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What Role For Research In The Autonomous Vehicle Innovation Ecosystem? Insights From A Meta-Analysis Of 298 Trb Papers Over 5 Years

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1 **WHAT ROLE FOR RESEARCH IN THE AUTONOMOUS VEHICLE INNOVATION**
2 **ECOYSTEM? INSIGHTS FROM A META-ANALYSIS OF 298 TRB PAPERS OVER 5**
3 **YEARS**

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5
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1 ABSTRACT

2 In light of the fast pace of innovations linked to AV technology, the question arises as to the role
3 academic research can play in the overall innovation ecosystem surrounding autonomous vehicles.
4 To explore this question, the authors examined a body of 298 papers presented at the last 5 editions
5 of TRB Annual Meetings (2014 to 2018), and selected using a list of queries related to AV
6 technology (road vehicles only). The review examined the context of the research as well as its
7 contents (including typologies for building blocks of knowledge and for technology readiness
8 levels) and the nature of partnerships involved in the production of knowledge.

9 Main findings are that American contributors are prominent, followed by contributors
10 from the Netherlands and China. The five more active institutions are four US universities and one
11 Dutch university. As expected, the most productive authors belonged to the most active institutions.
12 Very few contributions from the private sector were identified.

13 Research on the vehicle and on operations still dominate, in most cases involving
14 technologies at the stage of proof of concept. Research on demand is growing but still involves
15 technologies with low levels of maturity. Governance is growing as a research focus (especially as
16 real-life experiments develop) and involves technologies from low and high levels of maturity.
17 National and regional agencies are the major funding partners of AV research.

18 Academic research plays a supporting role in the AV innovation ecosystem, especially with
19 regards to technological and operational developments. More research is needed on demand and
20 governance.

21

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25 *Keywords:* Autonomous Vehicle, Meta-Analysis, TRB Annual Compendium, Innovation

26 Ecosystem, Technology Readiness Level

27

1 INTRODUCTION

2 Since the debuts of the Google Car in 2010, the autonomous vehicle (AV) technology has
3 undergone significant developments. Competition has been fierce in the automotive industry and
4 with transportation platforms and other service providers. Despite highly vocal criticism
5 following such events as the Tesla Autopilot crash in May 2016 or the Uber driverless car crash
6 in March 2018, it is becoming increasingly accepted that self-driving cars could be on the roads
7 in the next decade. Faced with rapid technological change and industrial upheaval, governments
8 have started to regulate the nascent industry and to set appropriate frameworks (including
9 roadmaps, taxonomies, etc.) to guide the technology development. In the United States, the
10 National Highway Traffic Safety Administration (NHTSA) after developing a first classification
11 for vehicle automation levels as early as 2013 later adopted classification J3016 by the Society of
12 Automotive Engineers (SAE) (1) in 2016 (2). SAE classification J3016 lists and defines 5
13 automation levels. Level 0 means no automation, whereas level 1 implies driver assistance and
14 level 2, partial automation. Levels 0–2 refer to lower-level automated vehicles (LAVs), whereas
15 levels 3–5 refer to highly automated vehicles (HAVs). Level 3 is known as conditional
16 automation, whereby a driver must be in the vehicle but is not required to monitor the
17 environment at all times. Level 4 refers to high automation (i.e. full automation on designated
18 use cases), and level 5 to full automation. European countries modified the Geneva Convention
19 on Road Traffic and the Vienna Convention on Road Traffic in 2016 to accommodate the new
20 technology and make real-life experimentations possible.

21 Parallel to such technological and political developments, academic research on
22 autonomous vehicles has been growing rapidly (3; 4) covering a wide range of domains from
23 robotics, computer science and engineering (3) to political or societal domains (4). It has also
24 been rapidly evolving. In the first half of the decade, a large majority of studies focused on the
25 technological aspects of vehicle automation (4; 5). Progressively, more and more research papers
26 have taken into account social impacts and policy formulation (4; 6), while research on AV
27 technological aspects made further progress.

28 In light of the fast pace of innovations linked to AV technology, what can be the place of
29 academic research in the overall innovation ecosystem surrounding autonomous vehicles?

30 As a preliminary exploration of the question, the authors propose to examine all papers
31 discussing AVs that were presented at one of the five most recent editions of the Transportation
32 Research Board (TRB) Annual Meeting (2014 to 2018). TRB Annual Meetings are a privileged
33 arena for sharing information on transportation practice and policy among researchers and
34 practitioners but also for stimulating the emergence of new research. These meetings contribute
35 to the main mission of the TRB, an institution under the aegis of the US National Academy of
36 Sciences, which is to promote innovation and progress in transportation through research. As far
37 as AV technology is concerned, the title of Session 334 of the 2016 TRB Annual Meeting
38 effectively sum up the question raised in this paper: “Can We Keep Up? Accelerating Research
39 Processes to Keep Pace”.

