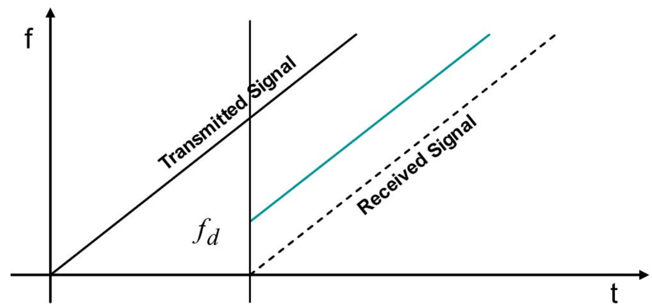
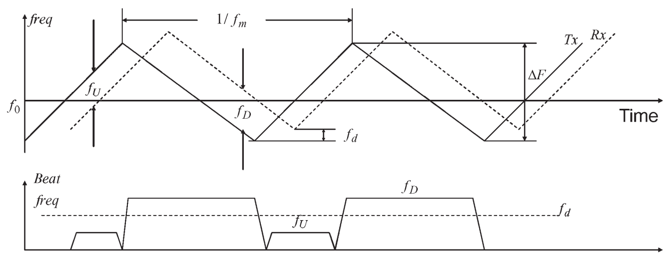


Fig. 14. Transmitted and received signal frequencies.



$$R = (f_D + f_U) \cdot c / (8 f_m \cdot \Delta F)$$

$$V = f_d \cdot c / 4 f_0 = (f_D - f_U) \cdot c / (4 f_0)$$

f_0 Central frequency of radar operation

Fig. 15. Principle of measuring range and speed by FMCW.

environments with moving objects, the FSF-laser-based range finder is unacceptable.

1) FMCW Realized by Waveform Modulation: Chirped pulse laser sources can also be realized by modulating the intensity of the continuous-wave (CW) laser [12]. The system has the same problem as described in the previous section. In contrast to this approach, the National Aeronautics and Space Administration (NASA) Langely Research Center [11] developed waveform-modulated FMCW laser radar to aid the NASA new space exploration initiative for manned and robotic missions to the moon and Mars. Fig. 15 shows the transmitted (solid) and the received (dashed) linearly chirped triangular modulation functions. The target range R and speed V can be obtained, providing that the two frequencies f_D and f_U of the beat signal are measured.

The method measures the target range and speed with high precision. However, the period of the triangular modulation function in [11] is as long as 5 ms; therefore, the scanning speed of the laser radar is no larger than 200 times per second. To improve the scanning speed, the transmitted signal length should be as short as possible.

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A Note on the ITS Topic Evolution in the Period 2000–2009 at T-ITS

Manolo J. Cobo, Antonio G. López-Herrera, Francisco Herrera, and Enrique Herrera-Viedma

***Abstract*—In this paper, we extend the study of the intelligent transportation system (ITS) topic evolution presented by Li *et al.* To do so, we apply an approach that combines both H-index-based performance analysis and science mapping to detect, visualize, and evaluate conceptual ITS themes and ITS thematic areas published by the journal IEEE TRANSACTIONS ON INTELLIGENT TRANSPORT SYSTEMS during the decade (2000–2009). The primary consequence of this is the detection of three important thematic areas: *COMPUTER-VISION* and *TRAFFIC-FLOW*, which are related to research in ITS applied to vehicles, and *AIRCRAFT-TRAFFIC*, which is related to research in ITS applied to aircraft/airport.**

***Index Terms*—H-index, intelligent transportation systems (ITSs), knowledge visualization, science mapping analysis.**

I. Introduction

Recently, we have observed that the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS (IEEE T-ITS) is interested in the analysis of intelligent transportation system (ITS) research contained in papers published in the journal [2]–[4]. In [3], Prof. F. Wang, Editor-in-Chief of the journal, provides a first approach to study the journal publications and their impact during the period 2000–2009. In [5] a commissioned group of researchers presents a bibliographic analysis of the papers published in the journal during the past decade by identifying the most productive and high-impact authors, institutions, and countries/regions. Then, in [1], an analysis of the collaboration patterns and the ITS topics' evolution of the journal are presented.

