacts of authors, institutions and countries/regions, as well as uncover the evolution tendency of development in the ITS field. However, some important issues are still not be solved as the following:

- The publications to be analyzed should include not only journals but also conferences.
- How should we better assess the impact by not only considering the number of citations but also the publication longevity of the cited papers?
- How many topics should be selected in this field, and what is the topic tendency?
- How should we describe collaboration relationships between researchers and papers?

We believe that the data sources from journals and conferences of the ITS field could help us to understand the status of ITS and present interesting insights on future technical trends. In this paper, we present a comprehensive analysis of the ITS field through collecting and analyzing the ITS data published by four top journals and one premier conference in the ITS field. In a nutshell, the main contributions are listed as the following:

- We present a research framework for multi-aspect analysis of the ITS field. We obtain basic bibliographic analysis results by exploiting statistical methods. We find that there are many excellent authors and institutions from the USA. However, China and Europe cannot be underestimated and have begun to make great contribution to this field over the recent years.
- We identify high-impact research papers and scientists, which will serve as a valuable reference for researchers in this field.

- We analyze topic evolution to show the research trend of this field over last 20 years.
- We construct and visualize three networks to study collaboration patterns, including a *co-authorship network*, a *keyword co-occurrence network* and an *author co-keyword network*.

The rest of this paper is organized as follows. Section II gives a brief review on the related literature. Section III provides an overall framework of our approach. Section IV reports the impact analysis of papers and authors. Section V presents the topic analysis. In Section VI, we show three collaboration networks. Finally, we draw our conclusions in Section VII.

## II. Related Work

In recent years, the proliferation of ITS research and development activities has attracted scientists to analyze the research status through the published literature, and to explore the development of this field by using data mining methods. Three main areas in bibliometrics are used to explore the ITS field, namely performance analysis, topic evolution, and science mapping [7].

One of basic tasks is to find high impact scientists or organizations, which include high-impact papers and authors, institutions and countries/regions. Performance analysis aims to evaluate the citation impact of the scientific production of different researchers and institutes. In 2010, Wang [2] used statistical methods to study publications and impact of the papers published in T-ITS during 2000-2009. At the same year, Li *et al.* presented a bibliographic analysis by identifying the most productive and high-impact papers and authors, institutions and countries/regions [3]. In 2016, Moral-Martínez *et al.* proposed an index H-Classics to measure those scientific authors, institutions and countries/regions in the field of intelligent transportation systems [4].

Tendency of topic evolution shows development of the ITS field. Some researchers [8] extended the study of ITS topic evolution from 2000 to 2009. They visualized the conceptual ITS themes and ITS thematic areas that constitute the research core of the papers published in the journal of IEEE T-ITS. The study combined both H-index-based [9] performance analysis and science mapping [10] to detect and evaluate conceptual ITS themes. The keyword co-occurrence network is useful to find active research topics. Consequently, in 2014, keyword co-occurrence network was constructed to find hot research topics and predict new research directions [5].

Discovering collaboration patterns is another research hot topic in ITS, which typically involves the analysis of three networks: the *co-authorship network*, the *keyword co-occurrence network* and the *author co-keyword network*. The co-authorship network mainly interprets cooperative relationship between authors. The author co-keyword network can identify authors with common research interests [11]. Li *et al.* provided an analysis of collaboration patterns and constructed those networks to analyze the data from 2000 to 2009 [6]. Then, four years data from 2010 to 2013 were analyzed using the same method by Wang *et al.* [12]. The authors clustered the networks by Girvan-Newman (*GN*) algorithm [13].

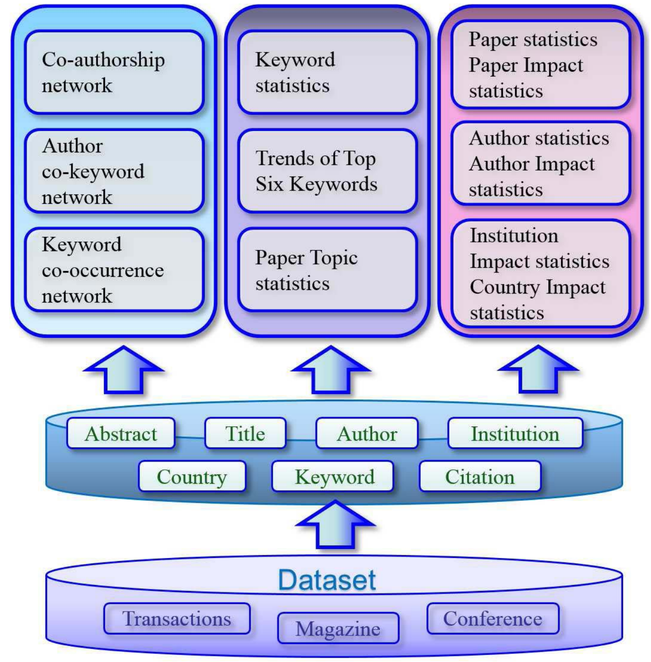


Fig. 1. Proposed data analysis framework.