40 The concept of innovation ecosystem refers to the collaborative effort of a diverse set of
41 actors from both the production (supply) side and the use (demand) side, towards innovation (7;
42 8). Ecosystems encompass communities of organizations, institutions, and individuals that
43 influence the fate of a local firm (7) or a dedicated technology such as AV. Innovation
44 ecosystems are dynamic. They emerge, expand and consolidate, and then die or renew
45 themselves (8). Although value creation usually predominates over value capture in innovation
46 ecosystems (as opposed to business ecosystems) (9), relationships among actors in the ecosystem
47 could be unstable, possibly moving from cooperation to competition and vice-versa, especially in

1 the presence of a radical innovation (9). In such a context, what can be the role and position of
2 academic research? Is it a supporting role or a leading role involving direct value creation, or yet
3 an entrepreneurial role (8)? Has the role of academic research evolved with the increasing level
4 of maturity of the AV technology (10) and the expansion and complexification of the innovation
5 ecosystem?

6 The AV innovation ecosystem considered in this paper focuses on surface transportation
7 solutions using road vehicles. Automated or autonomous as well as self-driving or driverless
8 road vehicles are in the scope, but the authors did not consider guideway transportation (e.g.
9 personal rapid transit).

10 The paper is organized as follows. The next section describes the process for selecting
11 papers and the analytical framework (accounting for, inter alia, considerations of technology
12 maturity). A second section presents descriptive statistics regarding the main contributors
13 (countries, institutions and authors). A third section focuses on the content of research (including
14 focuses on the building blocks of knowledge and on the maturity of technology considered) and
15 the forms of partnerships involved in research production. A final section discusses the role of
16 academic research in the innovation ecosystem and draws out perspectives for future research.

17 **METHODOLOGY**

18 **A Body of 298 Papers**

19
20 Being the largest annual conference on transportation research globally, the TRB Annual
21 Meeting offers a broad perspective on ongoing research on a wide range of topics, from
22 infrastructure to safety including travel behaviors, etc. Besides, due to a very efficient selection
23 process of papers (5 months from initial submission to presentation in the conference, including
24 a single-blind reviewing process and the resulting revision of the paper), research presented at
25 TRB usually covers the hottest topics of research in pace with, if not in anticipation of,
26 publications in scientific journals. The authors therefore considered that the compendium of
27 papers of TRB would provide a relevant baseline for developing and testing on a limited
28 selection a methodology for the meta-analysis of the literature dedicated to autonomous vehicles.

29
30 Autonomous vehicles being a recent, very dynamic topic in transportation research, they
31 have been the focus of a growing number of papers presented at TRB over recent years. They
32 even became the focus of dedicated sessions (including lectern, poster, workshop and panel
33 sessions) starting in 2012 with a lectern session labeled “Ready for automated mobility” (session
34 181), several years after the first sessions dedicated to “vehicle-highway automation” started.
35 Papers included in this review were selected from the compendiums of papers of TRB Annual
36 Meetings from the last 5 years (2014 to 2018) using a list of queries which treated as synonyms
37 the words “automated”, “autonomous”, “driverless”, “self-driving”, in combination with the
38 words “vehicle”, “car”, “bus”, “taxi”, or “shuttle”. The phrases “robo-taxi” and “vehicle
39 automation” were also included in the list of queries. Authors used the search engine of TRB’s
40 compendium website to proceed the queries. Altogether, these queries led to a selection of 298
41 papers over 5 years, with a significant acceleration from 2016. 13 papers were presented in 2014,
42 which amounted to 1% of total papers in the 2014 compendium, 15 papers in 2015 (1% of total),
43 49 in 2016 (2% of total), 75 papers in 2017 (3% of total), and 146 papers in 2018 (4% of total).
44 Thus, 25% of the corpus was retrieved from the 2017 compendium and almost half of all the
45 papers from the 2018 compendium. The yearly number of papers focusing on AVs increased
46 more than tenfold over a 5-year period. The authors noticed a similar acceleration regarding the
47 ratio of the number of TRB sessions explicitly dedicated to AVs to the total number of sessions

1 at a given TRB Annual Meeting. Indeed, the 10 sessions that were focused on AVs at the 2014
 2 Annual Meeting and the 31 sessions focused on AVs at the 2018 Annual Meeting respectively
 3 amounted to 1% of all TRB sessions in 2014 and 4% of all TRB sessions in 2018.
 4

5 **Analytical framework**

6 A systematic approach was used for the collection of a wide range of information from each
 7 paper, from authors' names and affiliations to methods used, also including the types of data, the
 8 thematic focuses, the level of automation considered, etc. In order to explore the place of
 9 academic research in the overall innovation ecosystem surrounding autonomous vehicles, the
 10 present paper reviews the selected papers from four main analytical perspectives covering the
 11 context of the research as well as its content.

12 First, the review examines where academic research emanates from, with specific
 13 focuses on the most actively contributing countries (where institutions are based), institutions,
 14 and authors.

15 Second, the review analyzes on which building block(s) of knowledge academic
 16 research is focused, be it: a) the vehicle and its components (hardware and software innovations,
 17 technological options, etc.); b) operations (operational optimization, business models of services,
 18 etc.); c) demand (market segments, diffusion process, customer acceptance, willingness-to-pay,
 19 travel behaviors, social acceptance, etc.); or d) governance and regulation.

