AUTONOMOUS VEHICLES:
Scientometric and bibliometric studies.

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1. Introduction

Present for over five decades, the robotics industry has been contributing to many everyday aspects. Many IT-related industries are emerging in the second information revolution based on mobile information technology, which is sometimes called the fourth industrial revolution (Rifkin, 2011; Schwab, 2017). In this context, the first car-like robot appeared in the mid-1980s with Carnegie Mellon University's Navlab. Since then, several advances have been made in this area and numerous major companies and research organizations have developed Autonomous Vehicles (AVs) prototypes.

There is a strong expectation that AVs could be used to provide accessibility for people in need, reducing costs and time in transportation systems, and offer comfort for people who do not (or cannot) drive (Mutz et. al., 2016). Although the reality of AVs may seem distant, it is increasingly evident their progress and their arrival is inevitable in the near future.

Several agencies and companies around the world are making progress in AVs development. Automated driving technology is changing fast due to road safety concerns, potential cost savings, and technology innovations (McKinsey & Company, 2016). The current state of technology along with expected improvements and the already-announced plans of several large OEMs and others, make it likely that autonomous vehicles[1] will be available by the mid-2020s.

In the business context, AVs have been gaining more and more attention; countless companies have been standing out, such as Tesla, Google, Uber, and Ford in a “race” for the leadership in this innovation process. It is also worth noting that the formation of partnerships among companies has been a very common way for development and advances of new technologies. In this context, is the BMW's alliance with Intel and Mobileye, which aims to put a fleet of around 40 autonomous testing vehicles on the road in the second half of 2017. Another example is the partnership with Mercedes-Benz, McLaren, Otto, Nvidia, and Udacity (University of Silicon Valley) to create an online course for training engineering professionals in the area.

Even though there has been an establishment of a theoretical field regarding ADS, it is not yet evident the main aspects that permeate the thematic, as well as its conceptual base, tendencies, and characteristics. Regarding such considerations, the following questions emerged as a guideline for this paper: how does the field of studies regarding AVs perform? What are the main trends of analysis? In this sense, our aim in this paper is to identify, from a scientometric and systematic literature review of AVs studies indexed in the Web of Science database, the main characteristics of this object of study, as well as its evolution, in order to highlight potential gaps for prospective studies. There are several contributions on the subject, and the transition from a long-established industry (automotive) to a new configuration (autonomy) is still surrounded by uncertainties as to the inherent aspects of regulatory factors, technology, business models and

[1] By the SAE classification, autonomous vehicles are those equipped with Driving Automation System (DAS), specially from the levels 4 and 5 (SAE, 2016).

market. Through the investigation and map of the main features that permeate this object (AVs), a studies' panorama can be established in order to contribute to the field and build a context that meets the agenda of world developing.

2. Methodology

This study was guided by a scientometric systematic literature review, carried out during the months of November – 2016 to February – 2017, aiming at systematizing the studies indexed in the Web of Science database regarding Autonomous Vehicles in order to map the main characteristics of this object of study and identify possible gaps in prospective studies. We used the scientometric technique which is a research method that refers to knowledge domain visualization or mapping (Pollack & Adler, 2015). This is a quantitative technique that applies bibliometrics to published literature (Börner, Chen & Boyack, 2003). It is used to map the structure and evolution of numerous subjects based on the large-scale scholarly data set through network modeling and visualization. The scientometric research aims to analyze the intellectual landscape of a knowledge domain and to perceive questions that researchers have been attempting to answer, as well as methods that they have developed to achieve their goals (Chen, 2006).

A systematic review consists of collecting, knowing and understanding, analyzing, synthesizing, and evaluating a set of scientific articles with the purpose of creating a theoretical-scientific foundation (state-of-the-art) on a particular topic or subject studied (Conforto, Amaral & Silva, 2011). In this sense, the results of a systematic review are useful for 1) measuring and understanding the body of knowledge of a given subject; 2) providing a solid theoretical basis for a study; 3) providing evidence and the basis for the research problem; 4) presenting the justifications for conducting the study; 5) contributing to better define and structure the research method, objectives, and questions for the study.

In the development of a systematic literature review, one should be concerned with focusing on the main published studies to identify patterns about characteristics and/or limitations of a given field of study (Carvalho, Fleury & Lopes, 2013). Based on these methodological procedures, the present study proposes four steps in the conduction of a systematic literature review, which are described as follows and elucidated on Figure 1.

- **Step 1 – Delimitation of the scope of analysis and selection of papers:** the articles were searched on the "*Web of Science*[2]" database in a single search, from 1945 to 2016[3] using the Boolean operator "OR" and were selected by the following terms in the title, abstract and keywords of the articles[4]: *autonomous_car*; autonomous_vehicle*; autonomous_automobile*; driverless_car*; driverless_vehicle*; driverless_automobile*; self-driving_car*; self-driving_vehicle*; self-driving_automobile*; intelligent_car*; intelligent_vehicle* and intelligent_automobile**. This summing up to 6,711 papers, which constituted the corpus of the present study. It is worth clarifying that the Boolean operator

[2] Web of Science is the main research database on an international level, which includes other indexed databases such as Scopus, ProQuest and Wiley. In addition, it provides a set of metadata, essential for systematic literature reviews.

[3] Given that the data collection was carried out at the beginning of 2017, the data related to the year 2016 may present some differences.

[4] Although some of these terms are not recommend by the Society of Automotive Engineers (SAE, 2016), they have been used over several year and must be considered.

underline '_' was used to ensure the search yielded results in which only the pair of words appeared together. The operator star '*' was used to ensure both singular and plural terms were included in the search results.

- **Step 2 – Descriptive analysis of papers based on Web of Science metadata:** based on this metadata, the following analysis were performed: 1) number of articles published per year; 2) number of citations per year; 3) the ten most cited articles; 4) the authors who published more; and 5) higher publications journals.
- **Step 3 – In-depth analysis of papers based on CiteSpace:** we carry out an in-depth analysis of the 6,711 articles using the CiteSpace software tools (Chen, 2004; 2006). Thus, we performed: 1) analysis of the most relevant keywords; 2) analysis of the main Web of Science categories in which the articles were published; 3) analysis of the countries that most published and 4) co-citation analysis.
- **Step 4 - Interpretation and discussion of results:** we carried out a joint interpretation and discussion of the results found in steps 2 and 3, in order to identify the main research gaps within the field of studies.