To develop the ITS topic evolution study presented in [1], the authors use the author-provided keyword cooccurrence network and cluster the keywords to topics by using the Girvan–Newman algorithm [6]. Then, they present a brief analysis of the evolution of the most

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The authors are with the Research Center on Information and Communications Technology, University of Granada, E-18071 Granada, Spain (e-mail: mjcobo@decsai.ugr.es; lopez-herrera@decsai.ugr.es; herrera@decsai.ugr.es; viedma@decsai.ugr.es).

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important topics using the number of papers published in each one each year. We think that this study of the ITS topic evolution is short and that it could be improved by considering an alternative bibliometric analysis tool such as that provided in [7]. It would allow us to find out more about the ITS topics treated by the journal. In this way, we present an enriched analysis of ITS topic evolution by showing how the ITS research field is conceptually and intellectually structured and measuring the impact of both the detected themes and thematic areas.

This paper is organized as follows: Section II introduces the bibliometric analysis tool [7] and the data set. Section III presents our new analysis. In addition, Section IV contains our concluding remarks.

II. Bibliometric Tool and Data

A. Bibliometric Analysis Tool

In bibliometrics, there are two main procedures in exploring a research field, i.e., performance analysis and science mapping [8]. Performance analysis aims at evaluating groups of scientific *actors* (countries, universities, departments, and researchers) and the impact of their activity on the basis of bibliographic data. Science mapping aims at displaying the structural and dynamic aspects of scientific research, delimiting a research field, and quantifying and visualizing the detected subfields by means of co-word analysis [9] or document co-citation analysis [10].

In [1], the authors use a co-word bibliometric tool to identify the ITS topics published by the IEEE T-ITS during the period 2000–2009. Then, they study the ITS topic evolution by analyzing the number of papers published on each topic per year. However, an enriched analysis of the ITS topics could be developed using the bibliometric approach defined in [7].

In [7], we define a bibliometric tool that combines both performance analysis tools and science mapping tools to analyze a research field and to detect and visualize its conceptual subdomains (particular topics/themes or general thematic areas) and its thematic evolution. 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 [11]. Additionally, we develop a performance analysis of a specific theme or thematic area using different basic bibliometric indicators. In the bibliometric analysis tool defined in [7], we establish four phases to analyze the themes and thematic evolution of a research field.

1) *To detect the research themes*. To do so, first, we have to compute the co-occurrence matrix by assuming that the co-occurrence frequency of two keywords is extracted from the corpus of documents by counting the number of documents in which the two keywords appear together. Second, we have to compute the equivalence index among keywords [12], which is called e_{ij}: $e_{ij} = c_{ij}^2/c_i c_j$, where c_{ij} is the number of documents in which two keywords i and j co-occur, and c_i and c_j represent the number of documents in which each one appears. At the end of this phase, we cluster keywords to topics/themes by using the simple center algorithm [13], which automatically returns labeled clusters, and therefore, a postprocess to label the clusters is not needed. Through this process of clustering, we locate keyword networks that are strongly linked to each other and that correspond to centers of interest or to research problems that are the object of significant interest among researchers.
2) *To build strategic diagrams*. In the clustering process, we obtain a set of interconnected networks or themes. Then, in this context, each keyword network or theme can be characterized by two parameters [12].

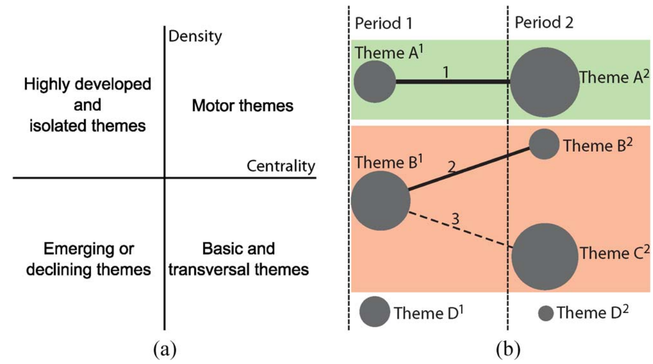


Fig. 1. (a) Strategic diagram. (b) Thematic evolution.

a) *Centrality*: It measures the degree of interaction of a network with other networks, and it can be defined as $c = 10 * \sum e_{kh}$, with k being a keyword belonging to the theme and h being a keyword belonging to other themes. Centrality measures the strength of external ties to other themes. We can understand this value as a measure of the importance of a theme in the development of the entire research field analyzed.
b) *Density*: It measures the internal strength of the network, and it can be defined as $d = 100(\sum e_{ij}/w)$, with i and j keywords belonging to the theme and w being the number of keywords in the theme. Density measures the strength of internal ties among all keywords describing the research theme. This value can be understood as a measure of the theme's development.