20 Third, the review considers the level of maturity of the objects on which academic
 21 research is carried out, using the US Federal Highway Administration (FHWA)'s 9-level
 22 Technology Readiness Level (TRL) scale (10) as a reference (Table 1). The TRL scale is
 23 designed to evaluate how complete was the technology when it was tested and how
 24 representative the test environment was (10). The papers were classified according to a list of
 25 questions Cuddy et al. (10) consolidated for each of the 9 TRLs. As an illustration, to achieve a
 26 TRL rating of 3 that characterizes the "proof of concept", the technology considered should yield
 27 positive answers to the following questions: "Are system performance metrics established? Is
 28 system feasibility fully established? Do experiments or modeling and simulation validate
 29 performance predictions of system capability? Does the technology address a need or introduce
 30 an innovation in the field of transportation?" (10).

31 Fourth, the review analyzes the nature of partnerships disclosed by academic research
 32 with other stakeholders in the process of research production, e.g. on funding, data sharing, etc.
 33

34 **TABLE 1 The FHWA's Technology Readiness Level Scale (10)**
 35

TRL	Description
1	Basic principles and research
2	Application formulated
3	Proof of concept
4	Components validated in laboratory environment
5	Integrated components demonstrated in a laboratory environment
6	Prototype demonstrated in relevant environment
7	Prototype demonstrated in operational environment
8	Technology proven in operational environment
9	Technology refined and adopted

36 **Scope and limits** 37

1 Although the TRB Annual Meeting is an open conference, the reach of which is intended to be
2 global, the authors acknowledge there is a geographical bias to the selected body of research, if
3 for no other reason than for the additional costs incurred by researchers from outside the US to
4 attend the conference. Language could also be a barrier. Given that the reviewing process
5 specifically asks about clarity of writing, writers who are not native speakers or do not have
6 access to efficient editing can be disadvantaged. The results of the review regarding where
7 academic research emanates from, might therefore not be representative of the research on
8 autonomous vehicles published in scientific journals or in the grey literature. Plus, fierce
9 competitive climate refrains manufacturers and operators to contribute to such publications.

10 Besides, for the purposes of this meta-analysis, the authors chose not to discriminate
11 among the papers based on the level of automation of the technology considered. Such an
12 inclusive approach was made possible by the limited size of the selected corpus of papers. All
13 levels of automation rated 1 (driver assistance) to 5 (full automation) on SAE scale J3016 (*I*)
14 were therefore included in the scope of the review. It should however be noted that 165 out of
15 the selected 298 papers made no explicit mention of the level of automation considered, which
16 would limit the accuracy of (future) analyses based on this entry.

17 **WHO CONTRIBUTED THE MOST TO AV RESEARCH AT TRB?**

18 **Home Countries of the Contributing Institutions**

19 Authors of the selected papers were classified according to the institution to which they belonged
20 and the country where this institution was based. 96% of the papers were co-authored by two or
21 more authors and 81% by three or more authors. 44% of the papers were affiliated to two or more
22 contributing institutions.

23 Contributing institutions were based in 28 different countries. 11 countries were most
24 active as they hosted institutions contributed to 5 or more papers over the period 2014-2018.
25 American institutions largely dominated the AV research with contributions in 201 papers on the
26 subject (Figure 1). They were followed by institutions from the Netherlands (21 papers) and China
27 (20 papers). Papers from the US represented two thirds of the body, which is ten times more than
28 the Netherlands in second position. As already mentioned, this gap could partly be explained by
29 the fact that, despite its international dimension, the TRB meeting takes place every year in
30 Washington, DC and therefore remains strongly focused on North America. Institutions based in
31 European countries (including the UK and Switzerland) contributed to 80 papers and East Asia to
32 36 papers. It is interesting to notice that China's first TRB contributions on the subject occurred in
33 2016. Chinese institutions contributed to three papers in cooperation with American institutions
34 that year and continued a tight cooperation with the US as 12 of their 20 papers were authored in
35 cooperation with the US. Altogether, 10% of American paper contributions resulted from a
36 collaboration with one or more foreign countries.
37
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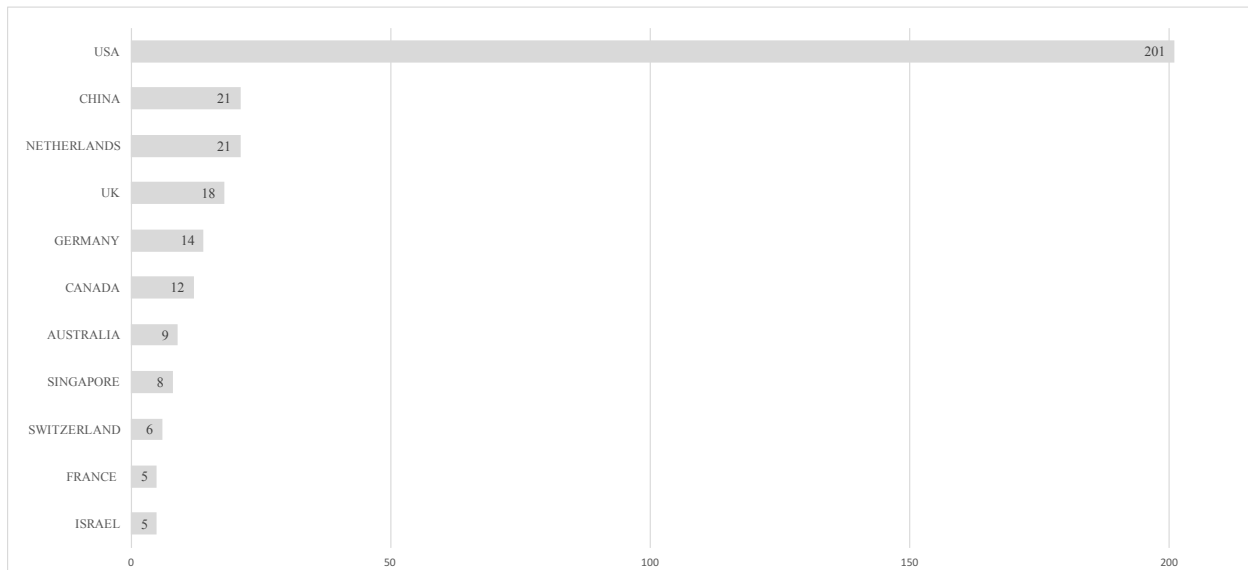