## III. The Overall Framework

Fig. 1 shows the framework of our approach which consists of five parts: data source, data extraction, impact analysis, topic analysis, and collaboration patterns analysis.

### A. Data Source

We collect data from the IEEE and Elsevier websites using a web crawler developed by us, including journals, magazines and a premier international conference. There are four top journals and one premier conference in the ITS field. The IEEE Transactions on Intelligent Transportation Systems (T-ITS) is one of the top journals in the area, which is launched in 2000 and has 18 years of publishing history. The journal focuses on the advances of the ITS field. The IEEE International Conference on Intelligent Transportation Systems (ITSC) is one of the top conferences in the field of ITS. It started in 1997 and has more than 20 years of publishing history. The IEEE Intelligent Transportation Systems Magazine (ITSM) and IET Transactions on Intelligent Transportation Systems (IET) are also two premier journals of ITS. Transportation Research Part C: Emerging Technologies (PartC) is a famous journal in the field of transportation from Elsevier. This journal is related to computing, artificial intelligence (AI), control and other disciplines.

### B. Data Extraction

We extract the meta data about papers from the data source, including titles, abstracts, authors, author affiliations, and keywords, as well as the citation information from Google Scholar. Clearly, the collected data is heterogeneous. We only use the data with link information on website and delete the data without link information, because these usually are

TABLE I
DATASET STATISTICS

| Journal | Year | Number of Papers | Impact factor |
|---|---|---|---|
| T-ITS | 2000-2017 | 2,106 | 3.724 |
| ITSM | 2009-2017 | 194 | 3.654 |
| IET | 2007-2017 | 621 | 1.194 |
| ITSC | 1997-2017* | 5,001 | - |
| PartC | 1993-2017 | 1,825 | 3.805 |
| Total | - | 9,747 | - |

*except 1998, 2017

reviews or guest editorials for special issues. We also remove the editorial papers, conference diaries, and erratum.

### C. Impact Analysis

Firstly, we analyze the bibliographic information by using statistical methods. Secondly, we conduct impact analysis of papers and authors. In addition, the impacts of institutions and countries/regions are also analyzed. The details are given in Section IV.

### D. Topic Analysis

We identify the topics of each paper and analyze the topic evolution. We construct a keyword co-occurrence network for demonstrating the topic evolution. The technical details are given in Section V.

### E. Collaboration Patterns Analysis

We construct two networks for discovering the collaboration patterns, including a co-authorship network and an author co-keyword network. We use an improved *GN* algorithm to cluster the networks so as to demonstrate their collaboration patterns. To show our results more intuitively, the networks are visualized by Ucinet NetDraw [14]. The details are given in Section VI.

## IV. IMPACT ANALYSIS

In this section, we present our impact analysis from the aspect of papers and authors. First, we identify the most cited papers. Second, we present the top ten most productive authors, as well as institutions and countries.

### A. Paper Statistics

The results of the dataset statistics are shown in Table I. It should be noted that there is no paper information of ITSC in 1998 because the conference was not held that year. It should be also noted that T-ITS published 4 issues each year before 2014. During the period of 2014 to 2015, T-ITS published six issues each year. Since 2016, T-ITS has been publishing 12 issues every year

In our dataset, there are 9,747 papers in total which involve 20,341 authors from 2,513 institutions of 76 countries. Fig. 2 shows every year's paper number for each data source. As Fig. 2 shows, the number of publications in the ITS field by year has kept increasing. Until 2009 the number

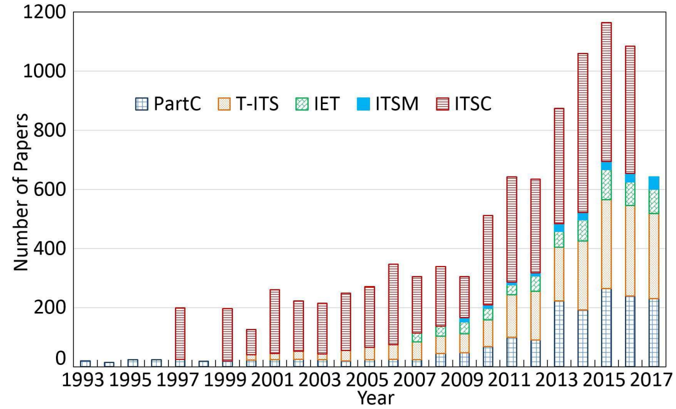


Fig. 2. Distribution of papers by year (1999-2017).