A strategic diagram is a 2-D space built by plotting themes according to their centrality and density rank values. As an example, in Fig. 1(a), a strategic diagram is presented. Thus, with both parameters, a research field can be understood to be a set of research themes, mapped in a 2-D space, and classified into four groups [12].

1) Themes in the upper-right quadrant are both well developed and important for the structuring of a research field. They are known as the *motor themes* of the specialty, given that they present strong centrality and high density.
2) Themes in the upper left quadrant have well-developed internal ties but unimportant external ties and are therefore, of only marginal importance for the field. These themes are very specialized and peripheral in character.
3) Themes in the lower left quadrant are both weakly developed and marginal. The themes of this quadrant have low density and low centrality, mainly representing either emerging or disappearing themes.
4) Themes in the lower right quadrant are important for a research field but are not developed. Thus, this quadrant groups transversal and general basic themes.

Furthermore, the strategic diagrams can be enriched by adding a third dimension to show more information. Thus, for example, the themes can be represented as a sphere, its volume being proportional to different quantitative (or qualitative) data, such as the number of documents associated with the theme or the number of citations received by the documents associated with the theme.

3) *To detect the thematic areas*. We analyze the evolution of the detected themes through the different subperiods studied, to detect the main general thematic areas of the research field, their origins, and their interrelationships. In [17], we provide a tool based on the inclusion index [14] to detect conceptual

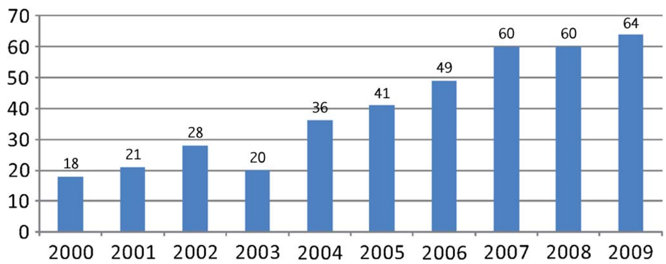


Fig. 2. Documents published in IEEE T-ITS from 2000 to 2009.

nexus between themes of different periods and, in this way, to identify the thematic areas in a research field. Thus, a *thematic area* is defined as a group of evolved themes across different subperiods. Note that, depending on the interconnections among them, one theme could belong to a different *thematic area* or could not come from any. In Fig. 1(b), an example of a thematic evolution bibliometric map is shown through two time periods. The solid lines (lines 1 and 2) mean that the linked themes share the same name: Both themes are labeled with the same keywords, or the label of one theme is part of the other theme $(\text{name of theme} \in \{\text{thematic nexuses}\})$. A dotted line (line 3) means that the themes share elements that are not the name of the themes $(\text{name of theme} \notin \{\text{thematic nexuses}\})$. The thickness of the edges is proportional to the inclusion index, and the volume of the spheres is proportional to the number of published documents associated with each theme. Then, we can observe two different thematic areas delimited by different color shadows, with one composed of themes $ThemeA^1$ and $ThemeA^2$, and the other composed of themes $ThemeB^1$, $ThemeB^2$, and $ThemeC^2$. $ThemeD^1$ is discontinued, and $ThemeD^2$ is considered to be a new theme. As the themes have an associated set of documents, the thematic areas could also have an associated collection of documents obtained from the union of the documents associated with their set of themes.

4) *To carry out a performance analysis*. In this phase, we can measure (quantitatively and qualitatively) the relative contribution of themes and thematic areas to the whole research field, detecting the most prominent, productive, and highest impact subfields. To do so, we use the following bibliometric indicators applied to the different detected themes and thematic areas: the number of published documents, the number of received citations, and the H-index [15]–[17].

We should point out that the co-word analysis is carried out with the software CoPalRed [18]–[21]. It is based on the simple center algorithm to detect the themes through different subperiods of years. The plotting of the themes in the strategic diagram, the drawing of the thematic networks, and the detection of thematic areas are done with specific ad-hoc software.