FIGURE 1 Paper contributions of the 11 most active countries in AV research at TRB (2014-2018)

Institutions

Universities and national research centers are in majority among the contributors (Table 2). Private companies, governments at local, regional and national scales, and associations were also among the contributors to AV research.

Academia accounted for 84% of the contributions and 76% of the institutions that published on the subject. Almost half of the academic institutions involved in AV research presented at TRB were American. They accounted for 59% of the academic contributions. On the opposite, private companies accounted for 15% of the institutions but less than 10% of the papers.

The 5 institutions most represented were universities. Four were from the US: Came first the University of Texas at Austin with 23 papers, then the University of California at Berkeley with 14 papers, the MIT with 12 papers, and Texas A&M with 11 papers. It is interesting to notice that Delft University of Technology from the Netherlands ranked second with 19 articles.

TABLE 2 Contributing Institutions by Category

Type	Institutions	<i>US Institution Percentage</i>	Contributions	<i>US Contribution Percentage</i>
Academia	167	47%	402	59%
Associations	9	67%	10	70%
Private companies	34	47%	44	55%
Governments	17	76%	21	81%
Total	233	76%	477	60%

Authors

The most productive author among the 760 different authors was the Dutch scientist Bart van Arem, director of the TU Delft Transport Institute and head of the Department of Transport & Planning at the Delft University of Technology in the Netherlands. The transportation modeling professor was the (co)author of 16 papers over the 5-year period. He was followed by Professor

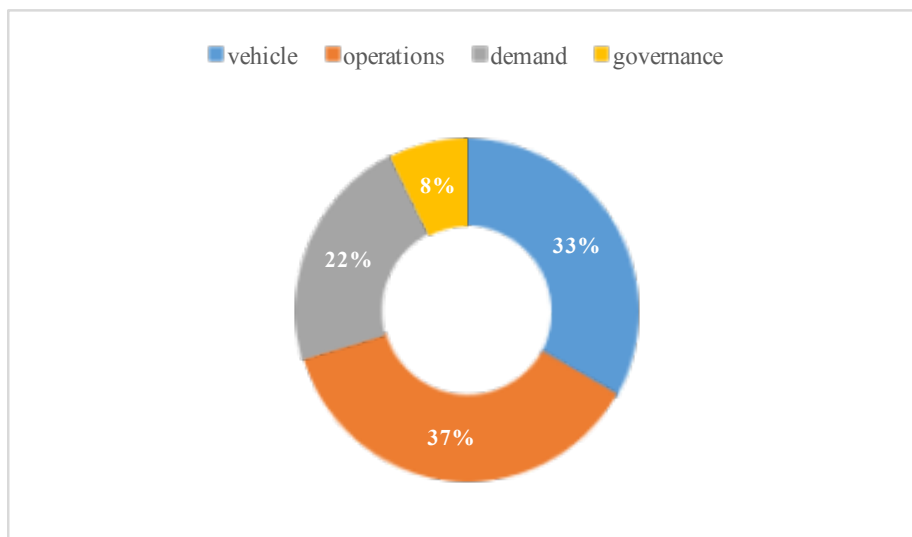
1 Kara Kockelman (transportation engineering and planning) from the University of Texas at
2 Austin (13 papers). The next most active authors with 7 papers each were the American scientists
3 Steven E. Shladover from the University of California at Berkeley (automation and control),
4 Hani S. Mahmassani from Northwestern University (transportation modeling) and Jiaqi Ma from
5 University of Cincinnati (advanced computing applications in transportation). Bart Van Arem
6 and Steven E. Shladover were very active in 2018 as each of them made contributions to 5
7 articles in the corpus. As expected, the most productive authors belonged to the most active
8 institutions.

10 ON WHAT AND HOW WAS THE RESEARCH DONE?

12 The Building Blocks of Knowledge

13 The 298 papers were classified according to the main building block of knowledge (one of four)
14 addressed by the research, i.e. a) the vehicle and its components (hardware and software
15 innovations, technological options, etc.); b) operations (operational optimization, business
16 models of services, etc.); c) demand (market segments, diffusion process, customer acceptance,
17 willingness-to-pay, travel behaviors, social acceptance, etc.); or d) governance and regulation.
18 The classification focused on the single dominant block for each paper, and secondary blocks
19 were not considered in the interests of simplification.