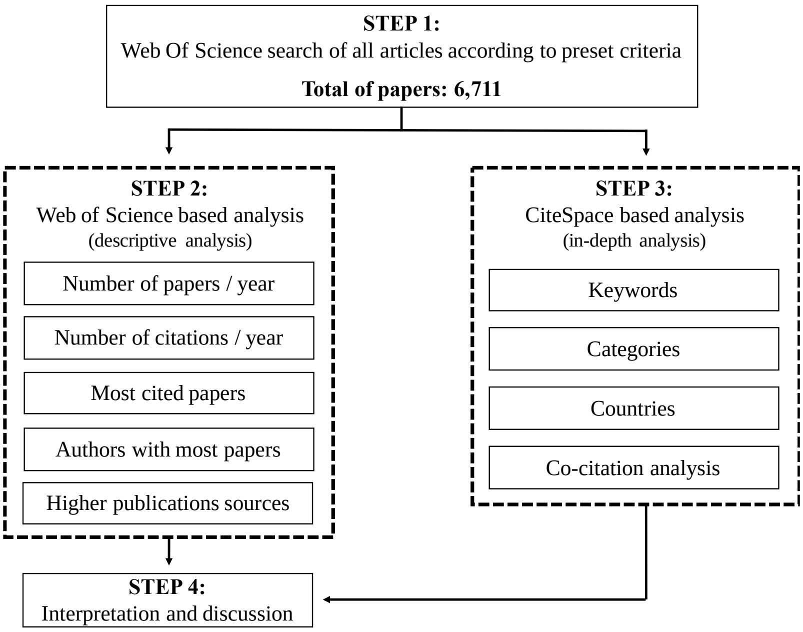


Figure 1. Methodological research design.

3. Results and discussion

The results and discussion of this paper are presented in two stages, with a descriptive analysis of the selected papers and an in-depth analysis of the theme using the software CiteSpace.

3.1 Descriptive analysis

3.1.1 Number of papers/year

The temporal distribution of the 6,711 papers published on the subject of AVs began in 1969 with Palatnick and Inhelder's work (Palatnick & Inhelder 1970). The uninterrupted evolution of

AVs publications began in 1982 with the work of Roberts and Mathews (1982) and, from there, it followed an exponential curve (Figure 2), being the years 2014 and 2015 with the greatest number of publications respectively.

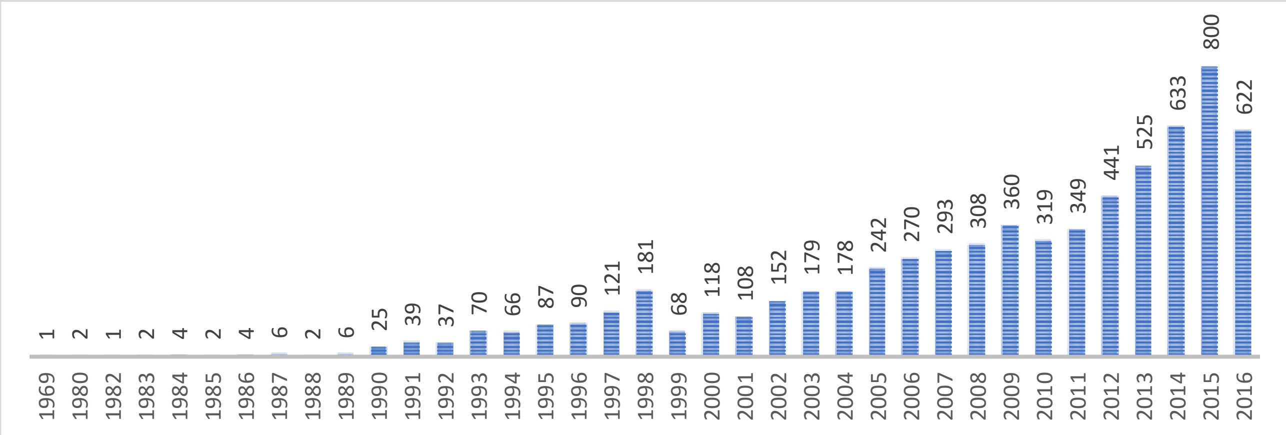


Figure 2. The number of papers per year based on Web of Science data.

3.1.2 Number of citations/year

This analysis refers to the number of citations the searched papers had, where Figure 3 shows an exponential trend, similar to the one observed in Figure 2. The first citation dates back from 1984 with four works, however, the uninterrupted evolution in the citations on the AVs subject began in 1988. The years of 2015 and 2016 were the ones that presented the largest volume of citations, adding up to 16,75% and 13,73% of the citations, respectively.

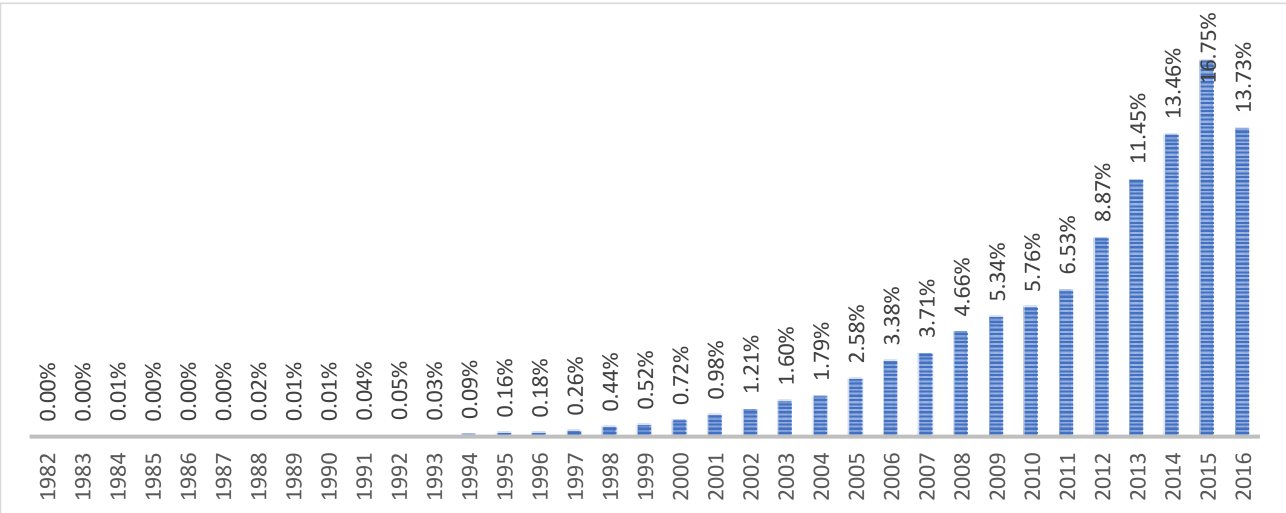


Figure 3. The number of citations per year based on Web of Science Data.

3.1.3 Most cited papers

Table 1 presents the list of the 10 most cited papers regarding AVs, in addition to the year of publication, the total citation count since the publication and the average citations per year. Of the 10 most relevant articles, 9 were published in journals or proceedings belonging to the Institute of Electrical and Electronics Engineers (IEEE). It is worth noting that only two papers were published in the 1990’s and all the other eight are relatively more recent (2000’s onwards), demonstrating the contemporaneity of this field of study.

