

# A bibliometric analysis of the intelligent transportation systems research based on science mapping

M.J. Cobo, F. Chiclana, A. Collop, J. de Oña and E. Herrera-Viedma

**Abstract**—In this paper we highlight the conceptual structure of the Intelligent Transportation Systems (ITS) research field in the period 1992-2011. To do that, an automatic approach for detecting and visualizing hidden themes and their evolution across a consecutive span of years is applied. This automatic approach, based on co-word analysis, combines performance analysis and science mapping. To show the conceptual evolution of ITS, three consecutive periods have been defined: 1992-2001, 2002-2006, 2007-2011. We have identified that the ITS research has been focused on six main thematic areas: *VEHICLE-AND-ROAD-TRACKING*, *DRIVER-BEHAVIOR-AND-SAFETY*, *SCENARIOS-SIMULATION*, *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT*, *VEHICLE-CONTROL* and *VEHICLE-NAVIGATION*.

**Index Terms**—Intelligent Transportation Systems, Science Mapping Analysis, Co-word Analysis, H-index.

## I. INTRODUCTION

According to the IEEE Intelligent Transportation Systems (ITS) Society (<http://sites.ieee.org/itss/>), ITS can be described as systems that utilize “synergistic technologies and systems engineering concepts to develop and improve transportation systems of all kinds”.

*Science Mapping Analysis* [1], [2] is a powerful bibliometric technique that allows the study of the conceptual structure of a particular research field. It can be described as a spatial representation of how disciplines, fields, specialities, and individual documents or authors are related to one another. It is focused on monitoring a scientific field and delimiting research areas to determine its structure and its evolution.

In the ITS research community we find few bibliometric studies. Only IEEE Trans. ITS journal has shown interest in developing a bibliometric analysis of its particular output [3]–[6]. Therefore, a complete ITS science mapping study is still in need. In this paper we present a complete longitudinal Science Mapping Analysis where the whole ITS research field is analyzed and its conceptual evolution discovered. We use the research documents related with ITS during the period 1992-2011 published in the most important and influential journals in the field (*J. of Int. Trans. Sys.*, *ITS Journal*, *IET Int. Trans.*

*Sys.* and *IEEE Trans. ITS.*). Furthermore, we complete the dataset by selecting others documents containing the keyword “*Intelligent Transportation*”. The Science Mapping Analysis is performed using the software tool SciMAT [7], [8].

The rest of the paper is organized as follow: Section II shows the approach and software used in the Science Mapping Analysis. Section III presents the results of our analysis. Finally, in Section IV some conclusions are remarked.

## II. SCIENCE MAPPING ANALYSIS: METHODOLOGY AND SOFTWARE TOOL

In bibliometrics, there are two main procedures to explore a research field: performance analysis and science mapping [9]. The former is focused on the citation based impact of the scientific production and the latter is focused on the discovering of the conceptual structure of the scientific production. In [7] we define a bibliometric approach that combines both approaches. Co-word analysis is used in a longitudinal framework which allows us to analyze and track the evolution of a research field throughout consecutive time periods [10].

Our bibliometric methodology establishes four phases to analyse a research field [7]:

- 1) *Research themes detection*. To do so, an equivalence index [11] normalized bibliometric co-word network of keywords co-occurrence is built [12]. This is followed by a clustering of keywords to topics/themes using the simple centers algorithm.
- 2) *Low dimensional space layout of research themes*. This is achieved by plotting research themes using two-dimensional strategic diagrams based on their centrality and density rank values [11]. Centrality measures the degree of interaction of a network with other networks and it can be defined as:  $c = 10 * \sum e_{kh}$ , with  $k$  a keyword belonging to the theme and  $h$  a keyword belonging to other themes. Density measures the internal strength of the network and it can be defined as:  $d = 100 \frac{\sum e_{ij}}{w}$ , with  $i$  and  $j$  keywords belonging to the theme and  $w$  the number of keywords in the theme. Thus, the research themes can be classified into four groups [7]: a) *motor-themes*, b) *basic and transversal themes*, c) *emerging or declining themes*, and d) *highly developed and isolated themes*.
- 3) *Discovery of thematic areas*. The evolution of the research themes is analyzed to detect the main general evolution areas of the research field, their origins, as well

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as their interrelationships. To do that, an evolution map is built. The inclusion index is used to detect conceptual nexus between research themes of different periods.