20 The two blocks most represented in the selection of papers were the vehicle and
21 operations blocks, followed by the demand block and last by the governance block (Figure 2).



23
24
25 **FIGURE 2 Distribution of papers according to the 4 building blocks of knowledge (n=298)**

26
27 Distribution between the 4 knowledge building blocks remained more or less similar over the 5-
28 year period. The authors observed a general increase of papers for each block over the years
29 (Figure 3). Research focused on the supply side, which would include both the vehicle block and
30 the operations block, has increased rapidly since 2015. The demand block took off in 2016 and
31 the governance block in 2017.

32

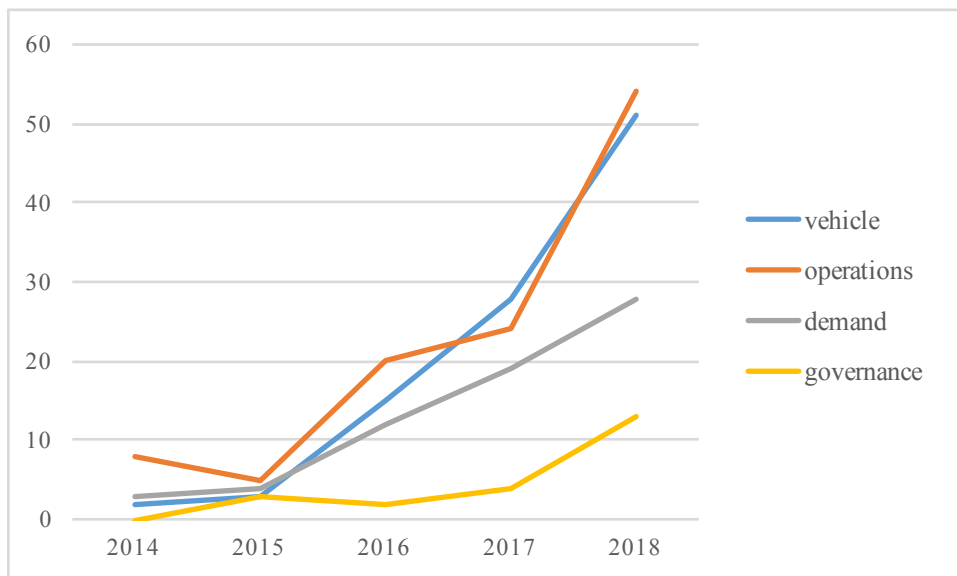


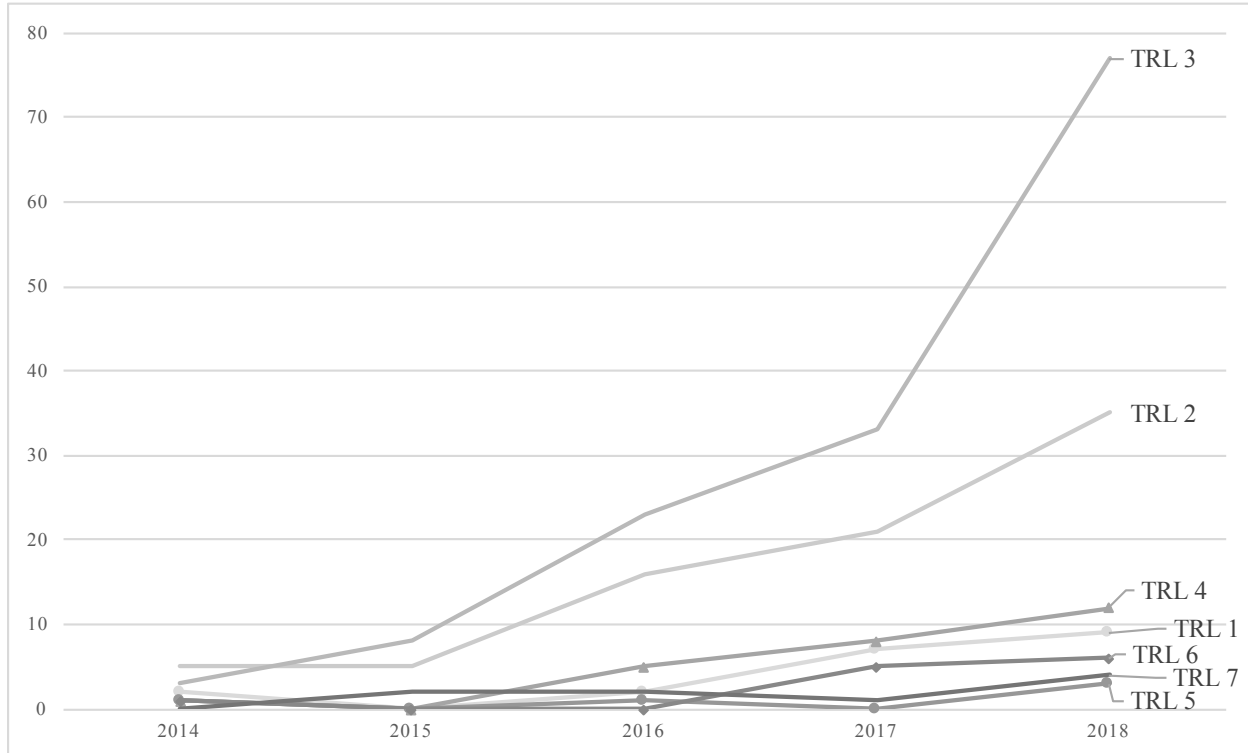
FIGURE 3 Evolution of the distribution of papers according to the 4 building blocks of knowledge (n=298)