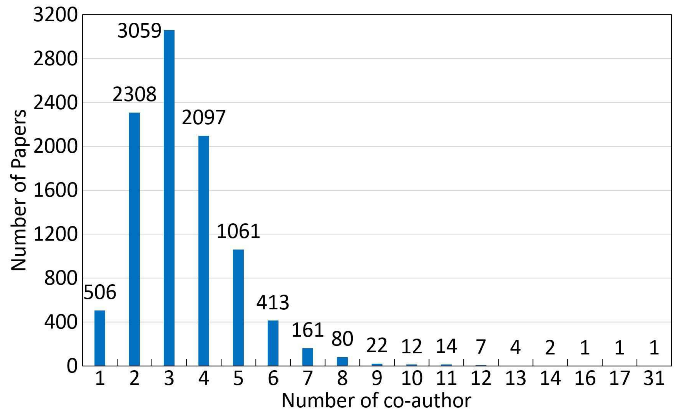


Fig. 3. Distribution of author numbers of research papers.

of publications is just around 300, and most of the papers were published by ITSC. From 2010 to 2012, the number of publication has been doubled. Over the last three years, the number has been tripled. Especially since 2015, around 1100 papers were published in the single year. Clearly, ITS as a popular field has attracted an increasing interest from research communities.

Fig. 3 shows the distribution of author numbers of papers. Among them, it is worth noting that the paper "Making Bertha Drive-An Autonomous Journey on a Historic Route" has 31 authors [15]. In average, one paper typically has two to four authors.

### B. Paper Impact Analysis

There are several ways to rank paper impact, such as the citation number, h-classic and so on. We use Google Scholar 3, to find all papers' citation numbers (before January 2018). Generally speaking, a paper has more impact if the paper receives more citations. Table II shows the top 10 cited papers. In Table II, the majority of the most cited papers are from the USA. Eight of the top ten papers are from ITS Transactions. The other two papers are from Part C.

In Table II, the first paper "A review of conflict detection and resolution modeling methods" [16]. The second paper is about detection and classification of vehicles problem [17].

TABLE II
TOP 10 MOST CITED PAPERS

| Rank | Title | Country/ Region | Citations | NCII | Journal | Refs |
|---|---|---|---|---|---|---|
| 1 | A review of conflict detection and resolution modeling methods | USA | 1019 | 56.61 | T-ITS | [16] |
| 2 | Detection and classification of vehicles | USA | 1017 | 63.56 | T-ITS | [17] |
| 3 | Detecting stress during real-world driving tasks using physiological sensors | USA | 931 | 71.62 | T-ITS | [18] |
| 4 | Video-based lane estimation and tracking for driver assistance: survey, system, and evaluation | USA | 929 | 77.42 | T-ITS | [19] |
| 5 | Automatic license plate recognition | Taiwan | 839 | 59.93 | T-ITS | [20] |
| 6 | Challenges of intervehicle ad hoc networks | USA | 713 | 50.92 | T-ITS | [22] |
| 7 | Comparison of parametric and nonparametric models for traffic flow forecasting | USA | 697 | 43.56 | PartC | [23] |
| 8 | A License Plate-Recognition Algorithm for Intelligent Transportation System Applications | Greece | 670 | 55.83 | T-ITS | [24] |
| 9 | Travel-time prediction with support vector regression | Spain | 667 | 47.64 | T-ITS | [25] |
| 9 | A real-time computer vision system for vehicle tracking and traffic surveillance | USA | 667 | 33.35 | PartC | [26] |

TABLE III
*NCII* TOP 10 PAPERS

| Rank | Title | Year | Country/ Region | Citations | NCII | Journal | Refs |
|---|---|---|---|---|---|---|---|
| 1 | Traffic Flow Prediction With Big Data: A Deep Learning Approach | 2015 | China | 291 | 97.00 | T-ITS | [27] |
| 2 | Evaluation of traffic data obtained via GPS-enabled mobile phones: The Mobile Century field experiment | 2010 | Chile | 648 | 81.00 | PartC | [28] |
| 3 | Video-based lane estimation and tracking for driver assistance: survey, system, and evaluation | 2006 | USA | 929 | 77.42 | T-ITS | [19] |
| 4 | Looking at Vehicles on the Road:A Survey of Vision-Based Vehicle Detection, Tracking, and Behavior Analysis | 2013 | USA | 373 | 74.60 | T-ITS | [29] |
| 5 | Detecting stress during real-world driving tasks using physiological sensors | 2005 | USA | 931 | 71.62 | T-ITS | [18] |
| 6 | Making Bertha Drive - An Autonomous Journey on a Historic Route | 2014 | Germany | 266 | 66.50 | ITSM | [15] |
| 7 | Detection and classification of vehicles | 2002 | USA | 1012 | 63.25 | T-ITS | [17] |
| 8 | Current map-matching algorithms for transport applications: State-of-the art and future research directions | 2007 | UK | 669 | 60.82 | PartC | [30] |
| 9 | Automatic license plate recognition | 2004 | Taiwan | 839 | 59.93 | T-ITS | [20] |
| 10 | Real-Time Urban Monitoring Using Cell Phones: A Case Study in Rome | 2011 | USA | 409 | 59.86 | T-ITS | [31] |

The third paper detects stress during real-world driving tasks using physiological sensors [18]. The forth one reviews driver assistance system [19]. The fifth paper is about automatic license plate recognition (LPR) [20]. All these papers have received remarkable citations (each paper received more than 800 citations and the top one paper received 1019 citations).