- 4) *Performance analysis*. In this phase, the relative contribution of research themes and thematic areas to the whole research field is measured (quantitatively and qualitatively), which is used to establish the most prominent, productive and highest-impact subfields. Some bibliometric indicators used are: number of published documents, number of received citations, and h-index [13].

Finally, the open-source software SciMAT [7], [8] is used.

### III. CONCEPTUAL STRUCTURE OF ITS RESEARCH FIELD

We develop our analysis of ITS field by using the research documents published in the main journals of the field (*J. of Int. Trans. Sys.*, *ITS Journal*, *IET Int. Trans. Sys.* and *IEEE Trans. ITS.*). We complete the corpus with those documents containing the keyword “*Intelligent Transportation*”. Then we retrieve the necessary data from the ISI Web of Science (ISIWoS) using the following query:  $TS=(“INTELLIGENT TRANSPORT*”) OR SO=(“Journal of Intelligent Transportation Systems” OR “ITS Journal” OR “IET Intelligent Transport Systems” OR “IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS”)$ . The query is divided in two parts: i) documents related with the term “*Intelligent transport*” and its variations, and ii) documents published in the main journals in the field. We retrieve a total of 2045 documents (articles, letters, notes and reviews) from 1992 to 2011. In this study the citations to the documents are also used; for this reason, citation counts up to September 11th 2012 were considered.

Once the data was downloaded, we import it into SciMAT [8]. A de-duplicating process was applied over the keywords (as unit of analysis we jointly use the author’s keywords and the Keywords Plus) in order to group those words representing the same concept. Furthermore, because some documents did not contain any keywords, a manual addition of descriptive keywords matching title words with keywords present in the knowledge base was done for completeness purposes. Finally, some keywords meaningless in this context such as stop words, or words with a very broad and general meaning, such as *Intelligent Transportation Systems*, were removed.

To develop our study the whole time period (1992-2011) is divided into three consecutive periods of time: 1992–2001, 2002–2006 and 2007–2011, with 793, 1565 and 3249 keywords, respectively.

In what follows we identify the ITS research themes for each period and analyze the thematic evolution of the ITS field.

#### A. Identifying the ITS research themes

In order to analyze the most highlighted themes of the ITS field for each period several strategic diagrams are shown. In them, the sphere size is proportional to the number of published documents associated with each research theme. Additionally, the number of citations achieved by each theme is shown in parenthesis.

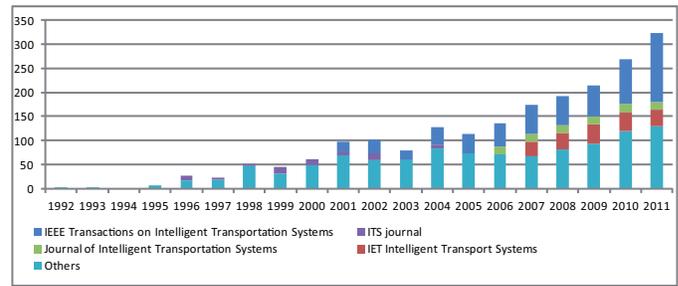


Fig. 1. ISIWoS ITS research documents published from 1992 to 2011.

During the period 1992-2001 (Fig. 2.a and Table I), the ITS research field was focused in three main themes (see Fig. 2.a): i) *VEHICLES*, dedicated to the vehicle surveillance, traffic and incidents detection; ii) *TRAVELER-INFORMATION-SYSTEM*, focused on to assist and guide the traveler in the choice of route, and also it is related with the management of traffic; iii) *SHORTEST-PATH*, centered on to find the best path, both in time and distance, in a traffic network.

TABLE I  
PERFORMANCE MEASURES FOR THE THEMES (1992-2001).