Overall, the papers of Table 1 are characterized by a more technical-based focus, such as algorithms; modeling; SLAM; among other factors that corroborate with the technical improvements on AVs.

Table 1. Top 10 most cited papers according to Web of Science data

Author(s)	Paper	Publication Name	Year	Citations (total)
Olfati-Saber, R.	Flocking for multi-agent dynamic systems: Algorithms and theory.	IEEE Transactions on Automatic Control	2006	1459
Cortes, J., Martinez, S., & Karatas, T.	Coverage control for mobile sensing networks.	IEEE Transactions on Robotics and Automation	2004	892
Dissanayake, M. G., Newman, P., Clark, S., Durrant-Whyte, H. F., & Csorba, M.	A solution to the simultaneous localization and map building (SLAM) problem.	IEEE Transactions on Robotics and Automation	2001	877
Davison, A. J., Reid, I. D., Molton, N. D., & Stasse, O.	MonoSLAM: Real-time single camera SLAM.	IEEE Transactions On Pattern Analysis And Machine Intelligence	2007	808
Hall, D. L., & Llinas, J.	An introduction to multisensor data fusion.	Proceedings of the IEEE	1997	783
Varaiya, P.	Smart Cars on Smart Roads - problems of control.	IEEE Transactions on Automatic Control	1993	508
Leonard, N. E., & Fiorelli, E.	Virtual leaders, artificial potentials and coordinated control of groups.	Proceedings of the 40th IEEE Conference on Decision and Control	2001	478
Sun, Z., Bebis, G., & Miller, R.	On-road vehicle detection: A review.	IEEE Transactions on Pattern Analysis and Machine Intelligence	2006	387
Karaman, S., & Frazzoli, E.	Sampling-based algorithms for optimal motion planning.	International Journal of Robotics Research	2011	386
Enzweiler, M., & Gavrila, D. M.	Monocular Pedestrian Detection: Survey and Experiments.	IEEE Transactions on Pattern Analysis and Machine Intelligence	2009	380

3.1.4 Authors with most papers

There is a great heterogeneity when regarding the authors with most publications. Based on the Web of Science results, a sum of 6,944 authors was responsible for the 6,711 papers published in the analyzed period. Focusing on the top 20 authors in Figure 5, it is possible to corroborate the heterogeneity of the field since the author who published the most, Alberto Broggi, was responsible for only 0.611% (41 papers) of all 6,711 publications.

From this result, a parallel with Price's Elitism Law (1976) can also be made: the author states that the number of elite’s publishing authors corresponds to the square root of the total number of authors, and half of the total production is considered as a criterion to know if the elite is productive or not. In the present paper, we observe that the elite corresponds to 82 authors ($\sqrt{6,711}$) who are responsible for 1,630 out of the total of 6,711 papers found. This value corresponds to less than the considered by the elitism law, assuming that, for productive elite, these 82 authors should be responsible for the production of approximately 3,355 papers (half of the total number of publications – 6,711). In this sense, we infer that the AVs field is still incipient considering the reduced number of works-per-author, with no existence of considerable productive elite.

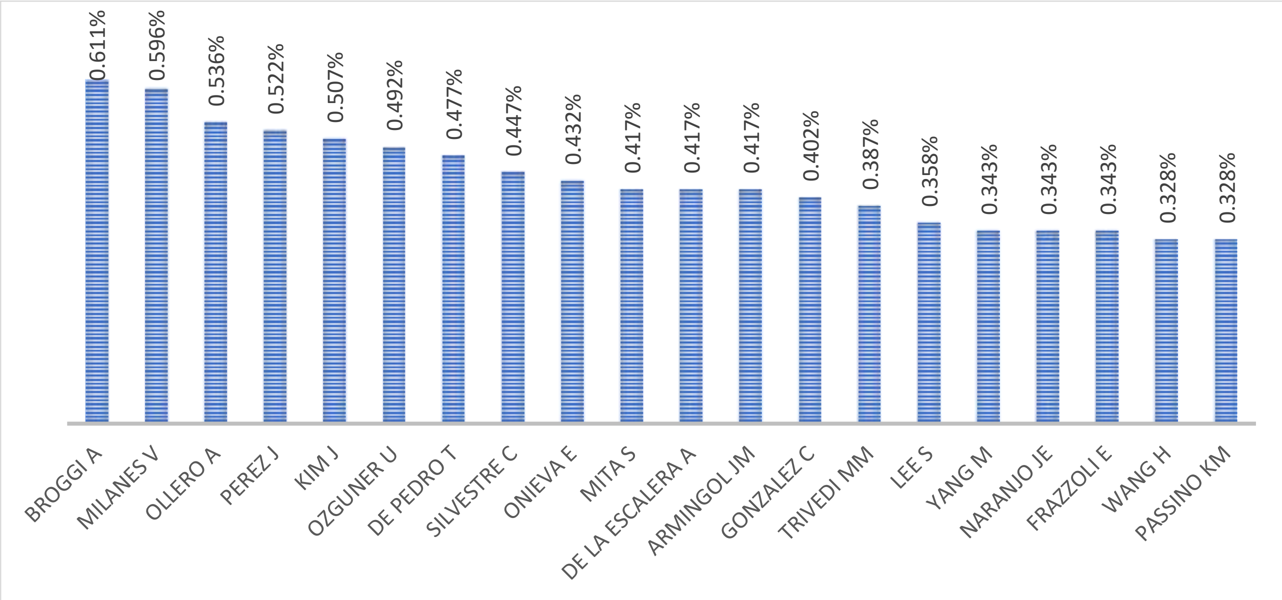


Figure 4. Top 20 authors with most published papers based on Web of Science Data.

3.1.5 Higher publications sources

As for the number of publications, we carried out a Bradford's dispersion Law (1934) analysis. In this analisys, there are three distinct zones in which papers could fit in, each one containing 1/3 of the total of relevant articles. The first zone (nucleus) contains a small number of highly productive journals, the second one a larger number of less productive journals, and the third includes more journals, but each with less productivity.

