Research Article

Autonomous Vehicles and People with Disabilities: A Scientometric and Integrative Analysis of the Literature

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ABSTRACT

Autonomous vehicles (AVs) promise a new mobility reality for People with Disabilities (PWDs) by offering more possibilities for their inclusion into modern transport systems. When considering AVs' dissemination for PWDs is related to different types and features of disabilities. Via a scientometric and integrative review, this paper proposes a research agenda on the field of AVs and PWDs. The search and analyses were based on papers indexed on Scopus, having resulted in a total of 294 articles. This database was chosen since it contains a larger number of records when compared to other academic databases, but mainly by yielding more complete metadata to be used on bibliometric analytical software. The articles were collected in a single search. As for the main results, research on AVs and PWDs is concentrated in Europe (mainly in the Netherlands), Asia, and United States. The research agenda provides a guidance for researchers in AVs, human disabilities, and transport inclusion. It was possible to envisage some principles: proper communication with PWDs about transport technologies along with the industry; engagement with users or PWDs consumers with interactive technologies, and adequate regulations of accessibility and safety. The main contributions of this study were: to delineate a landscape of the past research on AVs and PWDs, and to envision a research agenda on this subject. Another important contribution was to observe that some benefits of AVs applicable for PWDs could be also applied to the elderly. Therefore, the elaboration of new technologies on transport must be inclusive and interactive.

Keywords: Autonomous Vehicles, People with Disabilities, Research Agenda, Transport Inclusion, Scientometric Review, Integrative Review.

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INTRODUCTION

Autonomous Vehicles (AVs) represent a possible evolution in urban mobility, by having the potential to transform the urban design, by promising to provide first-and last-mile accessibility to urban and peripheral areas as well as by enabling commute alternatives for those how cannot or do not drive.[1,2]

Since AVs are still under development, it is most usual to find studies with applied models and simulations to assess AVs' impact.[3] The main aspects currently related to AVs development and implementation relates to proper regulation systems for AVs operation, safety, and its efficiency aspects. On the other hand, more elements should be considered into this discussion. One of those is to investigate what are the real possibilities that AVs could bring on reducing inequalities in transport; especially providing greater mobility for People with Disabilities [PWDs].[4,5]

In a review paper, Milakis *et al.*[6] have described varied effects that AVs could generate on society (traffic, use of urban space, etc.). The authors state that social effects such as PWDs inclusion and accessibility are elements that should be more investigated and could contribute to a better understanding of the AVs impacts and consequently guarantee their best implementation in society.

This study poses the following research question: How does the literature consider the possibilities and challenges for the inclusion and usage of AVs by PWDs? By proposing a research agenda via a scientometric analysis and an integrative review.[7-12] These procedures can identify trends for future studies in this research field. After this brief introduction, section 2 presents a brief overview on AVs and PWDs.

AVs and PWDs: Overview and social implications

Autonomous Vehicles are conceived as connected and interactive transport solutions and are allocated into five different levels of automation. Faisal *et al.*[13] described specifically the automation levels and their main features based on SAE's[14] criteria of operations: From level 1(minimal automation with driver's assistance) to level 5(full automated vehicles with no driver needed). Currently AVs are already present in conditional automation level 3(monitoring driving environment, steering, acceleration e deceleration systems).

For PWDs, AVs must guarantee full accessibility,[15] in this sense, proposals of interactive and universal design for AVs are needed.[16,17] AVs' usage intentions depend on the interaction with societal outcomes, such as equal opportunity for mobility.[18] Thus, their implementation should not reinforce car dependency, and its environmental, and social negative consequences.[19]

Hence, AVs must provide accessibility for all users. Diverse experts on accessibility argue that these effects are mixed and could vary to optimistic (favoring positive urban redesign) or even to negative outcomes for PWDs due to possible higher costs of Avs.[20] These findings corroborate the arguments concerning the uncertainties of AVs benefits for PWDs pointed by Milakis *et al*.[6]

Thus, there are several pressing topics that should be addressed when it comes to AVs implementation. In terms of social impacts, AVs could positively contribute to becoming available to the population with policies towards inclusion within transport automation. On the other hand, negative impacts could be observed in future due to AVs becoming a privileged mode of transport.[19]

For distinct kinds of disabilities, AVs adoption could result in different impacts and demand distinct needs for PWDs. For blind or visual impaired persons, AVs could offer more independence and mobility. However, according to these users, AVs must be: safe, affordable, inclusive, interactive, and participative.[21,22] As for the physically disabled, concerns on safety are relevant and impressions towards AVs are majorly negative or ambivalent among these users. However, when compared to non-disabled persons' perceptions, their view was more positive.[23] As for the intellectually disabled, freedom, fear, and curiosity are important elements for AVs acceptance.