B. Data Set

We use the IEEE T-ITS publications from 2000 to 2009 as in [1] and [5]. We have downloaded them from two important scientific databases, i.e., Scopus[1] and ISI Web of Science[2] (ISIWoS). As IEEE T-ITS is indexed in ISIWoS from 2001, the papers published in 2000 proceed from Scopus and the rest from ISIWoS. The data set includes 397 papers with 318 articles, one letter, 74 proceeding papers, and four reviews. We have not considered eight editorial introductions. In Fig. 2, the distribution of documents per year is shown.

As previously mentioned, the keywords of the documents are used to develop our analysis. Due to the fact that the majority of the data have been downloaded from the ISIWoS, the author-provided keywords and the Keywords Plus of the documents are jointly used. A normalization process is carried out prior to this over the keywords, where the plural and singular forms of the keywords are joined. The acronyms are also joined with the respective keywords. Finally, we have obtained about 416 valid keywords for our study. We consider valid keywords to be those that present a frequency score greater than 2. As in [1], we have dropped the top-ranked keywords ITS, because they are applicable to all IEEE T-ITS publications.

To avoid the smooth of the data, the best option would be to choose periods spanning only one year. In the case of the journal IEEE T-ITS, in a span of one year, there are not enough data for a good performance of co-word analysis. For this reason, the years are grouped in subperiods of time. Additionally, although it is common to use periods of the same time span, we have fixed a first subperiod of six years (2000–2005) because, in the first numbers of the journal, we find few researchers and publications. In this way, we provide a good input to the co-word analysis to detect the main themes. Therefore, the data are divided into two consecutive subperiods 2000–2005 and 2006–2009, with 164 and 233 keywords, respectively.

In this paper, the citations of the documents are also used. We have considered for each paper the citations received until November 15, 2010. (The data were downloaded on that date.) The citations that we take into account proceed from the ISIWoS.

III. Intelligent Transportation Systems Theme Evolution in IEEE T-ITS

In what follows, we develop the visualization of ITS themes, together with some ITS thematic networks, the evolution of ITS themes, and the ITS performance analysis according to the papers published in IEEE T-ITS.

A. Visualization of ITS Themes

To analyze the most highlighted themes of the ITS field for each subperiod, two kinds of strategic diagrams are built using CoPalRed. In the first one, the volume of the spheres is proportional to the number of documents associated with each theme, and in the second one, it is proportional to the number of citations received by the documents of each theme.

From 2000 to 2005, we obtain the strategic diagrams shown in Fig. 3 and the bibliometric indicators shown in Table I:

1) In general, observing the detected themes, we can say that the research of the ITS scientific community during this subperiod is focused on the development of ITS tools applied to vehicles (there are four themes in this field, i.e., *COMPUTER-VISION*, *TRAFFIC-FLOW*, *ADAPTIVE-CRUISE-CONTROL*, and *MARKOV-DECISION-PROCESS*), and a small part is focused on aircraft and airports. (There is only one theme in this field, i.e., *AIR-TRAFFIC-MANAGEMENT*.)
2) We can identify two best research themes in this subperiod, i.e., *TRAFFIC-FLOW* and *COMPUTER-VISION*. The research developed on the *motor-theme TRAFFIC-FLOW* presents an adequate number of citations and impact (the second H-index score), and similar results are found in the case of the *emerging-theme COMPUTER-VISION* that presents the highest impact in citations and H-index. Furthermore, both themes have received major interest from the ITS scientific community