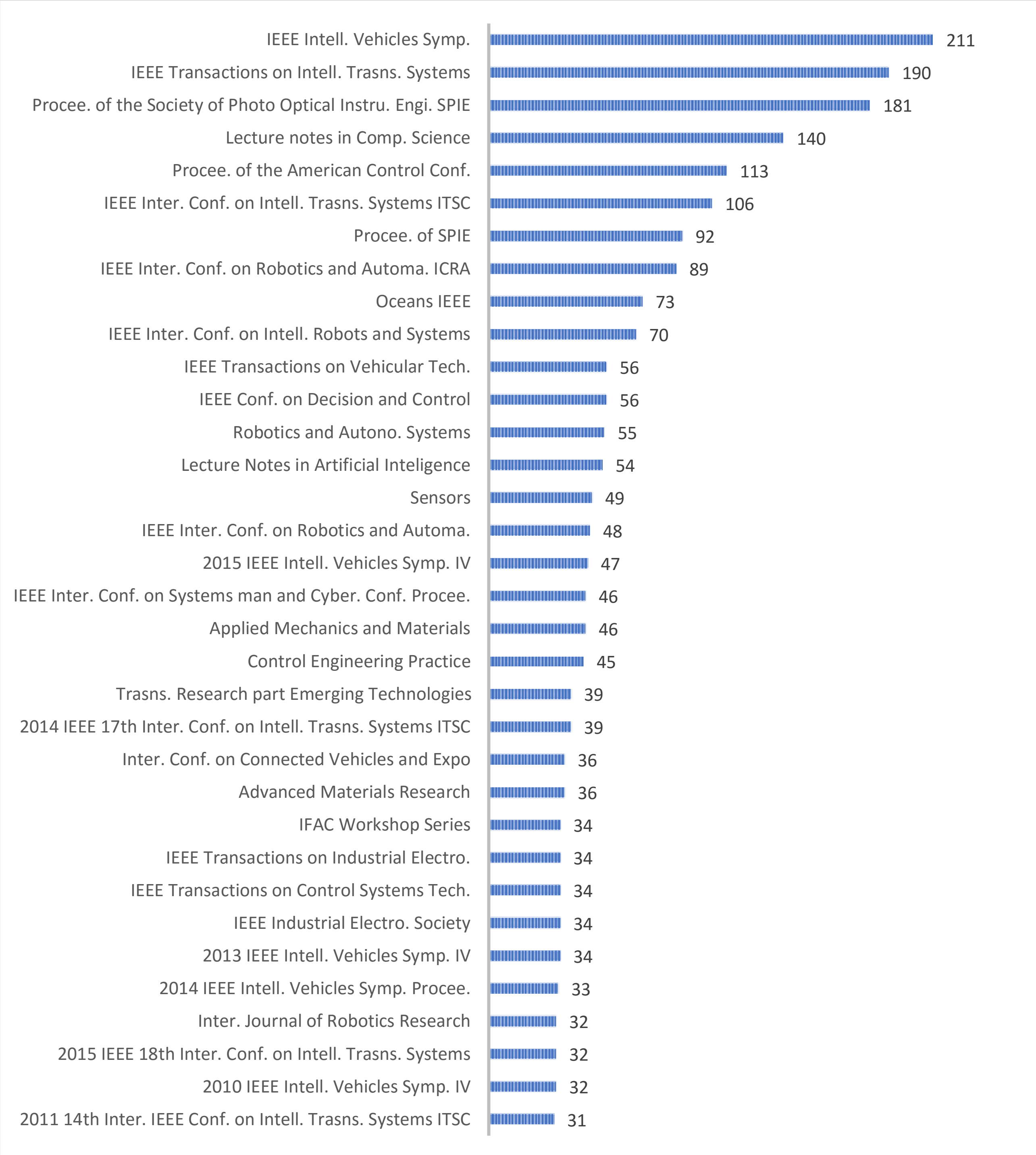


Figure 5. Top 34 higher publications (1st nucleus) of sources in numbers of papers based on Web of Science Data.

As described in Figure 5, the first nucleus (here understood as the subject's most devoted source) contains 34 distinct sources with a total of 2,247 publications. The second nucleus contained 180 different sources, which are responsible for 2,252 publications and, finally, the third nucleus, had 893 sources, responsible for 2,212 publications. Thus, we have observed that within the 1,108 sources responsible for publications in the area of AVs, only 34 (3%) were responsible for approximately 33% (2,247) of all the field's publications.

Figure 5 also shows the concentration of sources, included in the first nucleus, belonging to congresses or conferences (20 occurrences - 58%). This can be explained by the distribution of the works related to ADS, where, from the total documents, approximately 66% are proceedings papers in detriment of approximately 34% of journal articles, which may explain a recent recurrence of ADS in academia. This result also demonstrates that the discussion about AVs is far from being exhausted, characterizing this subject as a trending topic among the researchers. It is worth mentioning the IEEE eloquence in this field, with 20 occurrences among the components of the first nucleus (58%).

3.2 In-depth analysis

3.2.1 Keywords analysis

The keywords search on the 6,711 articles aimed at elucidating the main approaches in the field's evolution. To this end, we chose CiteSpace's analysis called burst-detection, which highlights the keyword bursts among the selected papers. According to Chen (2006), the citation and co-citation track is the intellectual foundation of a research front. The author reinforces that the Kleinberg's burst-detection algorithm (Kleinberg, 2002) is adapted to identify emergent research-front concepts. In order to elucidate the use of such algorithms for the keywords, it is worth highlighting that "the burst-detection algorithm can be adapted for detecting sharp increases of interest in a specialty" (Chen, 2006, p. 364). Although Kleinberg's states that the original algorithm was developed to detect the bursts of single words, "the algorithm is generic enough to be applied to a time series of multiword terms or citations of articles" (Chen, 2006, p. 364).

Figure 6 shows, in chronological scale, the 30 keywords with greater burst strength, according to Kleinberg's burst-detection algorithm. The first column displays the keywords, the second column shows the burst strength found by the algorithm, followed by the initial and final burst period, and finally, the corresponding burst time interval is shown by the red dashes.

In order to contextualize the observed results among the keyword bursts, it is worth highlighting the historical moment in which DARPA's Grand Challenge was inserted in the studies of Avs. We sought here to bring to light the discussion of the bursts as close to reality as possible in order to consider DARPA as a watershed on AVs. As pointed out by Lima (2015) the 2004 and 2007 DARPA's Grand Challenges were responsible for leveraging the tests and advancements on AVs research and development.