Technology Maturity

The authors further classified all the papers according to the 9-level TRL scale (Table 1), through a systematic rating of the maturity level of the innovation considered in each paper at the time the research was produced. The criteria associated with the 9-level scale enabled the straightforward classification of around 90% of the papers in the first round of examination. The remaining 10% of papers required further discussion among researchers to reach a conclusion as to their appropriate classification on the TRL scale, mostly for lack of an accurate description of the technology in said papers. As expected, the AV technology was still in early stages of development at the time the papers were written (Figure 4). No single paper met the criteria for a TRL of 9 which characterizes a “technology refined and adopted”, or yet for a TRL of 8 characterizing a “technology proven in operational environment”. TRL-6 and TRL-7 which characterize, respectively, a “prototype demonstrated in relevant environment” or a “prototype demonstrated in operational environment” were identified more frequently in papers from the 2017 and 2018 Annual Meetings than in papers from previous years. This finding partly reflects an increase in the number of real-life experiments of AV technology as it became ready to be tested in operational environments.

It is worth noting that half of the papers (144 papers) related to TRL-3. This level characterizes a “proof of concept” and mainly corresponded to modeling or simulation research papers (10). Proofs of concept altogether dominated over the 5-year period and represented around 50% of the papers from 2015 to 2018. TRL-2 ranked second for the number of papers. Characterizing an “application formulated”, this level was associated with all papers in which “potential system applications were identified; system components and the user interface were at least partly described; and preliminary analyses or experiments confirmed that the application met the user need” (10). The authors noticed an increase in the number of papers with a TRL of 1 over the period. TRL-1 focuses on “basic principles and research”. The authors also found an increase in the number of papers with TRLs of 4 or 5. These papers mostly presented laboratory experiments. Such simultaneous increase in the representation of different TRLs highlighted a process of progressive technology maturation. It also revealed an acceleration in said process as

1 prototypes were already on the roads while some basic principles were still being explored,
 2 especially regarding demand and governance.
 3



4
 5
 6 **FIGURE 4 Evolution of the distribution of papers according to the 9-level TRL scale**
 7 **(n=298)**

8
 9 70% of papers that focused on operations and 50% of papers that focused on vehicle considered
 10 technologies with a TRL of 3, which means that operational and technological aspects of
 11 autonomous vehicles were still under simulation. At the same time, real-life experiments (TRL-5
 12 to TRL-7) mainly related to papers on vehicle and operations. The demand block remained
 13 probably the least advanced of all knowledge building blocks as virtually no paper with this
 14 focus considered a technology beyond TRL-4. On the other hand, papers focused on the
 15 governance block varied widely between application formulations (TRL-1 and TRL-2) and
 16 demonstrations (TRL-7) (Figure 5).
 17

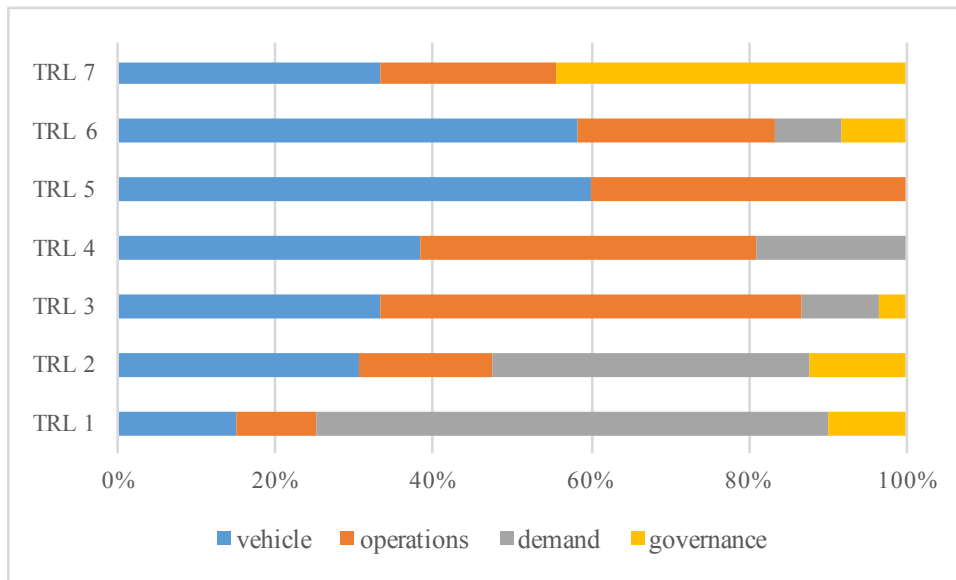


FIGURE 5 Distribution of papers per TRL level according to the 4 building blocks of knowledge (n=298)

The Role of Partnerships in Producing AV Research

Partnering for Data

Half of the papers relied on open data to realize the research. The ratio of papers based on open data sources was similar over the period. Restricted data (including industrial proprietary sources) accounted for 11% of the papers whereas academic data (mainly based on literature reviews) accounted for another 8%. Data directly produced by the research, e.g. through modeling (e.g. simulated or synthetic data), accounted for 30% of papers in the corpus.