Hence, one of the main issues when considering AVs' dissemination for PWDs is related to different types and features of disabilities. Therefore, the development of an AV for PWDs should, according to Bennett *et al*.[24] involve PWDs themselves on the R&D process. In this sense, the elaboration of a universal design is paramount to ensure their usability by everyone.[16,17]

For achieving a universal design, AVs should entail: Safety and non-safety features. Safety is critical for higher AVs acceptance, especially when considering PWDs. Therefore, it must not be controlled or decided by AV users (e.g., presence of real danger on the road). Hence, manufacturers must provide standard features considering a multi or unimodal system of communication – e.g.: visual, auditory, and tactile.[17]

As for non-safety critical features (e.g., a slight detour), multi or unimodal systems could be personalized according to users' needs and demands. For PWDs, this could provide proper adaptation according to their varied and specific disabilities as well as to promote higher interaction and control of the AVs by PWDs.[17]

This review intends, to bridge this gap considering the uncertainties regarding AVs and social inclusion as aforementioned. Therefore, this literature review is important to add value on this theme.[25]

Research Methods

Inspired by the work carried out by Gandia *et al*.[26] this paper proposes scientometric techniques for evaluating both scientific productions directions as the dynamics of a specific research field using the software VOSviewer.[8-10,27] This involves quantitative techniques which classifies academic research through: citations, publications, volume, authorship, co-authorship, keywords, among other criteria.[7-10]

For the integrative review part – which aims to both summarize and generate knowledge of a determined subject – this research considers the methodological structuring systematized by Torraco[11] as well as proposes a research agenda based on Filser *et al*.[28] The integrative review synthesizes the existing literature for generating new knowledge on a specific theme.[11] For this review, the papers selected and analyzed were published in the last four years, according to the procedures adopted by Filser *et al*.[28] which considers the scientific literature gaps the papers propose.

The search for articles was based on academic papers indexed on Scopus' Elsevier. This database was chosen since it contains a larger number of records when compared to other academic databases, but mainly by yielding more complete metadata to be used on bibliometric analytical software. The papers were selected using the terms described on Table 1 in the title, abstract, or keyword fields in database.

This search has resulted in a total of 294 articles, which constituted the *corpus* or the *Research front* of the present study. A research framework was elaborated, adapted from Prado *et al*.[29] with the adopted bibliometric research steps. All these elements are depicted on Table 1.

RESULTS AND DISCUSSION

Descriptive analysis of the research front on AV and PWDs

The temporal distribution of the sampled papers started in 1988 with the work from Fujimura and Samet[30] in which remote systems are proposed for dealing with moving obstacles. This

Table 1: Research design.

Research Steps		Description
1	Selection of the scientific databases, according to research theme	Research theme: literature assessment on AVs and PWDs; Chosen database: Scopus.
2	Paper Search procedures on Scopus	TITLE-ABS-KEY (autonomous_car OR autonomous_vehicle OR autonomous_automobile OR automated_car OR automated_vehicle OR automated_automobile OR driverless_car OR driverless_vehicle OR driverless_automobile OR self-driving_car OR self-driving_vehicle OR self-driving_automobile OR intelligent_car OR intelligent_vehicle OR intelligent_automobile OR automated_driving_system) AND TITLE-ABS-KEY (accessibility OR social_equity OR social_impact* OR vulnerable_social_group* OR social_exclusion OR person_with_disabilit* OR people_with_disabilit* OR disabled_person*)
3	Data collection	a) Download of references on Mendeley, spreadsheet format and, as metadata (.csv) for Vosviewer analyses; b) References organization in Mendeley; c) Matrix analysis in spreadsheet; d) Data analyses on Vosviewer.
4	Research front analysis *(based on Gandia et al., 2019)*	a) Temporal evolution of publications; b) Countries with most publications; c) Most published research areas; d) Institutions with most publications;
5	Intellectual base analysis *(based on Caputo et al., 2021)*	a) citation analysis of sources, authors, and articles; b) co-citation analysis of sources, authors, and articles; c) bibliographic coupling of sources, authors, and articles; d) Keywords analysis (occurrence and thematic clustering).
6	Research agenda (based on Torraco, 2016, and Filser *et al.*, 2017)	a) Integrative Review and; b) Research agenda on AVs and PWDs.

Source: prepared by the authors based on Prado *et al.* (2016).

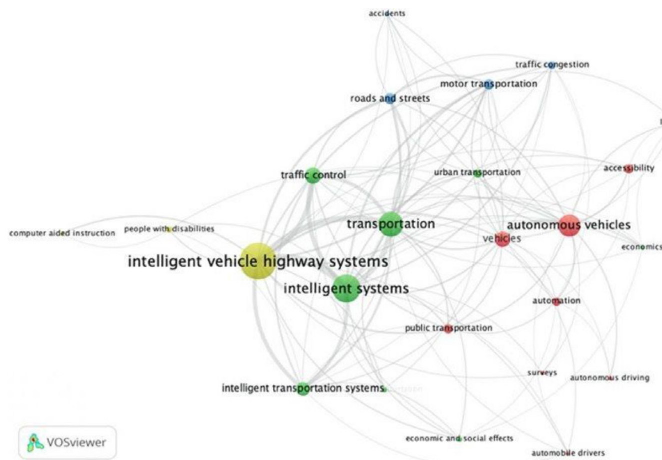

Figure 1: Evolution of the research front on AVs and PWDs.
* By the time of data collection, the year of 2021 was not yet over.
Source: Prepared by the authors based on Scopus data.

study presents the possibilities of this technology for future AV applications. As for most recent publications on AVs and PWDs, as exhibited in Figure 1, they were in exponential growth, peaking in 2020 with 67 papers and with an accumulated moving average of 9.53 papers per year for the analyzed period. This finding indicates the growing research interest on the inclusion of PWDs in autonomous mobility offerings.