[1] http://www.scopus.com/
[2] http://scientifc.thomson.com/products/wos/

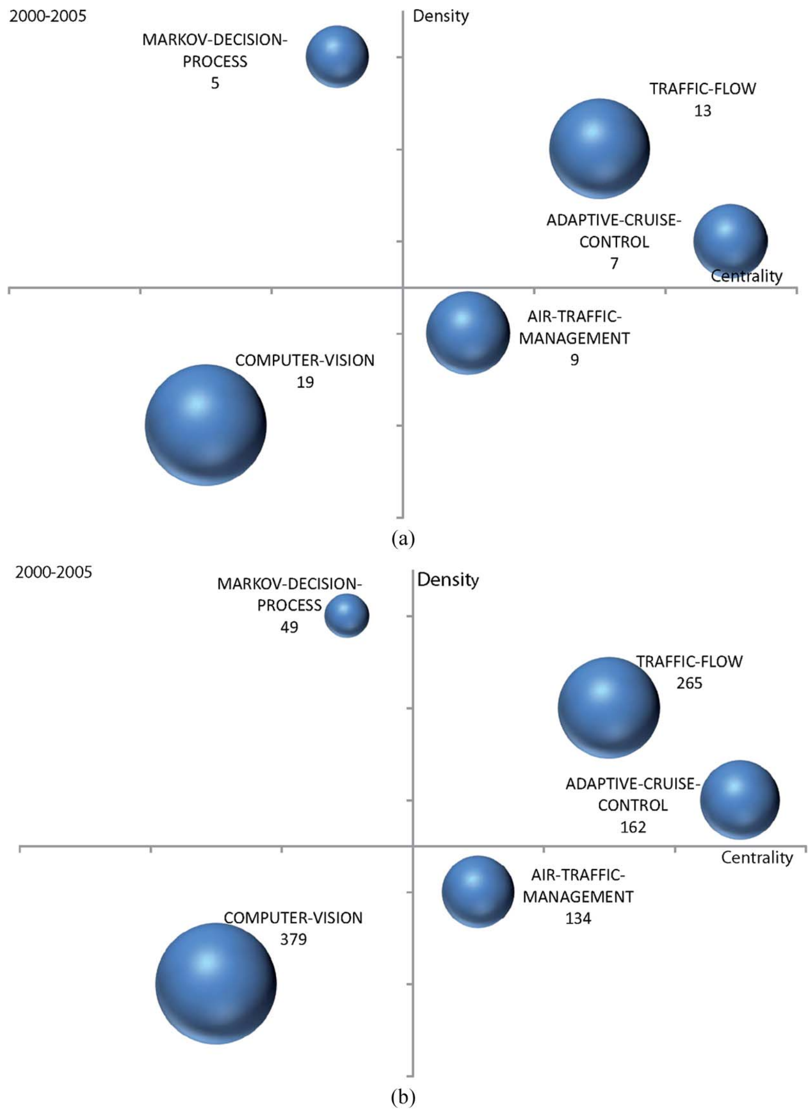


Fig. 3. Strategic diagrams for subperiod 2000–2005. (a) Strategic diagram based on documents. (b) Strategic diagram based on citation.

TABLE I
PERFORMANCE MEASURES FOR THE THEMES OF THE SUBPERIOD 2000–2005

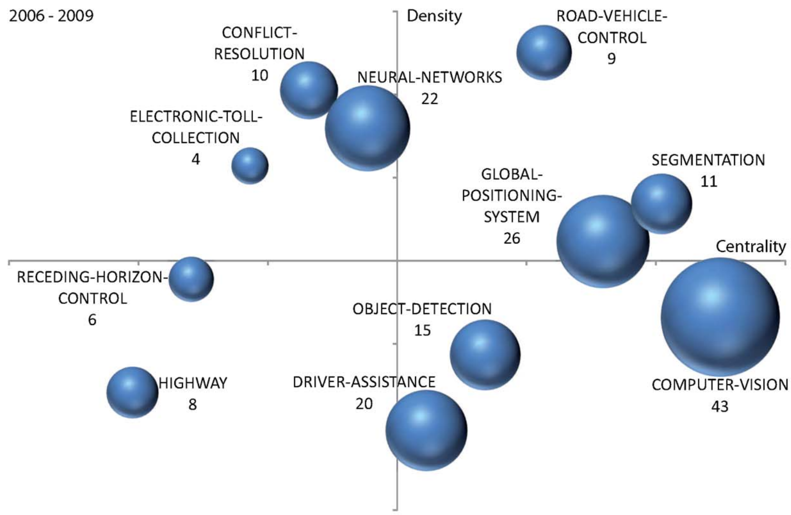
Theme name	Number of documents	Number of citations	h-index
COMPUTER VISION	19	379	13
TRAFFIC-FLOW	13	265	10
AIR-TRAFFIC-MANAGEMENT	9	134	5
ADAPTIVE-CRUISE-CONTROL	7	162	7
MARKOV-DECISION-PROCESS	5	49	4

of the journal, given that both present high numbers of publications.