As most papers focus on vehicle and operations, it comes as no surprise that they have the highest representation in most data types. Among the 150 papers based on open data, 108 are on vehicle and operations blocks. Simulated or synthetic data were only found in papers dedicated to vehicle and operations. These papers mainly presented modeling results. Similarly, restricted data concerned in majority these two blocks. 36 among the 69 papers that produced their own data were papers from the demand block. In most cases, these papers showed the results of user surveys.

Among the 150 papers based on open data, 82 referred to proofs of concept (TRL-3) and 44 to TRL-2. The higher the TRL, the more probable it was that the researchers would produce their own data.

Funding partnerships

Only half of the corpus (148 papers) explicitly mentioned specific (external) funding contributions to the research. The US institutions dominated not only the process of research production but also the funding of research. The US Department of Transportation was the most prominent funder with funding contributions to 37 papers over the 5-year period. The Department reaffirmed its effort to support research on AV technology in its Strategic Plan for 2018-2022 (11). It was followed by the US National Science Foundation (26 papers funded) and the US FHWA (11 papers funded). The specific role played by the FHWA in promoting AVs is worth noticing. The other key funders were the California State Transportation Agency (11 papers funded) and the Texas

1 Department of Transportation (10 papers funded). A clear relationship was established between
2 Departments of Transportation of California and Texas and the research they funded in the state-
3 owned Universities of California at Berkeley and of Texas at Austin.

4 With 9 papers funded, the National Natural Science Foundation of China was among the
5 top 5 funders. This institution along with other Chinese institutions (like the Ministries of
6 Transport and Science and Technology or the Fundamental Research Funds for the Central
7 Universities) illustrated the support of the Chinese national government to research on AV
8 technology. Like in the case of the US, research on AV technology in China was also supported
9 by state governments such as the Sichuan and Jiangsu provinces.

10 The role of national governments and institutions as the main funders of AV research was
11 also verified in other countries like Japan, South Korea, Qatar or European countries. However,
12 European countries remained quite specific. Their research was not only funded by governments or
13 agencies at national and regional scales but also by the European Union and to a lesser extent by
14 the automotive sector.

15 In general, the private sector was lagging behind the public sector in terms of funding
16 contributions to TRB papers on AV technology. Only 5% of the funders belonged to the private
17 sector. It should be noted that the authors could not trace the amounts of funding involved and
18 therefore do not presume which category of funding partners had the greatest financial
19 contribution. Companies from the digital economy, such as Google or Uber, were not mentioned
20 among the funders of the 298 papers. Moreover, they were not frequently mentioned in the corpus
21 as for example the Google Car and Uber were mentioned in only 4 papers each and Tesla in 6
22 papers.

23 A last finding was that some cities like Toronto in Canada or Tsukuba in Japan financially
24 supported research on AV technology, although in most cases cities were acknowledged for
25 contributions in kind.

26 **DISCUSSION AND PERSPECTIVES**

27 If early research on autonomous vehicles dates back to before 2010 (4; 5), a turning point occurred
28 around the middle of the decade. Since that time, research on AV has rapidly expanded and
29 evolved. The pace especially accelerated in the last 2 years, as illustrated by the portion of papers
30 examined here that were dated 2017 (25%) or 2018 (49%). This trend will very likely continue in
31 the coming years.

32 This trend has implications regarding the production of research on AVs. More
33 institutions belonging to different countries have started to contribute. The increase in research
34 production comes along with a diversification of contributors. Although the United States still
35 have center stage, other countries such as the Netherlands or China are becoming increasingly
36 prominent, at least on the TRB stage. Scientific fields have become more diverse. Beside
37 traditional disciplines like robotics, computer science or engineering, domains related to policy
38 and society have been better represented lately, underlining an AV ecosystem in construction.

39 So far, scholarly efforts have been mainly concentrated on the building blocks of
40 knowledge regarding the vehicle and its components or operations. Technological aspects of
41 vehicle automation still represent a major part of the knowledge building effort of research, as
42 noticed by prior research (4, 5). Proofs of concept (i.e. early stages of technology maturity)
43 dominate in recent research. The implications of autonomous vehicles in terms of demand and
44 governance are still under-researched. One assumption is that with more advanced TRLs (based
45 on real-life experiments), more studies on governance and demand will be needed. For now,
46 most of demand-oriented research consists in surveys and models based on situations that
47

1 respondents have not yet experienced. Another assumption is that, on the topic of governance
2 particularly, there has been a growth in grey literature on planning and regulation options for
3 AVs. yet, because much of such projections and analyses are still speculative, fewer papers on
4 such topics are likely to be presented at TRB Annual Meetings (if written at all). Governance-
5 oriented research already involves technologies at a more advanced stage of maturity, which may
6 reflect the regulator's need to adopt explicit positions to guide AV deployment.

7 Not a single paper was found to involve a TRL-8 or a TRL-9 technology, and very few
8 involved technologies rated beyond TRL-3 ("proof of concept"). One reason could be the pace of
9 research production, which could generate delays between actual advances in technology and
10 their reflection in research. Another reason could stem from car manufacturers (and other AV
11 players from the IT industry) being reluctant to partner for research production as AV-related
12 innovations become increasingly sensitive (strategically and commercially) as they make
13 progress on the TRL scale (3).