Based on the exponential growth in research on AVs and PWDs in the past decade as shown in Figure 1, we highlight the following papers: A focus group with PWDs which verifies the potential of this technology, in transportation for visual impairments or physical disabilities;[31] also, Brinkley *et al.*[22] investigate AV perceptions for blind and low vision consumers. In a broad discussion, Bissell *et al.*[4] stablish the wider impacts of AVs in the society (inclusion, transport in cities and so on). Specifically, three papers from the same authors highlight AV implications and its possible impacts and possibilities for intellectually, physical, and visually impaired based on their perceptions.[21,23,32]

As for countries leading the research on AVs and PWDs, the top 10 countries account for 81.29% of all papers published. The United States is leading both in number of publications and citations (84 and 1259 respectively), followed by Germany, the United Kingdom and China.

These findings are aligned with the results found by Gandia *et al.*[26] that also shown the prevalence of the U.S. regarding overall publications on AVs. Furthermore, as stated by Henderson and Golden,[33] for research on AVs and PWDs, the U.S. is leading research regarding the possibilities of social mobility inclusion for those groups of people.

As for the most published research areas, the field presents a wide degree of interdisciplinarity, corroborating the findings from Gandia *et al.*[26] In this sense, the research front presents a subdivision in the following areas, in descending order: Engineering (30.3%); Computer Sciences (24.8%); Social Sciences (21.3%); Mathematics (5.3%); and areas that in an accumulated value add up to 18.3%, including medicine, Economics, Business, Management and Accounting, among others.

At last, observing the number of documents published by institutions in our sample, the Massachusetts Institute of Technology (MIT) presents the largest number of papers (13), followed by Delft University of Technology (Netherlands) with 09 works. Following, a list of five institutions presents the same value of published works, namely the University of Toronto, the National University of Singapore, the Georgia Institute of Technology, the TUMCREATE Limited (Singapore) and, finally, the Singapore-MIT Alliance for Research and Technology. Therefore, United States, Europe (Netherlands) and Asia, take the lead on research on AVs and PWDs.

In-depth analyses of the intellectual research base

For the in-depth analyses, results are presented based on metadata extracted from Scopus and processed using the scientometric software VOSviewer.[34] These analyses followed the methodology proposed by Caputo *et al*.[7] and are divided into: analysis of publication sources, analysis of authors, analysis of papers, and keywords analysis.

Analysis of publication sources

As stated by Caputo *et al*.[7] this analysis provides a picture of the publication outlets that have most contributed to the development of the research field (AVs and PWDs) from three different perspectives: 1) the most relevant sources in the field (citation analysis), 2) the foundations of the field (co-citation analysis) and, 3) the network importance (bibliographic coupling).

For the citation analysis, the dataset consisted of publications from 170 sources, with a total citation count of 2494, and an average number of citations per source of 14.67 (S.D. 46.86). As seen on Table the top 10 most cited sources account for 63.35% of all citations, with *IEEE Transactions on Intelligent Vehicles* on the lead (485 citations; 19.45%), followed by the *Journal of Intelligent Transportation System* (229; 9.18%), the *Journal of Modern Transportation* (132; 5.29%) and so on. Thus, these appear to be the most impactful journals in the field of AVs and PWDs.

As for the co-citation analysis (that is, the cited sources by the articles in our sample), out of the 5454 sources, 11 received more than 40 citations (14% from the total). Studies on AVs and PWDs have mostly cited papers from the *Conference on Computer Vision and Patter Recognition* (191 citations; 3.50%), *Transportation Research Part C: Emerging Technologies* (85; 1.56%); *Transportation Research Record* (69; 1.27%) and so on. Regarding the bibliometric coupling analysis, as suggested by Ferreira.[35] a minimum threshold of two papers per source was set, thus resulting in 29 journals out of 170. Results show that the most connected journals (in terms of link strength) were: *Transportation Research Part A: Policy and Practice* (365 link strength; 14.07% from total); *Transportation Research Part C: Emerging Technologies* (296; 11.41%); *Transportation Research Record* (196; 7.56%).

At last, the colored matching numberings on Table 2, highlight the sources that are not only the most relevant in the field (citation analysis) but also that comprise the field's foundation (co-citation) and network importance (biblio. coupling). From this we can observe that the journal *Transportation Research Part C: Emerging Technologies* (green highlight) comes in 4th in the citation analysis and in 2nd for the co-citation and bibliographic coupling; *Research in*

Table 2: Comparison of citation, co-citation and bibliographic coupling of the top 10 sources.

	Citation analysis	
	Source	**Citations (TC)**
1	IEEE Transactions on Intelligent Vehicles	485
2	Journal of Intelligent Transportation Systems	229
3	Journal of Modern Transportation	132
4	Transportation Research Part C: Emerging Technologies	126
5	Machines	121
6	IEEE Conference on Intelligent Transportation Systems, Proceedings	119
7	Research in Transportation Economics	106
8	GeoInformatica	103
9	Transportation Research Record	81
10	Transport Reviews	78
1	Conference on Computer Vision and Pattern Recognition	191
2	Transportation Research Part C: Emerging Technologies	85
3	Transportation Research Record	69
4	European Conference of Computer Vision	67
5	IEEE International Conference of Computer Vision	65
6	Transportation	61
7	Transportation Research Part B: Methodological	54
8	IEEE Transactions on Intelligent Transportation Systems	51
9	Transportation Research Part A: Policy and Practice	49
10	IEEE Transactions on Pattern Analysis and Machine Intelligence	47
	Bibliographic coupling	
	Source	**Strength (LS)**
1	Transportation Research Part A: Policy and Practice	365
2	Transportation Research Part C: Emerging Technologies	296
3	Transportation Research Record	196
4	Research in Transportation Business and Management	195
5	Transport Reviews	186
6	Transportation Research Part D: Transport and Environment	186
7	Research in Transportation Economics	159
8	Transportation Research Procedia	156
9	Journal of Transport Geography	124
10	IEEE Conference on Intelligent Transportation Systems	122

Source: prepared by the authors based on research data.