Since the citation number of a paper is influenced by publication longevity in years, we use the Normalized Citation Impact Index (*NCII*) to balance their impact [21]. NCII takes into account the longevity of a publication which refers to the number of years the publication has been in print, as shown in

$$NCII = \frac{number\ of\ citations\ per\ publication}{publication\ longevity\ (in\ years)}. \quad (1)$$

In Table III, we observe that the paper “Traffic Flow Prediction With Big Data: A Deep Learning Approach” [19] takes the first place according to *NCII*, which represents a hot topic in this field. At the same time, two papers from UK and Germany show their European impact in the ITS field.

### C. Author Statistics

Table IV shows the top ten most productive authors. In Table IV, Google H-index is searched by every author’s name from Google Scholar. We can see that most of them are from the USA, the Netherlands and China.

TABLE IV
MOST PRODUCTIVE AUTHORS

| No. Author name | Paper# | H-index | Country |
|---|---|---|---|
| 1. Papageorgiou Markos | 80 | 60 | Greece |
| 2. Trivedi Mohan Manubhai | 72 | 70 | USA |
| 2. Hoogendoorn Serge P. | 72 | 51 | Netherlands |
| 4. Bart De Schutter | 64 | 52 | Netherlands |
| 5. Fei-Yue Wang | 53 | 64 | China |
| 6. Barth Matthew * | 47 | - | USA |
| 7. Ozguner Umit | 45 | 50 | USA |
| 7. Li Li * | 46 | - | China |
| 9. Rakha Hesham | 44 | 45 | USA |
| 10. Nedevschi Sergiu | 40 | 28 | Romania |

*no Google H-index

Papamichail and Papageorgiou [32] from Technical University of Crete is the most productive author with 80 papers. Mccall and Trivedi [19] is the second productive author with the highest H-index of 70. Both Tamp *et al.* [33] and Groot *et al.* [34] are from Delft University of Technology in the Netherlands. The fifth most productive author, Wang [2] is currently a professor in Chinese Academy of Sciences. It should be noted that we do not find the H-index for the seventh author Li Li because he or she has no personal page in Google Scholar. It is a typical issue of name ambiguity [35].

TABLE V
AUTHOR RANK RESULTS

| No. | Author Name | H-index | i10-index |
|---|---|---|---|
| 1 | Trivedi Mohan Manubhai | 70 | 313 |
| 2 | Fei-Yue Wang | 64 | 49 |
| 3 | Papageorgiou Markos | 60 | 176 |
| 4 | Bart De Schutter | 52 | 257 |
| 5 | Hoogendoorn Serge P. | 51 | 218 |
| 5 | Broggi Alberto | 51 | 135 |
| 7 | Ozguner Umit | 50 | 197 |
| 8 | Rakha Hesham | 45 | 156 |
| 9 | Hu Jianming | 36 | 159 |
| 10 | Dietmayer Klaus | 31 | 116 |
| 10 | van Lint Hans | 31 | 70 |

TABLE VI
MOST PRODUCTIVE INSTITUTIONS (BY COUNTS)

| No. | Institution name | Count | Country |
|---|---|---|---|
| 1 | University of California | 305 | USA |
| 2 | Delft University of Technology | 234 | Netherlands |
| 3 | Beijing Jiaotong University | 226 | China |
| 4 | Tsinghua University | 193 | China |
| 5 | Chinese Academy of Sciences | 94 | China |
| 6 | Tongji University | 93 | China |
| 7 | University of Tokyo | 75 | Japan |
| 8 | Ohio State University | 73 | USA |
| 9 | University of Minnesota | 66 | USA |
| 10 | Zhejiang University | 63 | China |

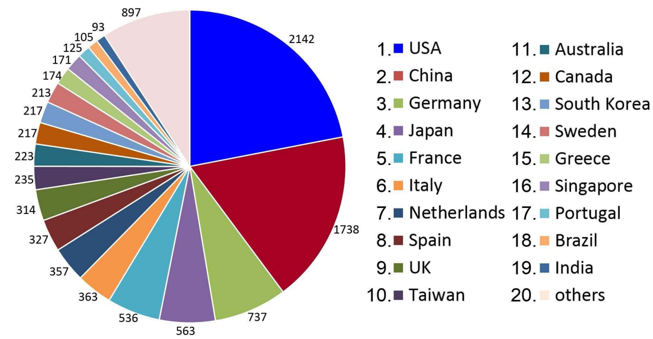


Fig. 4. Productivity per country/region.