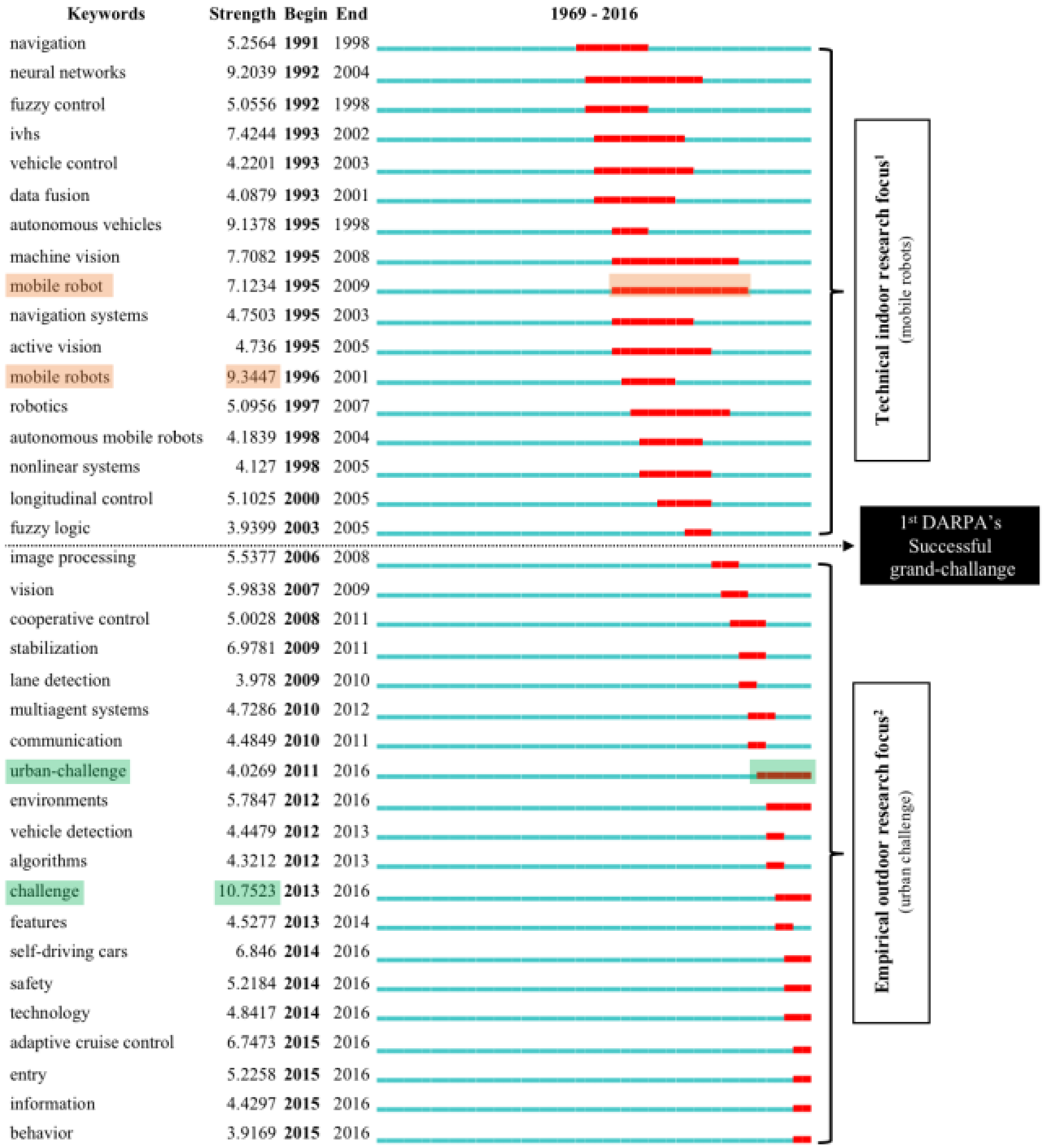


Figure 6. Keywords' burst-detection based on Web of Science Data.

As shown in Figure 6, a distinction among the keywords bursts was made, setting apart the pre- and post-DARPA periods. We observed that, on the years before the challenges, a concentration of terms featured as more technical-focused regarding the development of AVs, here denominated as *Technical Indoor Research Focus* with the highlight for two words (orange griffins) – "mobile robots" and "mobile robot", respectively as bursts stand out. The term "mobile robots" showed the strength of 9.3447 from 1996 to 2001, stating the subject strength in this period. Although "mobile robot" displayed smaller strength (7.1234) it remained for the longest time span (1995 to 2009), where, for approximately 14 years, the productions related to AVs somehow sought to understand/relate to mobile robots.

Regarding the period after DARPA, here called *Empirical Outdoor Research Focus*, we observed a concern not only centered on technical characteristics of AVs but also an approach to the systematization and empirical operationalization of vehicles beyond the laboratories. Highlighting the terms “challenge” and “urban challenge” with greater strength and time-span respectively (green griffins), we noted that the term ‘challenge’ had the greatest strength on the post-DARPA period (10.7523) from 2013 to 2016. It shows a strong relation to the publications and the challenges related to AVs' implementation, as well as to the term ‘Urban Challenge’, referred to one of DARPA’s challenge.

The term “urban challenge”, although not so strong (4.0269), was present for the longest period of time, from 2011 to 2016, with a relationship longer than 5 years within the field. It is also worth highlighting the terms “adaptive cruise control”, “entry”, “information” and “behavior”, which presented the most recent bursts started in 2015, demonstrating relationship among the AVs publications and their direction more related to the challenges of realizing the evolution between technology and its exposure to reality. At last, it is worth mentioning the relationship between “safety” and the studied topic, which appears as the most recent burst.

3.2.2 Categories analysis

Figure 7 presents the clusters of categories drawn from the words used in the papers’ titles. In total, 19 clusters were extracted and 126 areas composed this analysis *corpus*, demonstrating a multidisciplinarity in the field’s knowledge development. For automatically determining each cluster label, we used the *log-likelihood ratio* (LLR) test algorithm (Dunning, 1993), and the mutual information test. This tends to reflect a unique aspect of each cluster (Chen, Ibekwe-SanJuan & Hou, 2010). In this figure, five predominant clusters were observed (from #0 to #4). Cluster #0, characterized by the word "flow", has 14.3% of the total categories (18). For publication volume, the highlighted categories are Imaging Science & Photographic Technology (174 articles), Remote Sensing (155), and Oceanography (133), respectively. The cluster silhouette was 0.81, which the silhouette metric (Rousseeuw, 1987) is useful in estimating the uncertainty involved in identifying the nature of a cluster (Chen, 2010). The silhouette value of a cluster, ranging from -1 to 1, indicates the uncertainty that one needs to take into account when interpreting the nature of the cluster. The value of 1 represents a perfect separation from other clusters.

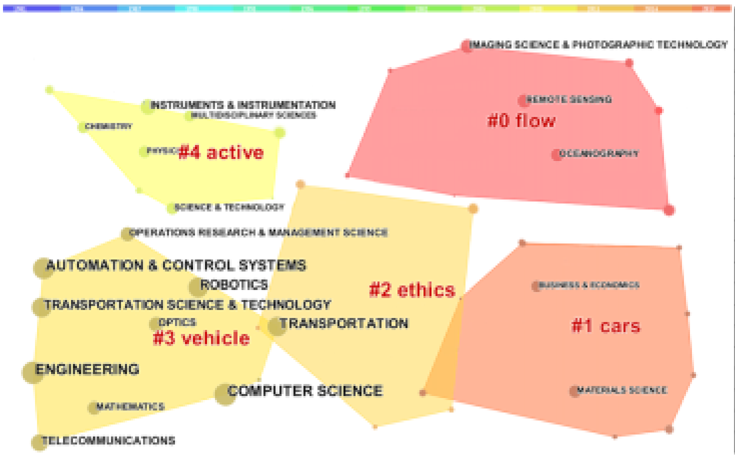
Considering this metric, there is a higher representation of cluster #0. As for the cluster’s average publication year, it is relatively old (1996), therefore more mature. At last, from the mutual term test, the word “field” was identified, demonstrating that a key aspect of this cluster revolves around the field needed for autonomous functionality.