Table 3: Comparison of citation, co-citation and bibliographic coupling of the top 10 authors.

Citation analysis			Co-citation analysis			Bibliographic coupling		
	Author	TC		Author	TC		Author	LS
1	Frazzoli E.	521	1	Kockelman, K.M.	153	1	Huff Jr.	2726
2	Paden B.	485	2	Van Arem, B.	73	2	Rus D.	2621
3	Yershov D.	485	3	Fagnant, D.J.	65	3	Ang M.H.	2604
4	Yong S.Z.	485	4	Frazzoli, E.	56	4	Eng Y.H.	2604
5	Čáp M.	485	5	Axhausen, K.W.	55	5	Pendleton S.D.	2604
6	Milakis D.	255	6	Newman, P.	53	6	Shen X.	2604
7	Van Wee B.	255	7	Milakis, D.	48	7	Meghjani M.	2498
8	Van Arem B.	228	8	Van Wee, B.	47	8	Andersen H.	2494
9	Asadi M.	132	9	Geiger, A.	44	9	Bose N.	1480
10	Bagloee S.A.	132	10	Litman, T.	43	10	Brito M.P.	1480

Source: prepared by the authors based on research data.

Transportation Economics (in blue) comes in 7th both for the citation analysis and bibliographic coupling; *Transportation Research Record* (in yellow) is seen in 9th for citation analysis and in 3rd both for co-citation and bibliographic coupling, and; *Transport Reviews* (in grey) comes in 10th for the citation analysis and in 5th for bibliographic coupling.

Thus, these four aforementioned journals have proven to be very impactful regarding the research field on AVs and PWDs. As stated by Panagiotopoulos and Dimitrakopoulos (2018), AVs could prompt technological advancements in robotics and artificial intelligence, which could provide accessibility to transport, if they are accepted and used by a large population. Therefore, based on the scope of publications in these journals, it is plausible to infer that advances in AVs' R&D have the capacity to diminish the costs incurred in transportation whereas boosting the rate of accessibility of services to population and individuals who have mobility problems.[36] Hwang *et al*.[31] have confirmed in a focus group that PWDs need more targeted strategies for access AVs benefits and to interact with PWD needs on transport.

Analysis of the authors

With 907 authors for the 294 publications, the research stream on AVs and PWDs is characterized by heterogenous communities of scholars. The average number of citations per author was 11.11 (S.D. 42.67). The top 10 most cited authors shown in Table 3, correspond to 34.37% of all citations. It is worth noting that the author with the highest number of citations (Frazolli, with 521 citations) have published only two papers in the field. A similar phenomenon happened with the following four most cited authors, Paden, Yershov, Yong and, Čáp[41] all with a total of 485 citations and only one paper each.

Regarding the results of the co-citation analysis in terms of authorship (that is: the most cited authors by the papers in our sample), out of 13927 cited authors, only 58 were cited more than 20 times.[35] Similarly to the analysis carried out by Caputo *et al*.[7] this emphasizes an academic reliance on a small number of individuals, demonstrating the importance of a few key scholars.

The author Kara M. Kockelman presents the highest number of co-citations (153). She also appears as co-author in publications with Daniel Fagnant, the third most co-cited author from the intellectual base (65), their paper: *Preparing a nation for autonomous vehicles: opportunities, barriers, and policy recommendations* (Fagnant and Kockelman, 2015) can be highlighted as one of the most influential papers for the academic field. Van Arem, Milakis and, van Wee also rank among the top 10 most co-cited authors (2nd, 7th, and 8th respectively), their paper: *Policy and society related implications of automated driving: A review of literature and directions for future research,*[39] stablish elements for public policies and regulation that might attend the social inclusion of PWDs from AVs' adoption.

Kay Axhausen also appears as a highly co-cited author (5th place), by discussing the implications for transportation and new urban technologies that promote inclusion from smart cities in: *Smart cities of the future.* Andreas Geiger with 44 citations (9th place) in the intellectual base highlighting: *Are we ready for Autonomous Driving? The KITTI Vision Benchmark Suite,*[38,40] review the recent features of autonomous technologies. Peter Newman (6th place) appears widely cited with his book: *Resilient cities: Overcoming fossil fuel dependence* (Newman, 2009), in which the creation of efficient transportation systems is discussed. Emilio Frazzoli (4th place) discusses technical aspects of AVs, as far as its usage is complex. At last, in 10th place, Tod Litman discusses implications for transport planning with the implementation of autonomous vehicles.