Theme name	Number of documents	Number of citations	h-index
VEHICLES	49	303	9
TRAVELER-INFORMATION-SYSTEMS	24	223	7
SHORTEST-PATH	21	214	6
NEURAL-NETWORKS	15	213	5
CDMA	10	220	7
SPEED	8	22	2

From 2002 to 2006, we obtain the strategic diagrams shown in Fig. 2.b and bibliometric indicators shown in Table II:

- The number of themes is increased.
- The majority of the *basic* and *transversal* themes are focused on vehicles, safety and traffic management.
- The theme *TRACKING* emerges as an important *motor theme* and it achieves the highest impact index.
- The theme *BEHAVIOR* appears as *motor theme* with high density and centrality values. It is focused on the behavior of the drivers and how they choose their travel routes.
- The research themes *TRAVELER-INFORMATION-SYSTEMS* and *NEURAL-NETWORK* related with traffic management, which previously were considered trend and emergent themes respectively, have been consolidated as basic theme.
- *DECISION-MAKING*, focused on safety and risk management, appears as a new *basic and transversal theme*.
- The *highly developed and isolated* themes are mainly focused on themes related with vehicle navigation such as: *GPS*, *VEHICLE-ROUTING*.

From 2007 to 2011, we obtain the strategic diagrams shown in Fig. 2.c and bibliometric indicators shown in Table III:

- There is a higher number of *motor themes* than in the previous period. Indeed, there is an adequate number of *emerging themes*, which indicates that the ITS research field is still developing and growing.
- The ITS research field increments its interest in themes related with vehicle tracking, such as: *TRACKING*, *CLASSIFICATION* and *RECOGNITION*.



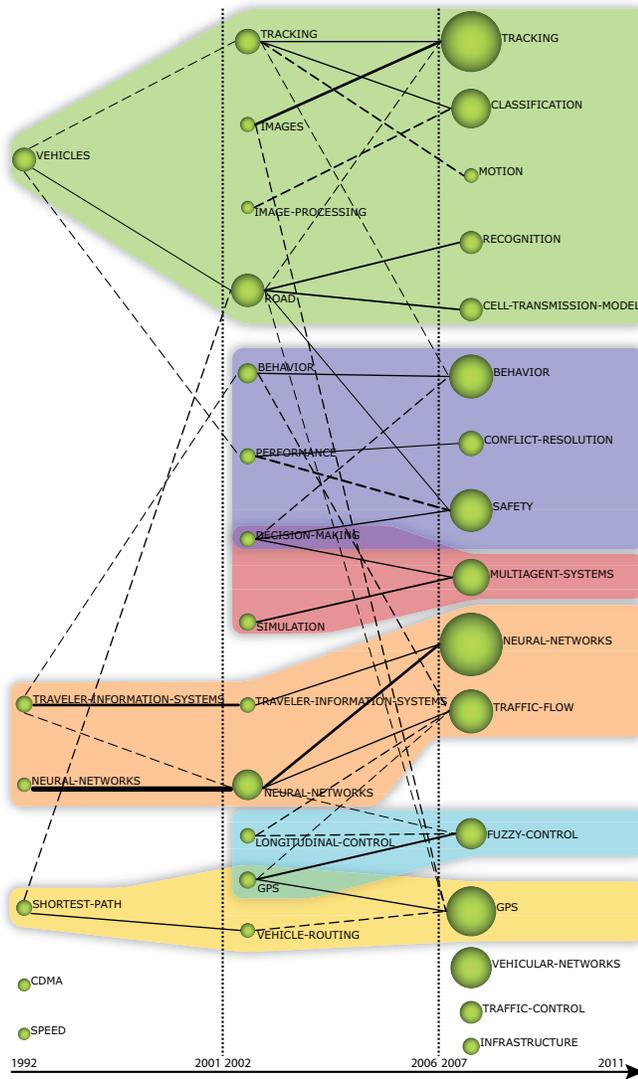


Fig. 3. Thematic evolution of the ITS research field (1992-2011).

- *DRIVER-BEHAVIOR-AND-SAFETY* arises comprised by *motor* and *basic* themes and one *isolated theme*. This thematic area evolves positively and their themes become important *basic* themes.
- *SCENARIOS-SIMULATION* is mainly composed by *highly developed but isolated* themes.
- *VEHICLE-CONTROL* starts from two *isolated* themes and it converges into an important *motor* theme.
- The theme *DECISION-MAKING* is shared by two thematic areas: *DRIVER-BEHAVIOR-AND-SAFETY* and *SCENARIOS-SIMULATION*. Similarly, the theme *GPS* belongs to two thematic areas: *GPS* and *VEHICLE-CONTROL*.

2) Regarding the structural evolution, the following should be pointed out:

- The ITS field presents great cohesion, due to the fact that the majority of detected themes are grouped under a thematic area and originate from a theme identified in a previous period. Furthermore, most

of the evolutions are part of a *thematic nexus*.