Following, cluster # 1 is characterized by the term “cars” (15 categories, cluster silhouette: 0.901), being Material Science, Business & Economics, and Management with most publications (108, 58, and 31 papers respectively). The average year of publications is relatively old (1995), and according to the mutual term test, the word “success” was identified as the most significant. This result points to the fact that the publications related to areas of prominence in this cluster such as business & economics, and management, are often focused on evaluating, measuring or enabling the success of autonomous vehicles.

Cluster #2 is characterized by the term “ethics” (14 categories, cluster silhouette: 0.894), with highlight to Psychology (36 papers), Ergonomic (33), and the Education & Educational Research (30). The publications’ average year was 1997 and, according to the mutual term testing, the world “remote” stands out.

The term “vehicle” characterizes cluster #3 (14 categories, silhouette of 0.719 – the lowest among all). This cluster has categories with great expression in a number of publications such as the Engineering (3.676 papers), Computer Science (2.791), Automation & Control Systems (1.913). As for the publication’s average year, this is the oldest cluster (1988), and regarding the mutual term test, the word “complex” stood out, indicating a strong relationship between AVs response and the vehicle’s complexity.

Cluster #4 (13 categories, silhouette: 0.837) is characterized by the term “active”, with Instruments & Instrumentation (288 papers); Science & Technology (89) and Physics (70) standing out. The cluster is the most recent when it comes to the average publication year (2003) and has the term “remote” standing out by the mutual term test, which indicates a strong research trend on the role of active and remote for the AVs.



Web of Science Category	Frequency	Centrality
Engineering	3676	0.07
Computer Science	2791	0.12
Automation & Control Systems	1913	0.01
Transportation	1325	0.30
Transportation Science & Technology	1183	0.04
Robotics	1180	0.00
Telecommunications	416	0.00
Instruments & Instrumentation	288	0.21
Optics	238	0.21
Operations Research & Management Science	178	0.04
Imaging Science & Photographic Technology	174	0.09
Remote Sensing	155	0.08
Oceanography	133	0.05
Mathematics	125	0.06
Materials Science	108	0.04
Science and Technology	89	0.09
Physics	70	0.07
Chemistry	65	0.06
Multidisciplinary Sciences	59	0.01
Business & Economics	58	0.15

Figure 7. Clusters of categories drawn from the words used in the papers’ titles.

The Optics category, although presenting a relatively low number of published works (238), holds the first publication on the subject in 1982. Most of its articles belong to Engineering category (3,676), followed by Computer Science (2,791). Although displaying a lower but representative number of papers, it is worth highlighting: Automation & Control System (1,913), Transportation (1,325), Transportation Science & Technology (1,183) and Robotics (1,180).

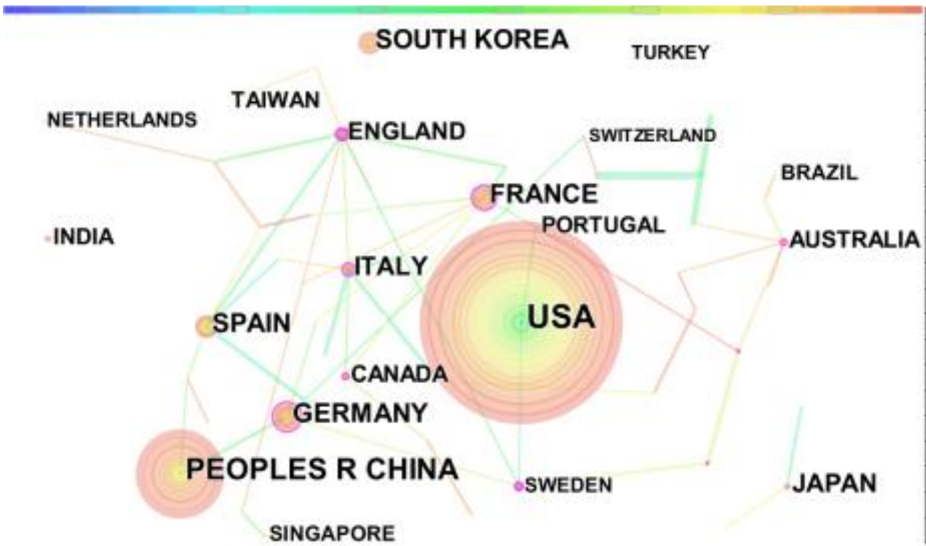
There is a great dispersion of the theme among several distinct areas in the period between 1990 and 1994. In five years, we verified the insertion of 40 distinct areas of knowledge. In contrast, the last five years of the search (2012-2016) have resulted in the insertion of only 10 new areas of knowledge (Biophysics, Logic, Nuclear Science & Technology, Ethics, Gerontology, History & Philosophy Science, Health Policy & Service, Philosophy, Law, Communication, and Paleontology). We observed that the categories inserted in the last 5 years comprehend, in a general way, a characterization of the field more directed to non-technical factors, but rather related to dimensions of knowledge related to social, legal and ethical aspects of the AVs. It is noteworthy that the evolution of the field to other areas of knowledge does not inhibit the evolution of older areas, but points to possible new paths in which the field may be evolving or moving in parallel. In this sense, it is important to mention the insertion of the ‘Law’ category in 2015, opening a parenthesis for the context in which the AVs are inserted today. For Anderson et al. (2014), the variety of AVs development efforts suggests that states may soon face the question of whether and how to regulate these vehicles. Different manufacturers may take different approaches to automated driving when it comes to legislation and its consequences.

The advancement of technological innovations, permeating the AVs and the intelligent robot industry, is part of the dynamic result established between technology, business model, and market (Yun et al., 2016). In this context, the possibility of changes in the dynamic relations between these three factors in order to obtain the expected results is on evidence. This change may be part of a process inherent in the role of a business model not established yet. In the future, it will be necessary to develop dynamic system models and more concrete simulation research on political leverage, including the market's growth pattern size.

In this sense, we evidenced (in Figure 8) the low incidence of papers in the Business & Economics (58) and Management (31) categories respectively. Such low incidence of business-related categories in relation to the other areas of knowledge demonstrates a possible mismatch between the technological evolution of the field and the businesses models and platforms necessary for the presence and consolidation of such vehicles in the market. At last, the business model plays an extremely important role in the events that precede the advancement of AVs in society (Yun et al., 2016). By increasing the level of the business model, even if the level of technology is not high, the size of the market increases through positive feedback (Yun et al., 2016; Shapiro & Varian, 1999).

3.2.3 Countries analysis

From the Web of Science countries analysis, we observed a great contribution on AVs around the world. The publications are distributed among 95 countries, where the countries' network analyzed by the number of publication is depicted in Figure 8. The USA holds the first position in number of papers (1.796), followed by China (851), Germany (390), South Korea (340), Spain (337), France (334), Italy (252), Japan (249), England (229) and Australia (184).