These academics ranked on Table 3 appear both as authors as well as co-authors in papers. As Grácio (2016) put it, the sharing of theoretical background or research methods, might show proximity in the co-citation networks. The author also states that higher co-citation counting make evident an acknowledgement network of the researchers, thus corroborating the previously mentioned arguments by Caputo *et al*.[7]

The bibliographic coupling showed that the authors with the greatest link strength, i.e. those with a higher centrality in the citation network and were highly embedded in the discussions, were: Huff Jr. (2726), Rus (2621) as well as Ang, Eng, Pendleton and, Shen (all with a link strength of 2604). As pointed out by Caputo *et al*.[7] these results shed some light on future directions for the field. Thus, the authors' analysis confirms the importance of a continuous production of knowledge and its renewal in a highly dynamic field that profoundly affects transportation research as a whole.

At last, we can also observe that besides coming in first place at the citation analysis, Frazolli (green highlight) also ranks in 4th as the most co-cited author. Milakis (in blue) comes is 6th for citation and 7th for co-citations, van Wee (in yellow) follows ins 7 hr and 8th respectively and, van Arem (in grey) comes in 8th for the citation analysis and in 2nd for co-citation. These results validate the importance of these four authors for the research field on AVs and PWDs.

Analysis of the articles

From the total of 294 articles in the dataset, the average number of citations per article was 8.34 (S.D. 34.23), the median was 1, while the mode was 0. As shown on Table 4 with the exception from the paper by Miller and Wu,[42] all the other top 9 most cited papers were published from 2016 onwards, thereby corroborating the recent growing academic interest in the research field (as shown on Figure 1). Furthermore, by analyzing the titles, abstract and objectives from these top 10 most cited papers in our sample, we observed a clear distinction in the scope of the papers, with 4 articles being more engineering and technical-oriented – focusing on motion planning, control, guidance, etc., (papers 1, 4, 6 and 9 from the citation analysis) and, with 6 articles more directed towards the applied social sciences, discussing topics such as: consumer behavior as well as, policy and society implications (papers 2, 3, 5, 7, 8 and 10 from the citation analysis).

As stated by Caputo *et al*.[7] the analysis of the references cited by the articles in the dataset (via co-citation analysis) provides a picture of the contributions of the main references – that is, the theoretical pillars – that have influenced the development of the field in recent years. By considering the 294 articles in our sample and fixing a minimum threshold of 4 citations per reference, the obtained set of 7 articles contains 36 cited references out of the 10073 total. These seven most connected references, which can be considered the main theoretical pillars of the field, are:

1. Fagnant DJ, Kockelman K. Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. Transp Res Part A Policy Pract 2015;77:167–81.
2. Fagnant DJ, Kockelman K. The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. *Transportation Research Part C: Emerging Technologies*, 2014;*40*:1-13.
3. Bonnefon JF, Shariff A, Rahwan I. The social dilemma of autonomous vehicles. Science (80-) 2016;352(6293):1573–6.
4. Harper CD, Hendrickson CT, Mangones S, Samaras C. Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. Transp Res Part C Emerg Technol 2016;72:1–9002E
5. Meyer J, Becker H, Bösch PM, Axhausen KW. Autonomous vehicles: The next jump in accessibilities? Res Transp Econ 2017;62:80–91.
6. Soteropoulos A, Berger M, Ciari F. Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies. Transp Rev 2019;39(1):29–49.
7. Zakharenko R. Self-driving cars will change cities. Reg Sci Urban Econ 2016;61(November):26–37.

The bibliographic coupling of the 294 articles in our sample shows that the largest set of connected documents contains 155 papers (52.72%). The top 10 publications with the highest index of bibliographic coupling are depicted on Table 4. At last, by observing the colored-matched labels for the articles, we acknowledge the academic relevance of the following studies to the field of AVs and PWDs:

- Milakis D, Van Arem B, Van Wee B. Policy and society related implications of automated driving: A review of literature and directions for future research. J Intell Transp Syst Technol Planning, Oper 2017;21(4):324–48. As highlighted in green: second most cited paper (223 citations), and 7th most connected.
- Meyer J, Becker H, Bösch PM, Axhausen KW. Autonomous vehicles: The next jump in accessibilities? Res Transp Econ 2017;62:80–91. Highlighted in blue: 5th most cited and 5th most co-cited paper.
- Panagiotopoulos I, Dimitrakopoulos G. An empirical investigation on consumers' intentions towards

Table 4: Comparison of citation, co-citation and bibliographic coupling of the top 10 articles.

Citation analysis			Co-citation analysis			Bibliographic coupling		
	Author(s)	**TC**		**Author(s)**	**TC**		**Author(s)**	**LS**
1	Paden, B. *et al.* (2016)[43]	485	1	Fagnant, D. J. and Kockelman, K. M. (2015)[37]	11	1	Yigitcanlar T., Wilson, M. and Kamruzzaman, Md. (2019)[44]	204
2	Milakis D., van Arem, B. and van Wee, B. (2017)	223	2	Fagnant, D. J. and Kockelman, K. M. (2014)[43]	5	2	Fitt, H. *et al.* (2019)	188
3	Bagloee, S. A. *et al.* (2016)	132	3	Bonnefon, J-F., Shariff, A. and Rahwan, I. (2016)[46]	4	3	Herrenkind, B. *et al.* (2019)[45,47]	184
4	Pendleton, S. D. *et al.* (2017)[48]	121	4	Harper, C. D. *et al.* (2016)[49]	4	4	Ahmed, T. *et al.* (2020)[50]	180
5	Meyer, J. *et al.* (2017)[51]	103	5	Meyer, J. *et al.* (2017)	4	5	Kovacs, F. S., McLeod, S. and Curtis, C. (2020)	174
6	Miller, H. J. and Wu, Y-H. (2000)	103	6	Soteropoulos, A., Berger, M. and Ciari, F. (2019)	4	6	Cohen, T. and Cavoli, C. (2019)	172
7	Panagiotopoulos, I. and Dimitrakopoulos, G. (2018)(36)	53	7	Zakharenko, R. (2016)[52]	4	7	Milakis D., van Arem, B. and van Wee, B. (2017)	171
8	Soteropoulos, A., Berger, M. and Ciari, F. (2019)	49	8	-	-	8	Adnan, N. *et al.*, (2018)[53]	152
9	Yang, Z. and Pun-Cheng, L. S. C. (2018)[54]	47	9	-	-	9	Abe, R. (2019)[55]	150
10	Romera, E., Bergasa, L. M. and Arroyo, R. (2016)[56]	41	10	-	-	10	Panagiotopoulos, I. and Dimitrakopoulos, G. (2018)	149