TABLE VII
MOST FREQUENTLY USED KEYWORDS

| No. | Keywords | Count |
|---|---|---|
| 1 | Road traffic | 2,857 |
| 2 | Traffic control | 2,802 |
| 3 | Road vehicles | 1,837 |
| 4 | Traffic engineering computing | 1,722 |
| 5 | Global Positioning System | 1,346 |
| 6 | Road safety | 1,038 |
| 7 | Vehicle dynamics | 920 |
| 8 | Driver information systems | 901 |
| 9 | Automated highways | 822 |
| 10 | Object detection | 817 |

### D. Author Impact Analysis

Generally speaking, we choose h-index and i10-index to rank authors' impact. A scientist has index of $h$ if $h$ of his/her $N_p$ papers have at least $h$ citations each, and the other $(N_p - h)$ papers have fewer than $h$ citations each. Meanwhile, the i10-index is the newest in the line of journal metrics and was introduced by Google Scholar in 2011. It is a simple and straightforward indexing measure found by tallying a journal's total number of published papers with at least 10 citations. In Table V, Trivedi Mohan Manubhai has the highest h-index, and we can see that he has made a significant contribution to ITS field. Fei-Yue Wang ranks the second in h-index. Papageorgiou Markos is the most productive author and ranks the third in h-index. Bart De Schutter ranks the fourth in h-index. Tamp *et al.* [33] ranks the fifth, and he is one of the most productive authors in Delft University of Technology, Netherlands. Besides, Gadepally *et al.* [36] is a professor from Ohio State University, USA. He focuses on intelligent vehicles, ITS, decentralized control and autonomy.

### E. Institution Statistics

Many universities have multiple campuses. We take a university into account as a unique entity, which means we count different campus of a university as one. In Table VI, *University of California* from USA takes the first place by publishing 305 papers. *Delft University of Technology* from the Netherlands takes the second place. *Beijing Jiaotong University* and *Tsinghua University* rank the third and the fourth place respectively. Both of them are from China. In addition, the overall paper number from the top ten institutions counts about 14.57% in our dataset.

### F. Country/Region Statistics

Fig. 4 shows the distribution of the research papers by country/region. It can be seen clearly that the USA has published the most papers. However, we also notice that China is the second largest part and half of the top twenty countries/regions are from Europe. As a result, we can conclude that China and Europe are in a very important position in the area and their impacts can not be underestimated.

## V. TOPIC ANALYSIS

In this section, we identify the most frequent keywords first. Then, we analyze the evolution of the top six keywords. Finally, we present a keyword co-occurrence network to cluster papers' research topics.

### A. Keyword Statistics

Table VII shows the most frequent keywords over the past 20 years. We cannot consider the keyword *intelligent transportation systems*, because it is used in journal and conference names. We also delete some common, non-representative words like *vehicles*, *roads*, and so on. Specifically, 2857 papers on *road traffic* and 2802 papers on *traffic control* were published by scientists in the ITS field.

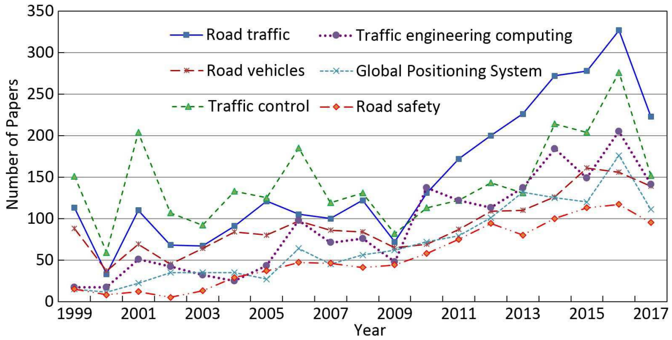


Fig. 5. Trends of top six keywords.

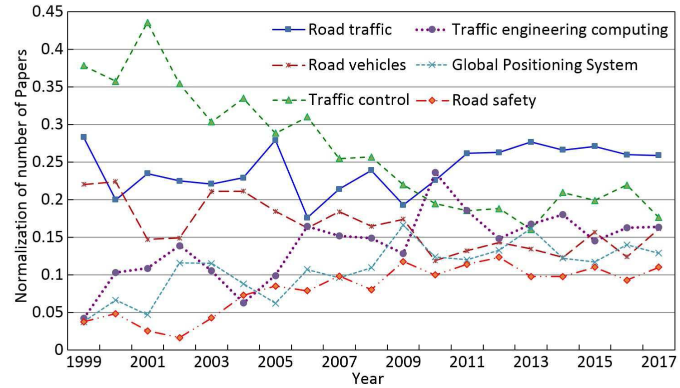


Fig. 6. Trends of top six keywords (Normalization of number of papers).