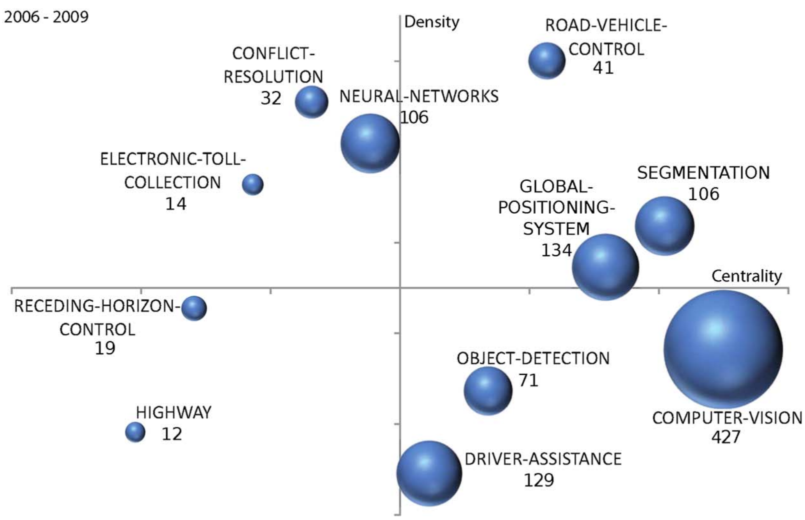
3) The research developed on the *basic-theme AIR-TRAFFIC-MANAGEMENT* does not present high indexes of impact.

From 2006 to 2009, we obtain the strategic diagrams shown in Fig. 4 and the bibliometric indicators shown in Table II.

1) First, we should point out that the number of themes is higher than in the previous subperiod, because we have more published papers and more keywords.
2) As in the previous subperiod, in this subperiod, the research themes related with vehicles aroused more interest among the ITS scientific community than those related with the aircraft and airports. Only the themes *CONFLICT-RESOLUTION* and *RECEDING-HORIZON-CONTROL* are related to the ITS tools applied to aircraft or airports (see their respective thematic subnetworks in Fig. 5).
3) The *motor themes* and *basic themes* are focused on ITS research applied to vehicles. The theme related with the aircraft/airport, which is called in this subperiod *CONFLICT-RESOLUTION*, has evolved and lost importance among ITS researchers, and it is considered a *marginal* and *peripheral theme*.
4) The research on the topic *COMPUTER-VISION* has been consolidated in this subperiod, given that it is considered a *basic theme*, and furthermore, it presents the highest impact in ITS research.



(a)



(b)

Fig. 4. Strategic diagrams for subperiod 2006–2009. (a) Strategic diagram based on documents. (b) Strategic diagram based on citation.

TABLE II
PERFORMANCE MEASURES FOR THE THEMES OF THE SUBPERIOD 2006–2009

Theme name	Number of documents	Number of citations	h-index
COMPUTER-VISION	43	427	12
GLOBAL-POSITIONING-SYSTEM	26	134	6
NEURAL-NETWORKS	22	106	6
DRIVER-ASSISTANCE	20	129	7
OBJECT-DETECTION	15	71	6
SEGMENTATION	11	106	5
CONFLICT-RESOLUTION	10	32	4
ROAD-VEHICLE-CONTROL	9	41	4
HIGHWAY	8	12	2
RECEDING-HORIZON-CONTROL	6	19	3
ELECTRONIC-TOLL-COLLECTION	4	14	3

5) One new and important *motor theme* appears, *GLOBAL-POSITIONING-SYSTEM,* which presents a good number of citations and an appropriate H-index.
6) We find two new and important *basic themes DRIVER-ASSISTANCE* and *OBJECT-DETECTION*, which present an adequate number of citations and impact.
7) Finally, we detect the appearance of two new *emerging themes RECEDING-HORIZON-CONTROL* and *HIGHWAY*, related with the ITS research in both fields, aircraft/airport, and vehicles, respectively.