- Three thematic areas start in the first period: *VEHICLE-AND-ROAD-TRACKING*, *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* and *VEHICLE-NAVIGATION*. The second period also includes the start of the following three themes: *DRIVER-BEHAVIOR-AND-SAFETY*, *SCENARIOS-SIMULATION* and *VEHICLE-CONTROL*.
- We find some very recent themes (for example, *VEHICULAR-NETWORKS* and *TRAFFIC-CONTROL*) that could not be identified with any thematic. They could be considered as the beginning of a new thematic area.
- There are no gaps in the evolution of the majority of thematic areas.
- The thematic areas *VEHICLE-AND-ROAD-TRACKING* and *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* present a growing pattern. On the other hand, *SCENARIOS-SIMULATION*, *VEHICLE-NAVIGATION* and *VEHICLE-CONTROL* shrink in the last period.
- We should point out that although a shrinking pattern is identified for *VEHICLE-NAVIGATION* and *VEHICLE-CONTROL*, they evolve as important thematic areas in the last period, merging together into one *motor* theme. In fact, *VEHICLE-CONTROL* appears as a bifurcation of *GPS*.

3) Regarding the performance and impact indicators it was found that:

- The thematic area *VEHICLE-AND-ROAD-TRACKING* is the most important in number of document, citations and with the highest h-index. Also, *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* reaches good bibliometric indicators as it is shown in Table IV.
- All thematic areas show a growing pattern in the number of document. Specially significant is the case of *VEHICLE-NAVIGATION* and *VEHICLE-CONTROL*, which despite reducing the number of themes across the periods, they increase in number of documents.
- Only *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* presents a descending pattern in both number of citations received and h-index. This suggests that although the research community is still interested in this thematic (it gets an adequate number of documents in the last period) the publication impact seems to be decreasing.

Once the thematic areas have been analyzed according to their structural, thematic and performance aspects, we provide a more detailed analysis of the conceptual evolution of each thematic area through the different time spans. In what follows, we describe how each thematic area evolves.

The thematic area *VEHICLE-AND-ROAD-TRACKING* starts in the period 1992-2001. In those years the thematic was not well developed being a transversal topic. In the next period

(2002-2006), the thematic broadened covering topics related with the extraction of the visual information present in the streets and roads [14], detection and recognition of different object [15], [16], road detection [17], vehicle tracking [18], etc. Finally, in the last period the thematic focused on object detection in complex situations, such as: lane curvature [19] or night vision [20]; as well as in advance problems such as: prediction of drivers intentions [21] and object detection in real-time [22].

*DRIVER-BEHAVIOR-AND-SAFETY* was mainly related with the improvement of the safety of the driver in the vehicle. To do that, techniques such as the driver's stress level detection [23], speed adaptation systems [24] and driver's behaviour control [25] were developed. This thematic area also covers topic such as the behaviour of drivers in traffic congestion [26].

*SCENARIOS-SIMULATION* starts in the period 2002-2006 with a focus on the simulation of different aspects such as, motorway network and traffic flow model [27]. Finally, in the period 2007-2001 the thematic area focused on the same topics, but using intelligent agents systems to develop simulations [28].

In the early years of the thematic area *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* we locate the firsts papers describing traveler information systems [29] and their use to reduce travel time and traffic congestion [30]. In the next period (2002-2006), the thematic area goes further in the development of advance traveler information system [31]. Finally, in the last period it evolves to focus on the prediction of traffic flow [32] in real time environments [33].

In the period 2002-2006 the thematic area *VEHICLE-CONTROL* focused on several issues related to autonomous vehicle control [34], [35]. In the last period, 2007-2011, several advance developments on specific topics of autonomous vehicle control were carried out: lane change [36], unintended lane departure [37], etc.

In the period 1992-2001, the thematic area *VEHICLE-NAVIGATION* focused on solving the shortest route problem, both in distance [38] and time [39]. In the next period the thematic area developed and it was divided in two main topics: GPS [40] and vehicle routing in real time [41]. Finally, in the period 2007-2011, the thematic area focused on the topic GPS, as well as in improving its accuracy, availability, and continuity of service [42].