Country	Frequency	Centrality
USA	1796	0.01
China	851	0.02
Germany	390	0.15
South Korea	340	0.00
Spain	337	0.10
France	334	0.12
Italy	252	0.15
Japan	249	0.00
England	229	0.40
Australia	184	0.14
Canada	165	0.12
Portugal	135	0.05
Taiwan	128	0.03
India	123	0.00
Singapore	104	0.03
Brazil	95	0.00
Netherlands	84	0.00
Sweden	82	0.28
Turkey	57	0.00
Switzerland	51	0.07

Figure 8. Countries' network analysis by the number of publication.

The current position of USA could be explained for the synergy of many stakeholders (academia, public organizations, automotive companies, technology companies, etc.). In the USA, universities are contributing significantly to the development of AVs technology. Uber e.g. has partnered with two academic institutions, the College of Optical Sciences at the University of Arizona[5] and the University of Michigan[6]. Besides of this, it is not only large companies driving the discussion on AVs, startups like Faraday Future[7] are also taking a role in imagining the applications of these vehicles (Gleave et al., 2016). It is important to highlight the DARPA Grand Challenge, that may also be a potential booster for North American publications.

China aims to race ahead of everyone in electrics and autonomous vehicles by 2030. In fact, the country has ambitious plans for AVs. They expect vehicles with "driver assistance" and “partial driving automation” to account for 50 percent of sales by 2020, "conditional driving automation" cars will take 15 percent of sales in 2025, and, by 2030, “high and full driving automation” vehicles will represent 10 percent of sales. That is 4 million completely robocars annually (Dunne, 2016). In this context, we can observe that the government enthusiasm could be one of the main stakeholders to develop the AVs in the country and this impact at the numbers of papers.

In the Europe Union, a number of countries are taking significant steps to be at the forefront of this research. The European Commission and other European bodies have demonstrated their interest in vehicle automation by funding a variety of research and innovation. One of the main areas of interest of the European Commission was the development and implementation of driver assistance systems to improve driving safety (Gleave et al., 2016). In particular, German manufacturers are promoting full driving automation vehicles and are currently undertaking tests. Manufacturers like Audi, BMW, and Mercedes-Benz are all active in this sector, leading experiments worldwide. The collaboration between companies is crucial for the AVs developing. An example is a partnership between BMW and the Chinese company of search engine and technology Baidu for the development of increasingly automated systems of driver assistance (Gleave et al., 2016). In view of this, Figure 9 presents a connection between these countries (Germany and China).

In addition, we analyze the countries’ centrality scores to understand how they are connected. CiteSpace also has a resource which performs analyses from the centrality of intermediation. The software normalizes a unit interval of [0, 1], in which a node of high centrality between the two usually connects two or more large groups of nodes with the same node between them, this being called intermediation. The colors indicate nodes with high centrality, these being indicated with purple finishes, this thickness indicative of force in its equilibrium centrality (the thicker, stronger) (Chen, 2014).

We observed that England has a predominant score (0.40), followed by Sweden (0.25), and Germany (0.15). Italy and Australia summed the same score (0.14). USA and China, the most signified countries in a number of publications, present a low influence in centrality score (0.01 and 0.02, respectively). The EU influence could be responsible for the high centrality score, being evident these members’ predominance. According to European Commission (2016), it is time to put into practice the possibilities of AVs in real traffic conditions. The experience from some

[5] NBC News, *Uber Working With University of Arizona to Create Self-Driving Cars*, 25/08/2015

[6] University of Michigan - Mobility Transformation Center, *Mcity Test Facility,* webpage, *http://www.mtc.umich.edu/test-facility.*

[7] Faraday, a company of just over 400 people, is looking at a user-driven approach to future vehicle design. The company presented its concept automated car – the FFZERO1 Concept – at CES 2016 and talks about vehicle intelligence not only being outwardly directed towards its surroundings, but capable of learning its users and making decisions based on passenger desires. The company has gained interest from poaching significant numbers of talent from other companies in the field and being very well funded.

Member States shall be used and test data should be exchanged. The official language, in contrast to English, can explain the low centrality score in countries with higher publications' numbers like China, South Korea, and Japan.

Finally, we observed that AVs' "race" is going beyond technological issues or as a battle between OEMs around the world. More than that, governments across the country, and indeed around the world, compete with each other, as well as Google and BMW (Turck, 2016). We analyzed the Department of Transportation's Reports about AVs around the world, and we observed that the government' battle real exists. For instance, the Pathway to Driverless Car from the UK inform the readers, in the very early pages that; "We are setting out the best possible framework to support the testing of automated vehicles, to encourage the largest global businesses to come to the UK to develop and test their technologies" (Department for Transport, 2015 p. 5). In this sense, the public sector has a crucial role and responsibility in enabling AVs development. To make sure that adequate safety standards are met it is necessary that these authorities set the conditions to undertake tests and authorize the use of automated vehicles on road infrastructure (Gleave et al., 2016).

3.2.4 Co-citation authors analysis

The co-citation analysis has identified a great dispersion within the field. The extracted clusters for this analysis corroborates with such heterogeneity given that 230 clusters were extracted, being 64 labeled as significant (Figure 9). In the categories' analysis, the clusters' labels were assigned from publications' titles by using the *Log-Likelihood Ratio Algorithm* (LLR) (Dunning, 1993). "The fundamental assumption is that co-citation clusters reveal underlying intellectual structures" (Chen, 2010, p. 4). In this sense, this analysis could suggest the main intellectual streams, as well as the main papers that are part of the construction of these research streams. In this study, we chose to discuss the 5 main clusters, as well as to identify the most representative work (in a number of co-citations) on each of these clusters.

The cluster #0 (composed of 91 papers, with a silhouette of 0,874 and average publication's year of 2008 – the most recent) is characterized by the label "driving". The main paper of this cluster is (Campbell, 2010). Such paper represents 9% of the cluster's citations within the AVs field.

As for cluster #1 (composed of 70 papers, with a silhouette of 0,861 and average publication's year of 1999), it is characterized by the label "target" and has the paper (Broggi, 2000) holding 14% of the cluster's citations. The cluster #2 (containing 51 papers, with 0.913 of silhouette and 2005 as the average publication year) has the term "recognition" as the label. The most relevant paper is (Fu, 2010), holding 12% of the cluster's citations.

Labeled as "reasoning", cluster #3 is comprised of 47 papers with a silhouette of 0.954 and average publication year of 1983 (the oldest one). It has the paper (Mitchel, 1987) holding 51% all citations within this cluster. At last, cluster #4, labeled as "stereo" with 47 papers, has the strongest silhouette among all (1,000) and average publication year of 1990, with the paper (Grosso,1995) evidenced with 74% of all citations within the cluster.