## B. Trends of Top Six Keywords

We extract the top six most frequently-used keywords from papers and visualize their evolution by year in Fig. 5. From the figure, we can see that the keywords *road traffic* and *traffic control* are relatively stable. These keywords *road traffic* and *traffic control* rank the top two in 2016. Delft University of Technology published 118 papers related to *road traffic*, and University of California published 82 paper related to *road vehicles*.

Over 200 papers about *road traffic* were published from 2012 to 2017 to make *traffic control* very popular recent years. Especially, *road traffic* ranked the first after 2010. Scientists from Delft University of Technology in Netherlands made their contribution by publishing most relevant papers in 2013 (14) and 2015 (14). We can see that the keyword *traffic control* achieved a dominant position before 2008.

The keyword *traffic engineering computing* is the peak (205) of Fig. 5 in 2016. In our dataset, the papers on *traffic engineering computing* are mainly from T-ITS and ITSC. Tsinghua University in China focuses on this research and contributes the most relevant papers (47). Notably, Tsinghua University published 12 relevant papers in 2014.

As we can observe, *Global Positioning System* (GPS) has become increasingly popular although it declined slightly in 2003 and 2007. 1325 papers mentioned *GPS*. In all institutions, University of California in USA ranks the first by contributing 56 papers. Finally, *road safety* is attracting more and more attention. There are 1038 papers on the topic and University of California is the top one which published 38 relevant papers.

Besides that, we present Fig. 6 to show the normalization of number of papers about top six keywords. We find that the trends of top six keywords in Figs. 5 and 6 are similar with each other.

## C. Keyword Co-Occurrence Network Analysis

The keyword co-occurrence network refers to the similarity between keywords that can be clustered into different topics. In the network, each edge represents two keywords appeared in one article and we select those keywords co-occurrence at least 40 times. This network includes 224 keywords and 704 edges. We use improved *GN* algorithm to cluster them and identify 49 topics. We regard the largest degree node as the topic of this cluster.

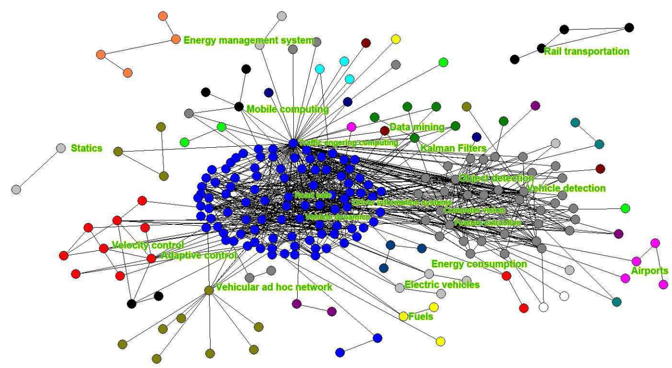


Fig. 7. Keyword co-occurrence network.

In Fig. 7, the blue cluster contains many keywords which occur frequently. It mainly includes *road safety*, *vehicle dynamic* and *driver information systems*. The dark gray one has *object detection*, *computer vision* and *feature extraction*. The red cluster is about *velocity control* and *adaptive control*, and the dark green one is *data mining* and *kalman filters*. Most of them are frequent keywords in the ITS field.

Some topics have intersecting relationship with other disciplines, such as *mobile computing* and *energy consumption*. Since the number of papers in the ITS field has been increasing significantly over past 20 years (Fig. 2), we expect that those topics will gradually attract more attention from researchers in the future, although they are not so active at the time of this writing.

# VI. Collaboration Patterns Analysis

In this section, we analyze collaboration patterns in the ITS field by using improved *GN* algorithm. We particularly construct three networks, including the co-authorship network, the keyword co-occurrence network and the author co-keyword network to illustrate the collaborations between authors.

## A. Co-Authorship Network Analysis

The co-authorship network can interpret collaboration patterns between authors. In order to find co-authorship effectively, we only select authors who published more than

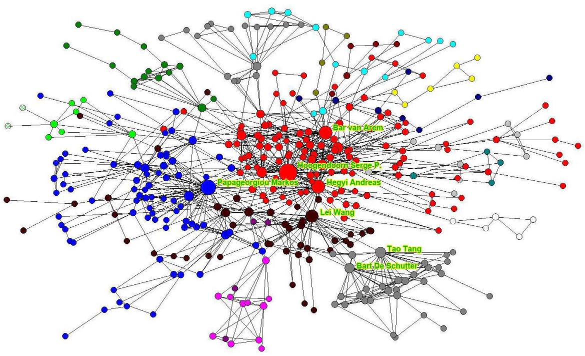


Fig. 8. Largest component in researcher-level co-authorship network.