14 Academic research appears to play a supporting role (8) in the AV innovation
15 ecosystem, involving direct value creation especially in fundamental research. Public funds at
16 national and regional levels, especially in the US and in China, appear to play an important part
17 in the production of academic research on AVs. AV investments in the US range from federal
18 programs to local collaborations (12), whereas in Europe, funding from the European Union or
19 car manufacturers is more common. The role of research could change in the near future, as a go-
20 between actor between regulators and innovators, between the general interest and private
21 interests, will be increasingly needed along the process of AV deployment.

22 This paper presents some limitations. As mentioned in the methodology section, the
23 corpus has a geographical and language bias. It will be necessary to update and enlarge this
24 selected body of papers to achieve better representation of research published on AVs around the
25 world. A first step will be to include papers from additional academic journals. In parallel,
26 analyses based on grey literature such as transportation plans (13) and on news articles should be
27 considered at they could help to fill the gap between academic research and local policies and
28 between academic research and the private sector. The categorization process developed for this
29 research could be applied to such different kinds of documents in order to better understand and
30 characterize the AV ecosystem that is currently under construction.

31 Research on AVs is now at a turning point as real-life experiments undergo rapid
32 expansion. Users and more generally citizens appear to remain out of the scope of most of the
33 innovation and research effort for now. Will academic research help them take center stage?
34 Research might be ready to address a wide range of issues raised by automated mobility. But will
35 it manage to keep pace? The authors hope this review can provide useful insights for TRB
36 standing committees as to the categories of research that should be encouraged in future years.
37 Especially, as far as governance research is concerned, a dedicated call for papers could be
38 considered advisable.

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2 The authors confirm contribution to the paper as follows: study conception and design: V.
3 Boutueil, G. Lesteven; data collection: V. Boutueil, J. Savaria; analysis and interpretation of
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5 Boutueil, J. Savaria. All authors reviewed the results and approved the final version of the
6 manuscript.

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REFERENCES

1. Society of Automotive Engineers. *J3016. Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. Society of Automotive Engineers, 2014. https://www.sae.org/standards/content/j3016_201401/ Accessed July 30, 2018.
2. National Highway Traffic Safety Administration. *Federal Automated Vehicles Policy Accelerating the Next Revolution In Roadway Safety*. September, 2016. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/av_policy_guidance_pdf.pdf Accessed July 30, 2018.
3. Katrakazas, C., Quddus, M., Chen, W., and Deka, L. Real-time motion planning methods for autonomous on-road driving: State-of-the-art and future research directions. In *Journal of the Transportation Research Part C: Emerging Technologies*, Vol 60, 2015, pp. 416-422.
4. Milakis, D., B. van Arem, and B. van Wee. Policy and society related implications of automated driving: a review of literature and directions for future research. In *Journal of Intelligent Transportation Systems*. 2017.
5. Rosenzweig, J., and Bartl, M. A Review and Analysis of Literature on Autonomous Driving. *The Making-of Innovation, E-Journal*, 2015.
6. Li, S., Sui, P., Xiao, J., and Chahine, R. Policy formulation for highly automated vehicles: Emerging importance, research frontiers and insights. In *Journal of the Transportation Research Part A: Policy and Practice*. 2017.
7. Autio, E., and Thomas, L. Innovation Ecosystems: Implications for Innovation Management. *The Oxford Handbook of Innovation Management*, edition: 1, 2014, pp.204-228. Autio et Thomas, 2014, Innovation Ecosystems: Implications for Innovation Management.
8. Dedehayir, O., Mäkinen, S., and Ortt, J. Roles during innovation ecosystem genesis: A literature review. In *Journal of the Transportation Research: Technological Forecasting and Social Change*, 2016.
9. Gomes, L.A.V., Figueiredo, A., Sergio, and M., Kazuo, R. Unpacking the innovation ecosystem construct: Evolution, gaps and trends. In *Journal of the Transportation Research: Technological Forecasting and Social Change*, 2016.
10. Cuddy, M., Deshmukh, N., Macheck, E., and Myers, J. Technology Readiness Level Assessments for Transportation Research. In *TRB 96th Annual Meeting Compendium of Papers. Transportation Research Board of the National Academies*, Washington, D.C., 2017.
11. U.S. Department of Transportation. *Strategic Plan for FY 2018-2022*. <https://www.transportation.gov/sites/dot.gov/files/docs/mission/administrations/office-policy/304866/dot-strategic-plan-fy2018-2022508.pdf> Accessed July 30, 2018.
12. Omidvar, A., Letter, C., and Elefteriadou, L. An Overview of Existing Pilot and Testbed Activities to Advance Connected and Autonomous Vehicle Technology: Common Threads and Future Priorities. In *TRB 97th Annual Meeting Compendium of Papers. Transportation Research Board of the National Academies*, Washington, D.C., 2018.
13. Cottam, B. Transportation Planning For Connected Autonomous Vehicles: How It All Fits Together. In *TRB 97th Annual Meeting Compendium of Papers. Transportation Research Board of the National Academies*, Washington, D.C., 2018.