B. Evolution of the ITS Themes in IEEE T-ITS

Analyzing the keywords of the research themes detected in each subperiod, in Fig. 6, we show the thematic evolution of the ITS research developed in IEEE T-ITS. As previously mentioned, the solid

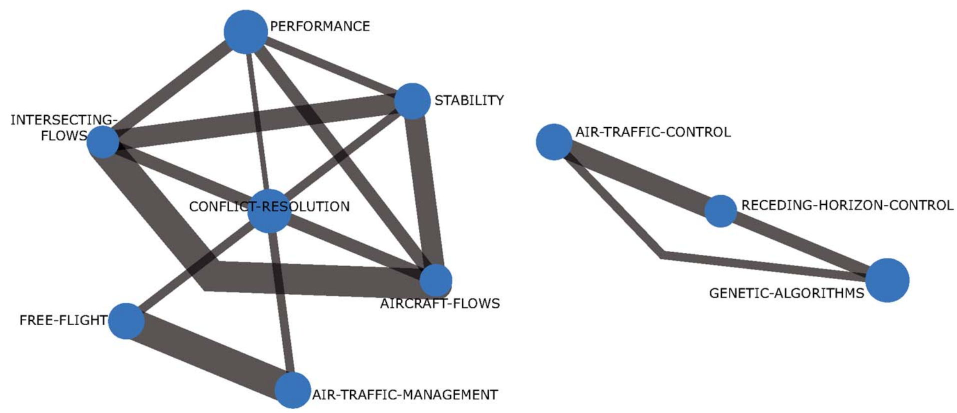


Fig. 5. Thematic networks related with aircraft. (a) CONFLICT-RESOLUTION. (b) RECEDING-HORIZON-CONTROL.

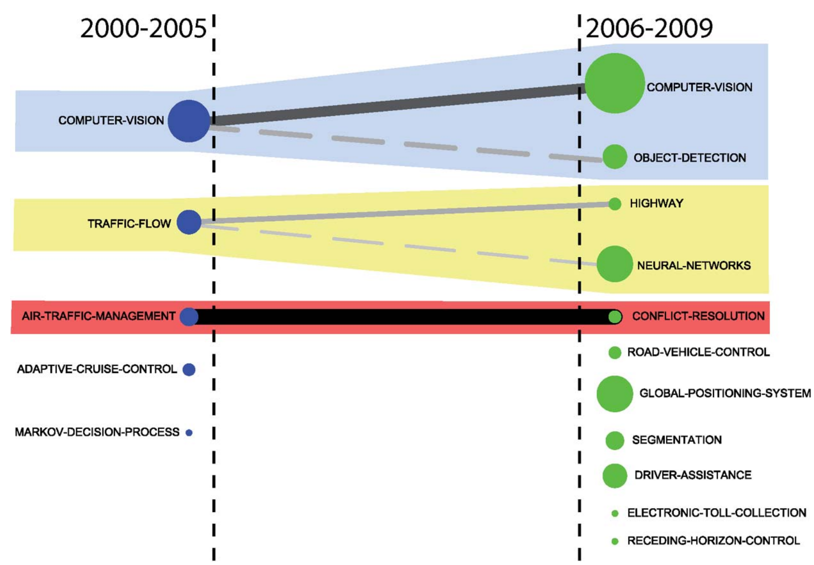


Fig. 6. Thematic evolution of the ITS research in IEEE T-ITS (2000–2009).

TABLE III
QUANTITATIVE AND IMPACT DATA FOR THE DETECTED THEMATIC AREAS IN IEEE T-ITS (2000–2009)

Theme name	Number of documents	Number of citations	h-index
COMPUTER-VISION	70	836	17
AIRCRAFT-TRAFFIC	42	383	12
TRAFFIC-FLOW	19	166	6

lines mean that the linked themes share the name: both themes have the same name, or the name of one of the themes is part of the other theme. A dotted line means that the themes share elements that are not the name of the theme. The thickness of the edge is proportional to the inclusion index, and the volume of the spheres is proportional to the number of published documents of each theme. The different color shadows group the themes that belong to the same thematic area. Those themes that do not belong to any thematic do not have a shadow. In Table III, we identify the main thematic areas and show their respective global quantitative and impact measures. Analyzing Fig. 6 and Table III, we should point out the following.