#### IV. CONCLUDING REMARKS

In this paper we have analyzed the conceptual structure of the *Intelligent Transportation Systems* (ITS) research area by means of science mapping analysis and co-word networks. Three consecutive period of time have been studied: 1992–2001, 2002–2006 and 2007–2011. We have considered the research documents developed in the following ITS journals: *J. of Int. Trans. Sys.*, *ITS Journal*, *IET Int. Trans. Sys.* and *IEEE Trans. ITS*. Moreover, we completed the dataset by selecting others documents containing the keyword *Intelligent Transportation Systems*.

The presented analysis provides a complete view of the conceptual structure of the ITS research field, giving us the

ability to uncover the different topics researched by the ITS community from 1992 to 2011.

We have detected six different main thematic areas: i) *VEHICLE-AND-ROAD-TRACKING* which evolves from topics related with vehicle surveillance, traffic and incidents detection to the tracking and detection of vehicles, pedestrian, etc. ii) *DRIVER-BEHAVIOR-AND-SAFETY* related with accident avoidance, conflict resolution and the behavior and safety of the driver, iii) *SCENARIOS-SIMULATION* associated with the simulations and test of traffic scenarios, iv) *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* related with different aspects of the traffic management using intelligent techniques such as neural networks, v) *VEHICLE-CONTROL* focused on the research of autonomous vehicles and vi) *VEHICLE-NAVIGATION* related with different aspects of traffic networks and route guidance.

Taking into account the detected themes and thematic areas, the following findings can be highlighted:

- The thematic area *VEHICLE-AND-ROAD-TRACKING* is the most important in all the three criteria used in the analysis. It is a growing research area and presents a good rate of published documents. Furthermore, the research developed under this thematic area captures the attention of the ITS field, as it is illustrated by the citations that it attracts.
- The thematic area *VEHICLE-NAVIGATION* and *VEHICLE-CONTROL* start as *isolated themes* with poor productive and impact rates, but in the last period they get more attention by the community and become two of its most important research topics.
- The thematic area *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT* seems a mature research topic and probably in the near future it might evolve following different directions.
- The thematic area *DRIVER-BEHAVIOR-AND-SAFETY* presents a constant growth.

Interestingly, the thematic areas are covered by the ITS journals in different ways, as it is shown in Table V. We can observe that the journal *IEEE Trans. ITS* is the most important journal of the research developed in ITS because it covers all the top ranked and most cited thematic areas. In particular, is the core journal in both thematic areas *VEHICLE-AND-ROAD-TRACKING* and *VEHICLE-CONTROL*. The journal *IET Intelligent Transport Systems* is centered on *DRIVER-BEHAVIOR-AND-SAFETY* and *VEHICLE-AND-ROAD-TRACKING*. The *ITS Journal* and *Journal of Intelligent Transportation Systems* are mainly focused on *TRAFFIC-FLOW-AND-TRAFFIC-MANAGEMENT*.

Finally, we should note that the ITS research field is developing at a fast pace. Some of the recent scientific documents are published in conferences or special issues. Although a bibliometric analysis of those documents could be interesting, the amount of documents is not enough to develop a science mapping analysis based solely on them.

#### ACKNOWLEDGMENTS

This work has been supported by the Excellence Andalusian Projects TIC-5299 and TIC-5991, and National Project

TABLE V  
JOURNALS PER THEMATIC AREA (DOCUMENTS / CITATIONS).

Journal	VEHICLE AND ROAD TRACKING	DRIVER BEHAVIOR AND SAFETY	SCENARIOS SIMULATION	TRAFFIC FLOW AND TRAFFIC MANAGEMENT	VEHICLE CONTROL	VEHICLE NAVIGATION
IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS	220 / 3111	115 / 983	54 / 526	124 / 1157	3 / 761	76 / 861
IET INTELLIGENT TRANSPORT SYSTEMS	41 / 72	60 / 112	13 / 16	30 / 46	6 / 3	20 / 40
ITS JOURNAL	12 / 53	3 / 58	2 / 23	21 / 106	1 / 0	4 / 3
JOURNAL OF INTELLIGENT TRANSPORTATION SYSTEMS	16 / 58	13 / 62	8 / 21	39 / 170	5 / 68	27 / 119
Others	184 / 1310	132 / 721	64 / 490	195 / 1625	50 / 249	75 / 594

TIN2010-17876.

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