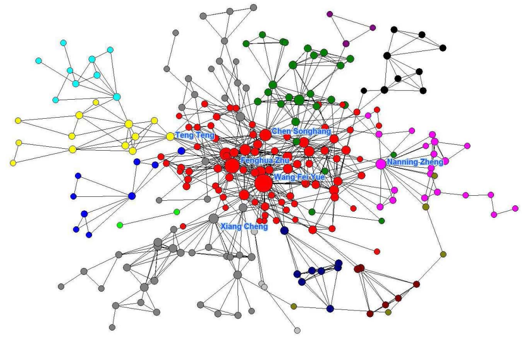


Fig. 9. Second component in researcher-level co-authorship network.

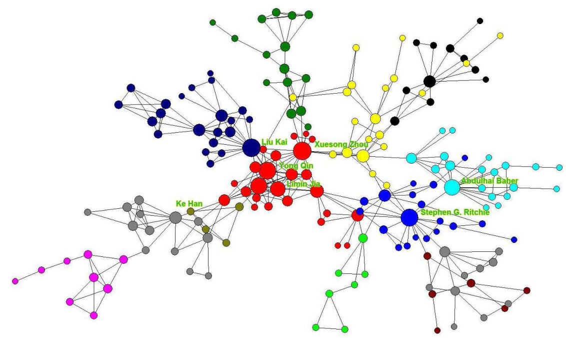


Fig. 10. Third component in researcher-level co-authorship network.

one paper. Each node represents an author, and each edge represents the fact that two authors published the same paper. Our network has 4627 nodes with 9880 edges. After clustering by the *GN* algorithm, we get 442 components. The three largest components have 384, 247, and 181 nodes respectively. The average degree is 4.27, which means the average times of collaboration between authors in a co-authorship network. In these figures, the size of node represents the node degree and color means different clusters.

Fig. 8 is the largest component with 384 nodes and 945 edges. The average degree is 4.92 and the clustering coefficient is 0.618. Therefore, the average times of collaboration between authors is 4.92, which means the relationship in this network is very close.

In red cluster, Hoogendoorn Serge P. has the largest number of collaborators (degree=65). He plays a key role in the largest component and is the most productive author. Han *et al.* [37] with the second largest degree (degree=42) is currently an Assistant Professor with Delft University of Technology. Tamp *et al.* [33] with the third largest degree (degree=40) is the ninth productive author in Table IV. All named authors with red are from Delft University of Technology in the Netherlands, so the red cluster in Fig. 8 represents the collaboration relationship among authors from the Netherlands.

The blue cluster denotes the collaboration among Greek authors. Papamichail and Papageorgiou [32] has the second largest number of collaborators (degree=49) in this component. He is the second most productive author in Table IV.

The black cluster including Bombini *et al.* [38] (degree=37) presents the collaboration of authors in Italy. It is easy to see that Fig. 8 depicts the collaborations of European authors.

In Fig. 9, the second largest component has 247 nodes with 741 edges. The average degree is 6.00 and clustering coefficient is 0.649. The red cluster presents the collaboration among Chinese authors. Wang [2] with the largest number of collaborators (degree=49) in this component is a professor from Chinese Academy of Sciences. He was a former Editor-in-Chief of IEEE T-ITS. Zhu *et al.* [39] with the second largest degree (degree=38) is currently an Associate Professor with the State Key Laboratory of Management and Control for Complex Systems, China. It is clear that Fig. 9 reveals authors' collaborations from China in the ITS field. Fig. 8 and Fig. 9 show the main collaboration relationship among authors from Europe and China.

Fig. 10 shows the third largest component with 181 nodes and 365 edges. The average degree is 4.03 and clustering coefficient is 0.59. Meng *et al.* [40] with the largest degree (degree=18) joined the School of Sustainable Engineering and the Built Environment at Arizona State University in 2013. Previously, he was an associate professor at University of Utah. Meanwhile, he serves as an Associate Editor for Transportation Research Part C: Emerging Technologies. Dai *et al.* [41] with the same degree (degree=18) is currently an Assistant Professor with the College of Computer Science from Chongqing University in China. His research interests include mobile computing, vehicular networks, and intelligent transportation systems.

### *B. Author Co-Keyword Network Analysis*

The author co-keywords network is built by the keywords of papers published by authors, which is a coupling network aggregated by authors. Common interests between authors are described by the author co-keyword network. Each edge represents that two authors used similar keywords. To focus on outstanding authors' interests, we set conditions in our experiments. Co-keywords number decides the size of co-keyword network. When co-keywords number is less than 70, the keywords in the co-keyword network are over 1000 and there