Source: prepared by the authors based on research data.

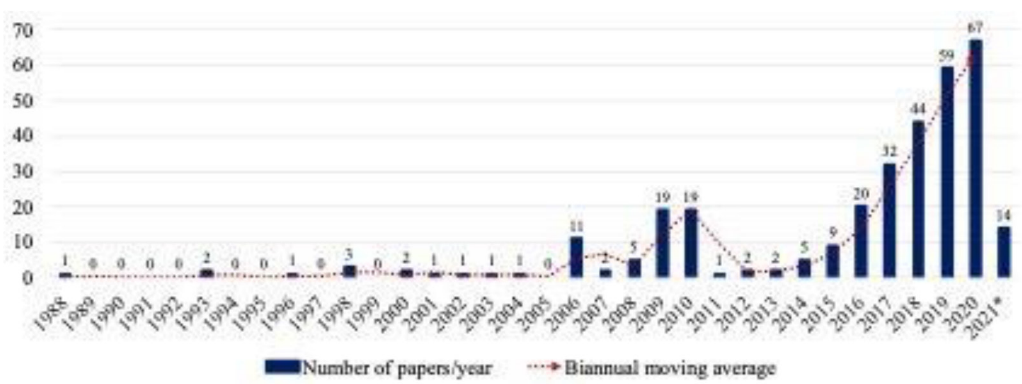

Figure 2: Network diagram of indexed keywords for the field of AVs and PWDs.
Source: prepared by the authors on VOSviewer based on research data.

autonomous driving. Transp Res Part C Emerg Technol 2018;95:773–84. Highlighted in yellow: 7th most cited and 10th most connected.

- Soteropoulos A, Berger M, Ciari F. Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies. Transp Rev 2019;39(1):29–49. Highlighted in grey: 8th most cited and 6th most co-cited.

To conclude this set of analyses (citation, co-citation and bibliographic coupling), we agree, and corroborate the assertion advanced by Caputo *et al.*:[7]

"The reasoning behind these different results pertains to the inherent biases of each indicator, assessing the results of these indicators together allows these perspectives to mitigate each other's biases, increasing the validity of the study and reducing the likelihood of omitting significant research."[7]

Keywords analysis

For the creation of keywords' networks, a minimum of 10 occurrences per term was considered. Thus, from the 2516 indexed keywords from the 294 articles in our sample, 24 were selected for this analysis. These selected keywords account for 19.07% of all occurrences. Figure 2 depicts the simplified network of connections among these top 24 keywords as well as the clusters generated by VOSviewer. Table in the sequence, better details the outcomes show of each cluster.

Table 5: Detailed cluster analysis for the keywords.

Cluster 1: AVs accessibility (red)					
	Keyword	**Freq.**	**Link strength**	**Num. of links**	**Avg. date**
1	Autonomous Vehicles	71	152	22	2018,37
2	Vehicles	46	147	21	2015,54
3	Accessibility	26	51	16	2014,92
4	Public Transportation	26	95	19	2013,46
5	Automation	24	66	21	2017,04
6	Land Use	12	34	12	2018,33
7	Autonomous Driving	11	32	16	2019,00
8	Automobile Drivers	10	29	10	2016,9
9	Surveys	10	34	15	2015,6
Cluster 2: Intelligent transportation systems traffic control (green)					
	Keyword	**Occurrence**	**Link strength**	**Num. of links**	**Avg. date**
1	Intelligent Systems	93	352	22	2013,57
2	Transportation	79	301	21	2012,11
3	Traffic Control	49	205	21	2010,31
4	Intelligent Transportation Systems	39	148	20	2013,26
5	Urban Transportation	23	86	21	2016,83
6	Economic and Social Effects	14	52	16	2014,64
7	Mass Transportation	12	47	16	2013,25
8	Economics	10	45	16	2015,70
Cluster 3: Road-related issues (blue)					
	Keyword	**Occurrence**	**Link strength**	**Num. of links**	**Avg. date**
1	Roads and Streets	32	137	21	2014,31
2	Motor Transportation	28	140	21	2014,46
3	Traffic Congestion	20	78	17	2015,00
4	Accidents	10	42	13	2017,00
Custer 4: Intelligent Vehicle Systems for PWDs (yellow)					
	Keyword	**Occurrence**	**Link strength**	**Num. of links**	**Avg. date**
1	Intelligent Vehicle Highway Systems	126	393	23	2012,21
2	People with Disabilities	16	40	15	2014,38
3	Computer Aided Instruction	11	14	2	2011,73

Source: prepared by the authors based on research data.