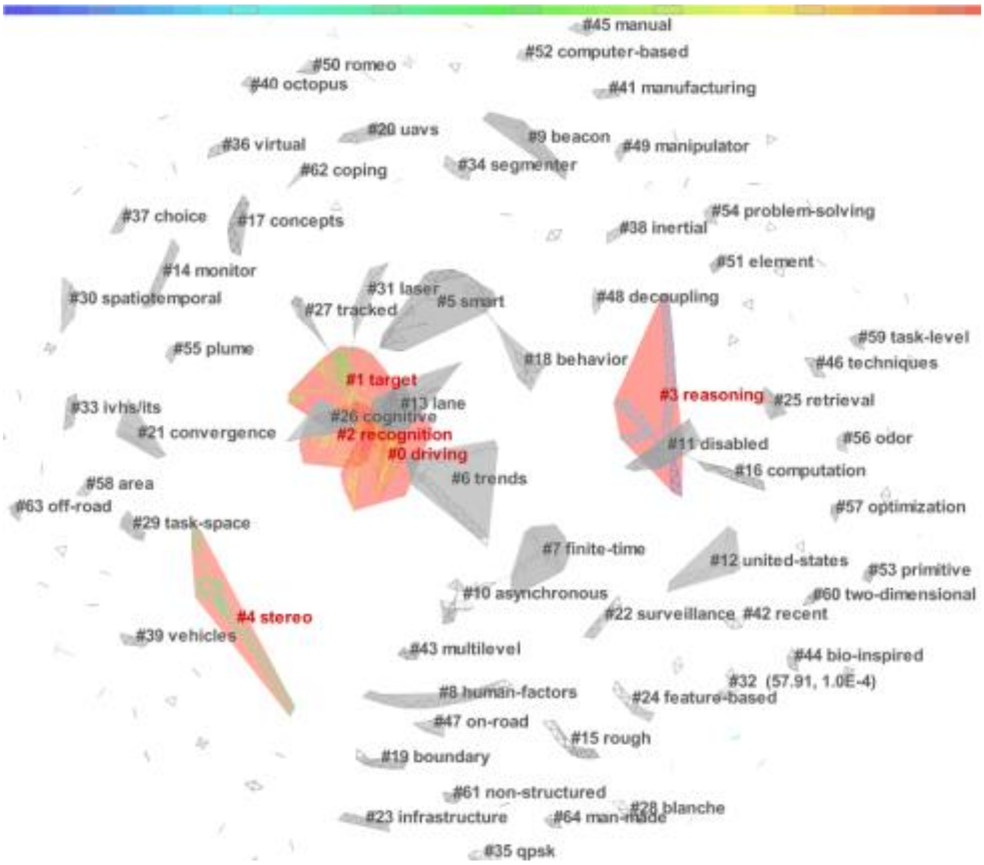


Figure 9. Co-Citation authors' clusters by publication titles.

Note that other clusters with less influence point to study tendencies under development, from several areas of knowledge, such as infrastructure, problem-solving, human factors, and decision-making.

4. Concluding remarks

This work focused on identifying, from a scientific and systematic review of the studies on AVs indexed in the Web of Science database, the main characteristics of this object of study, as well as its evolution, in order to evidence possible gaps for prospective studies. There is a growing demand on this topic over the years, as demonstrated by the exponential curve of the analysis of the number of papers/year and citations/year since 1982 (when occurring the first paper with an uninterrupted evolution of AVs' publications). The summit of publications and citations in the years of 2015 and 2016 corroborates with the current relevance of the subject, as well as the high number of proceedings papers (64%). From the analysis of higher publication sources, it was observed that only 3% of the sources are responsible for approximately 33% of the publications of the theme, with the IEEE being present in 58% of the publications of the first dispersion nucleus, evidenced by the law of Bradford (1934). Note that the whole scope related to autonomous vehicles is still being widely discussed in the scope of congresses and conferences, which shows a subject far from being exhausted by the Academy.

The AVs area presents heterogeneity, considering authors with most papers, category analysis, and co-citation authors' analysis. The dispersion of authorship in the field shows a non-fully constructed science, where a consolidated state of the art on the subject is not identified yet.

This fact is also evidenced by the analysis of Price's elitism law (1976) and the co-citation study corroborates this fact. Due to the predominant presence of 230 clusters, the studies on AVs are constructed from many distinct "fragments" of science that, even if correlated, have particularities. The co-citation map has presented a powerful research tool for highlighting the main subjects (through identified clusters) related to AVs.

The multidisciplinary is present in 126 areas of science in the field. Although there is a predominance of sciences more related to the technical evolution of AVs, we noted a growing presence of sciences that permeates automated vehicles (e.g. law by 2015). However, by the category analysis of each cluster, this is still incipient when compared to the technical evolution of the field. The great insertion of knowledge areas, in the period between 1990 and 1994, could be explained by the strengthening of the personal computer at this time (reducing the size and increasing its processing capacity), facilitating the emergence of more vehicles' prototypes and, consequently, more possibilities of applications.

Although there are studies related to business, economics, and management, there is a slight evolution of these domains related to AVs. In this sense, it is evident the technological evolution of AVs area. However, as in any other sector, there is a need to understand broader aspects of this industry such as market factors surrounding them, and other economic and managerial issues as well. The burst analysis of the keywords corroborates the recent requirements of the field to extrapolate the technological areas, indicating market plans. In the last years, there has been an explosion of the terms like *adaptive cruise control*, *entry*, *information*, and *behavior*, in publications from 2015 to 2016. Noteworthy, there is a consensus that technological factors are essential for the field' evolution and these should not be neglected at all. However, the other areas are also essential for the dissemination of the field and must follow the opportunities and needs of this emerging issue.

The historical moment in which the DARPA Grand Challenge was inserted, indicates that publications post-DARPA reflects a reproduction of publications that move closer to reality outside the laboratories of the AVs. In this sense, we observed that the AVs' field evolution indicated some gaps that researchers have to solve in order to establish its development. By the citation burst and co-citation authors analysis, it was evident that infrastructure, problem-solving, human factors, choice, safety, behavior, and information are areas that could help the AVs' advance and are still under formation. In this way, we observed that the government rules could direct impact the AVs' development. The countries' analyses demonstrated that the numbers of papers in the field were more representative in areas where public administration stimulated and attracted stakeholders setting the conditions to undertake tests and authorizing the use of automated vehicles on road infrastructure (e.g. USA, China, and EU).

As limitations of this study, it is important to mention the unique use of the Web of Science database, a fact that may not have considered possible works related to the area. Finally, we would like to emphasize the numerous research possibilities detached from this work. As an agenda for future studies, we suggest a more in-depth look at the publications of the sub-areas found as tendencies in this articles, such as law, business, management, economics, and political affairs, as a mean of understanding all the processes, dynamics and markets that involve AVs.

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