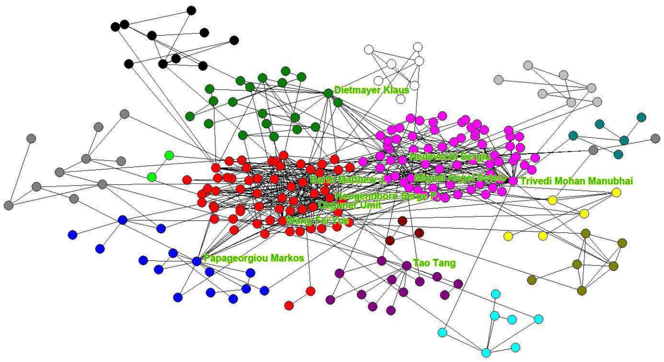


Fig. 11. Author co-keyword network.

are too many nodes in the co-keyword network. On contrary, if co-keywords number is over 70, some important keywords disappear from the network. Therefore, co-keywords number between two authors is set as 70. Fig. 11 has 255 nodes and 511 edges. Authors are partitioned into different groups by using our clustering algorithm. We identify 19 clusters and focus on explaining the top five clusters.

Red cluster is dominated by Fei-Yue Wang. The cluster has the largest degree (degree=43). It also includes Du and Barth [42] (degree=36), Gadepally *et al.* [36] (degree=30) and Hoogendoorn Serge P. (degree=23). These researchers more focus on research topics about vehicles, such as *intelligent vehicles*, *vehicle dynamics* and *electrical engineering*.

Trivedi Mohan Manubhai (degree=43) plays a key role for the purple cluster. The group also contains Alonso *et al.* [43] who is currently an Associate Professor at the University of Alcalá, Madrid, Spain. Their research more focus on topics about *intelligent vehicles* and *driver assistance*.

Finally, Papageorgiou Markos (degree=23) and Bengler *et al.* [44] (degree=19) are respectively the center nodes of the blue cluster and the dark green cluster. Dietmayer Klaus is Full Professor and Director of the Institute of Measurement, Control and Microtechnology in the School of Engineering and Computer Science at the University of Ulm, Germany. Yang *et al.* [45] (degree=10) as the center node of the dark purple cluster is the Academic Pacesetter with the National Key Subject Traffic Information Engineering and Control and the Director of the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing. He focuses on both high-speed and urban railway train control systems, as well as intelligent control theory.

Rakha Hesham is the center node of the yellow cluster. He is the Samuel Reynolds Pritchard Professor at Virginia Tech. His research areas include traffic flow theory, traveler and driver behavior modeling, dynamic traffic assignment and so on. Zhang *et al.* [46] is also in this group. Most of the researchers in this cluster are interested in topics on *driving assistance systems*, and *traffic flow and Modeling*.

## VII. Conclusions

With the growing applications of the Intelligent Transportation Systems (ITS), efficiently and comprehensively analyzing research publications in the field of ITS has been emerging as an important research topic. In this paper, we have conducted a comprehensive analysis of the ITS literature including impacts, topics and collaboration patterns. We gather 9747 relevant ITS papers' data from four top journals and one major conference during the period of last 20 years. We collect the ITS papers and retrieve authors, institutions, countries, titles, abstracts and keywords from these papers. Besides, we collect the citation number of every paper in our dataset. Our analysis of the research publications shows that the ITS field has attracted the increasing interests of researchers throughout years, which is observed in the significant growth of publications and citations. Based on our collected information, our study reveals several main findings.

For the impact analysis, we rank authors contribution based on h-index and i10-index. From the analysis, we identify that the USA plays a key role in this field because it has many productive researchers with high H-index. It is interesting to find out that China has begun to play an increasingly important role since it has produced a large number of high quality papers, particularly over the last few years. Furthermore, it is also worth to mention that the Netherlands shows its impact because some institutes such as Delft University of Technology have made great contribution to this field.

For the topic analysis, we identify six popular topics in this field. We develop a keyword co-occurrence network to cluster keywords so as to find the research tendency from the topic evolution of ITS. The results of the keyword co-occurrence network identify several active keywords (e.g., *road safety*) that are currently hot research areas.

For collaboration patterns, we analyze authors' collaboration patterns by constructing two additional networks, including the co-authorship network, and the author co-keyword network. The results of the co-authorship network shows collaboration relationship between authors in the ITS field. As demonstrated in our experimental results, it exhibits a close collaboration relationship among European authors. The similar observation can be found from the collaboration relationships among authors from China. The results of the author co-keyword network shows common research interests among scientists in the ITS field. Most of authors focus on the topics such as *intelligent vehicles*, *traffic management*, *driving assistance systems*. The two networks exhibit the collaboration relationships from different aspects in the ITS field.

These first-hand results offer an overall view on the current status of the research and development in the field of ITS. We hope that our work can help researchers better understand the research status of ITS and gain valuable insight on the future technical trends of the area. Meanwhile, we hope the analytical methodology presented in this paper can be applied to other research areas for the similar purpose.

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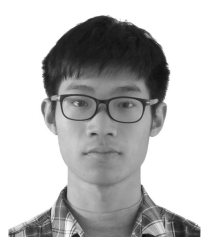

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