1) We identify three thematic areas: *COMPUTER-VISION*, *TRAFFIC-FLOW*, and *AIRCRAFT-TRAFFIC*. The former are related with the research in ITS applied to vehicles, and the latter is related with the research in ITS applied to aircraft/airport. Furthermore, when we find some theme that is not in a thematic area, this happens because it is not well described by keywords, and it is not possible to detect its connections with others (for example, the cases of both themes *ADAPTIVE-CRUISE-CONTROL* and *SEGMENTATION*), or it is very recent and could be considered to be the beginning of a new thematic area (for example, the case of the theme *GLOBAL-POSITIONING-SYSTEM*).
2) Regarding the evolution of the number of documents, looking at the volume of the spheres, both thematic areas related with the vehicles evolve in an increasing way; that is, in each subperiod, the number of documents increases with respect to the previous one. However, the thematic area related with the aircraft/airport follows a constant behavior. Therefore, we detect an increasing interest in the ITS community in thematic areas related with vehicle research.
3) Regarding the evolution of the number of themes, again, we find that both thematic areas related with the vehicle research evolve

TABLE IV
RECENT FREQUENTLY CITED PAPERS

Reference	Times Cited	Theme (T) or Thematic Area (TA)
[22]	17	*GLOBAL-POSITIONING-SYSTEM* (T)
[23]	8	*TRAFFIC-FLOW* (TA)
[24]	8	*DRIVER-ASSISTANCE* (T)
[25]	8	*DRIVER-ASSISTANCE* (T)
[26]	7	*COMPUTER-VISION* (TA)
[27]	7	*COMPUTER-VISION* (TA)
[28]	6	*TRAFFIC-FLOW* (TA)
[29]	6	*COMPUTER-VISION* (TA)
[30]	5	*TRAFFIC-FLOW* (TA)
[31]	3	*COMPUTER-VISION* (TA)

in an increasing way. Furthermore, we should point out that, in the second period, many new themes appear as the beginning of new thematic areas.

4) Regarding the thematic composition of each thematic area, two conditions hold.
   a) The *COMPUTER-VISION* is the strongest thematic area in the journal according to ITS thematic composition. It begins as an emerging theme *COMPUTER-VISION*, and in the last subperiod, it is composed of two basic themes, i.e., *COMPUTER-VISION* and *OBJECT-DETECTION*.
   b) *TRAFFIC-FLOW* could be considered to be an expanding thematic area in the journal because it begins as a basic theme, and then, it is composed of a specific theme *NEURAL-NETWORKS* and an emerging theme *HIGH-WAY*. On the other hand, *AIRCRAFT-TRAFFIC* could be considered a descending thematic area because it begins as a basic theme *AIR-TRAFFIC-MANAGEMENT*; then, it is composed of a specialized and peripheral theme *CONFLICT-RESOLUTION*.
5) In short, we should point out that the thematic areas related with vehicle research *COMPUTER-VISION* and *TRAFFIC-FLOW* are the most important areas in the journal with respect to the published papers and received citations and H-index (see Table III). In fact, we observe that those new research themes that are published in the journal are also related with the vehicle research, and in a similar way, they are achieving an important impact (see in Table II).

IV. CONCLUDING REMARKS

In this paper, we have completed the study on the ITS topic evolution presented in [1]. Thus, we have visualized the conceptual ITS themes and ITS thematic areas that constitute the research core of the papers published in the journal IEEE T-ITS.

We have detected three main thematic areas in the journal: *COMPUTER-VISION* and *TRAFFIC-FLOW* related with vehicle research and *AIRCRAFT-TRAFFIC* related with aircraft/airport. The former is the most important thematic area in IEEE T-ITS because it presents the best publication, citation, and impact measures. Regarding the latter, analyzing the number of the papers of each thematic area, we detect an increasing interest in the ITS community in thematic areas related with vehicle research.

We should point out that the results shown here, together with those presented in [1]–[5], can be used by both experts and novices to better understand the evolution of ITS research carried out by the papers published in IEEE T-ITS from 2000 to 2009. Furthermore, these results could be used to predict new future research trends, given that it is logical to suppose that papers associated with the most productive and impacting themes and thematic areas will be successful papers. For instance, in Table IV, we show a list of recent papers related with important themes detected in the last subperiod 2006–2009 (*GLOBAL-POSITIONING-SYSTEM* and *DRIVER-ASSISTANCE*) and important thematic areas (*COMPUTER VISISON* and *TRAFFIC-FLOW*) that are currently frequently cited. This list includes the most cited[3] papers published by IEEE T-ITS from 2009.

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