By analyzing the outcomes of both Figure 2 and Table 5, we see that cluster 1 (in red) is the largest considering the number of keywords. The research focus is centered around the relations among AVs, accessibility, and public transportation. A relevant stream of research is carried out with surveys aiming at assessing users' perceptions and behaviors towards the implementation of this technology on public transport and their impact on the used land in the cities. Thereby the prevalent research areas are the applied social sciences with greater emphasis on marketing research. It is also worth highlighting that this cluster presents the most recent keywords (in terms of average publication year), such as: autonomous driving (2019.00); autonomous vehicles (2018.37); land use (2018.33) and, automation (2017.04).

Cluster 2 (in green) is the second largest in number of keywords and has a broader spectrum than simple the vehicle (AV) itself. Research is focused on intelligent systems for our urban and mass transportation by tacking on one hand operational research (traffic control), and on the other the issues regarding the assessment of economic and social impacts of these novel technologies. The two most recent keywords for his cluster are: urban transportation (2016.83) and economics (2015.70).

Cluster 3 (in blue) deals with more operational elements on motor transportation. The main discussions surround AVs and PWDs regarding the role of roads and street designs as well as the implications on accidents and congestion (which by the way, are the most recent keywords in this cluster). At last, although cluster 4 (in yellow) is the smallest among the four, this cluster contains the keywork that has occurred the most and with the highest centrality link: intelligent vehicle highway systems. Thus, the main research focus of the papers in this cluster is to investigate (with computer aided instructions) the effects and relations between intelligent vehicle systems and PWDs. However, it is worth nothing that although relevant for the research field, this cluster presents the oldest publication years among them all.

Confirming the aspects of the keyword analysis, the most recent works, highlight the social implications for AVs on urban transportation, public transportation, accessibility, design and PWDs. As for previous papers, technical aspects of AVs are present such as Castillo *et al*.,[57] where the authors detail a proposal of a brain computer interface to command an autonomous car. Another important contribution for the field entails intelligent predictions systems.[58] At last, there are studies that favor transport for sustainable mobility with the development of multimodal transport for urban spaces.[59]

These aspects exhibited on Figure 2 and on Table 5 show that the research on AVs could be undergoing a transition between two main aspects: 1) technical and technological features, and 2) the socio-economic implications of AV's adoption and implementation. These aspects confirm similar impressions pointed by Gandia *et al*.,[26] in their review on AVs' literature. The next and final section of our results and discussion highlights the recent papers in the topic and our research agenda proposal for AVs and PWDs.

Table 6: Research agenda for AVs and PWDs.

Authors	Research agenda
Blas *et al*. (2020); Poliak *et al*. (2020); Costa *et al*. (2019); Guo *et al*. (2020); Fitt *et al*. (2019); Kuzio (2019); Metz (2017); Mohammed *et al*. (2018); Milakis *et al*. (2017); Boot *et al*. (2016).	The Need for appropriated regulations and polices for AVs.
Butler *et al*. (2020); Bissell *et al*. (2020); Bagloee *et al*. (2016).	Identify which are the main factors that could contribute on minimizing disadvantage on transport from AVs usage
Bennett *et al*. (2019a); Brinkley *et al*. (2017); Huff *et al*. (2019); Hwang *et al*. (2020a); Hwang *et al*. (2020b); Kovacs *et al*. (2020).	Empirical studies of possible benefits and negative impacts of AVs
Basu and Ferreira (2020)	Impacts of AVs possession on urban mobility and accessibility
Dias *et al*. (2020)	Elaboration of Intuitive, Interactive Tools and Systems for PWDs in transport systems.
Goggin (2019)	Need for a proper communication of AVs' for PWDs

Source: Prepared by the authors from research database.

Research Agenda on AVs and PWDs

For our research corpus in this section, we filtered our sample by considering only the papers were published in the past recent years (2016 – onwards).

We have found studies in which AVs are deployed as a transport solution for an aging population. As literature points out, there are coincident possibilities of usage of these technologies both for the elderly as well as for PWDs.[6,15,60] Therefore, we have also considered these works for the analysis as well as the studies from Costa *et al*.[16] and Ferati *et al*.[17]

Inspired by the methodological procedures from Filser *et al*.,[28] papers were chosen and analyzed due to their contributions and the scientific literature gaps which they propose to bridge. Therefore, our sub-sample of 22 papers are described, and a research agenda is suggested in Table 6.

As depicted on Table 6, the 22 studies are majorly distributed within five main blocks: the first one is: *The Need for appropriated regulations and polices for AVs*. This research agenda is the most relevant in our analysis comprising 10 of the 22 papers, these 10 papers are discussed as follow:

Blas *et al*.[61] investigate the economic and equity impacts of AVs in Buenos Aires' transport system, and defend regulation in this market for guarantee of accessibility and economic feasibility of AVs. Poliak[62] brings up evidence on regulatory and governance mechanisms for AVs, highlighting their possible benefits on social equity. Guo *et al*.[63] contributes with a framework for AVs that integrates accessibility, traffic emissions, and safety outcomes. Fitt *et al*.[64] stands for the efficacy of emerging transport technologies for ageing populations as far as they become accessible and affordable.

An interesting contribution comes from Costa *et al*.,[16] where the authors propose a conceptual model for Universal Design in AVs, considering technology, global competition, laws, ethics, disability, etc. Kuzio[65] considers the need for planning these new technologies entailing social equity aspects. Metz[66] advocates the capabilities of new technologies for transport based on internet and its necessary regulations to attend an aging population.[67] discuss the activities involved in the usage of AVs considering that the automakers should work to meet the needs of PWDs when fabricating these vehicles. Milakis *et al*.[6] state that AVs prompt a third order effect that could become social inclusive for elderly and PWDs. At last, Boot *et al*.[68] state that AVs technologies might impact the safety of ageing users. They affirm the need for interacting with users for elaborating better technologies.

The second block on the research agenda is the following: *Identify which are the main factors that could contribute to minimizing disadvantage on transport from AVs usage*. This block entails 3 papers: Butler *et al*.,[69] that stabilised a conceptual framework on transportation disadvantage. As authors state, smart mobility innovations depend on demand such as: shared transportation, intelligent transportation systems, electric mobility, AVs, and Mobility-as-a-Service platforms (MaaS). Bissell *et al*.[4] discuss more widely the social implications of AVs, whether they could promote inequalities on transport, labor, or even transform the mobility systems as a whole, and Bagloee *et al*.[70] discuss impact on traffic, safety, car possession and propose a framework with a navigation model.

The third block comprised of 6 papers, deals with the: *Empirical studies of possible benefits and negative impacts of AVs*. Brinkley *et al*.[71] discuss via focus groups, the opinions, and preferences of blind and low vision consumers regarding AVs or self-driving vehicles. They concluded that it is necessary to engage individuals with visual impairments in the development of AVs technology to increase awareness of manufacturers due to insecurities of PWDs related to these new technologies.[72] compares the perceptions of two groups of PWDs (physically and visually impaired) with experts on transport. The authors suggest three elements for spreading AVs for PWDs: 1) ensure accessibility and safety for all people; 2) provide education, training, and outreach programs and, 3) promote cooperative relationships among transit agencies, local authorities, and industries. Hwang *et al*.[31] show evidence in which transit experts and PWDs, expect benefits from AVs for mitigate mobility issues.

Next, Bennett *et al*.[23] examine the attitudes towards AVs among PWDs by their levels of interest in new technology, anxiety, intensity of disability, prior knowledge of AVs, etc. Kovacs *et al*.[73] state that the implications of AVs for elderly people are likely to be varied and, importantly, will be influenced by policy responses, and Huff *et al*.,[74] in a focus group research, revealed that PWDs believed that AVs can enhance their mobility and independence, they were concerned about their reliability and safety, purchase such and the training required to operate it.

Other aspects of the research agenda such as: *Impacts of AVs possession on urban mobility and accessibility; Elaboration of intuitive, interactive tools and systems*, and *Need for a proper communication of AVs' for PWDs* are scattered, and present only one study each: for Basu and Ferreira[75] automated mobility and emerging mobility services have mixed effects on the city but may increase accessibility. Dias *et al*.[76] highlight the need for elaboration of intuitive, interactive tools and systems to improve the experience of the socially excluded people in transport. At last Goggin[77] states the problem of communication of AVs for PWDs the author affirm that equality, diversity, and design are principles that should be observed when delivering these technologies for PWDs. As a research agenda manufactures and PWDs might work together when developing these technologies.

CONCLUSION

The main contributions of this study were: to delineate a landscape of the past research on AVs and PWDs, and to envision a research agenda on this subject. Another important contribution was to observe that some benefits of AVs applicable for PWDs could be also applied to the elderly.[78] Therefore, our findings could also amplify a future market of AVs, considering the transport inclusion aspects for a larger social group.

We found that research on AVs and PWDs is concentrated in Europe (mainly in the Netherlands), Asia, and the United States. Furthermore, research on AVs and PWDs is on the rise as well as undergoing an interaction between technological and socio-economic aspects. This argument is proved by the networks of keywords and the papers and when discussing a future research agenda.

From the market standpoint, AVs are still considered as an emerging technology.[79] Therefore, empirical studies on AVs applications, still tend to offer expectations of future users and their acceptance degree towards AVs. When it comes to PWDs, there are both optimism and uncertainties regarding AVs[21,23,32,39,72] According to these papers, distinct disability types and levels provide different needs of technologies and accessibility features.

Our research agenda proposal intends to provide guidance for researchers in new technologies (AVs) disabilities and inclusion. It was possible to envisage some principles such as: proper communication with PWDs about new technologies along with the industry; engagement with users or PWDs consumers with interactive technologies and adequate regulations of accessibility and safety.

In terms of regulations AVs for PWDs must be affordable,[80] which was confirmed by Choromański and Grabarek, IET, and Milakis *et al*.[6,15,60] In our research agenda we highlight the aspects of universal design for PWDs,[16] and also the need for engagement with industry and public policies when elaborating AVs technologies.[67,76] In this sense the elaboration of new technologies on transport for PWDs, must be inclusive and interactive.

As for research limitations, we highlight the emphasis in a unique database. Therefore, other reviews could combine or include other databases such as Web of Science. Also, limitations on VOSviewer, and a restricted number of scientometric analysis performed should be considered.

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