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Fifty Years of Accident Analysis & Prevention: A Bibliometric and Scientometric Overview

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ABSTRACT

Accident Analysis & Prevention (*AA&P*) is a leading academic journal established in 1969 that serves as an important scientific communication platform for road safety studies. To celebrate its 50th anniversary of publishing outstanding and insightful studies, a multi-dimensional statistical and visualized analysis of the *AA&P* publications between 1969 and 2018 was performed using the *Web of Science* (*WoS*) *Core Collection* database, bibliometrics and mapping-knowledge-domain (MKD) analytical methods, and scientometric tools. It was shown that the annual number of *AA&P*'s publications has grown exponentially and that over the course of its development, *AA&P* has been a leader in the field of road safety, both in terms of innovation and dissemination. By determining its key source countries and organizations, core authors, highly co-cited published documents, and high burst-strength publications, we showed that *AA&P*'s areas of focus include the “effects of hazard and risk perception on driving behavior”, “crash frequency modeling analysis”, “intentional driving violations and aberrant driving behavior”, “epidemiology, assessment and prevention of road traffic injuries”, and “crash-injury severity modeling analysis”. Furthermore, the key burst papers that have played an important role in advancing research and guiding *AA&P* in new directions – particularly those in the fields of crash frequency and crash-injury severity modeling analyses were identified. Finally, a modified Haddon matrix in the era of intelligent, connected and autonomous transportation systems is proposed to provide new insights into the emerging generation of road safety studies.

1. Introduction

Accident Analysis & Prevention (*AA&P*) was founded by Professor Frank A. Haight (Golob & Haight, 2007) in 1969 two years after establishing *Transportation Research* (*TR*) (see Fig. 1) and affiliated with the Association for the Advancement of Automotive Medicine. The *AA&P* has had five editors-in-chief, the first of which was Professor Frank A. Haight himself (University of California) (1969-2004). Since 2005, there have been two co-editors-in-chief (Co-EIC), Professors Rune Elvik (Institute of Transport Economics) and Karl Kim (University of Hawaii). Since July of 2013, Professor Mohamed A. Abdel-Aty (University of Central Florida) has held the position and starting from January of 2020, Professor Helai Huang (Central South University) has served as a Co-EIC. According to the 2018 *Journal Citation Reports* (*JCR*) and the Essential Science Indicators (ESI) database of Clarivate Analytics, *AA&P*'s “ESI Total Citations” ranks 25th among the 2,234 journals in the research field named “Social Sciences, General”, making it one of the top quartile-1 journals in the field. The total number of citations of *AA&P* in 2018 is 17,335 in the Web of Science and its impact factor (IF) and 5-year IF are 3.058 and 3.524 respectively; detailed ranking information is provided in Fig. 2.

In 1969, *AA&P* published its first four issues, which included the very first paper by Jensen (1969), and has since become the flagship journal in road safety studies due to its outstanding contributions over the decades. As shown in Figs. 3 and 4, *AA&P* is at the center of both the journal-citation and journal co-citation (McCain, 1991) networks of road safety studies and dominates the field with the highest numbers of publications (Fig. 3) and citations (Fig. 4), i.e., it possesses the largest nodes.

Hagenzieker et al. (2014) conducted a quantitative analysis based on keyword frequencies to investigate the developments in the history of road safety research (Table 1). The authors confirmed that *AA&P* is the most productive journal in this area.

The early stage of *AA&P* was more about basic understanding of exposure, crash risks, crash rates, injury severity and crash causes, and later on, more concerns about the Haddon matrix (Haddon, 1968) for

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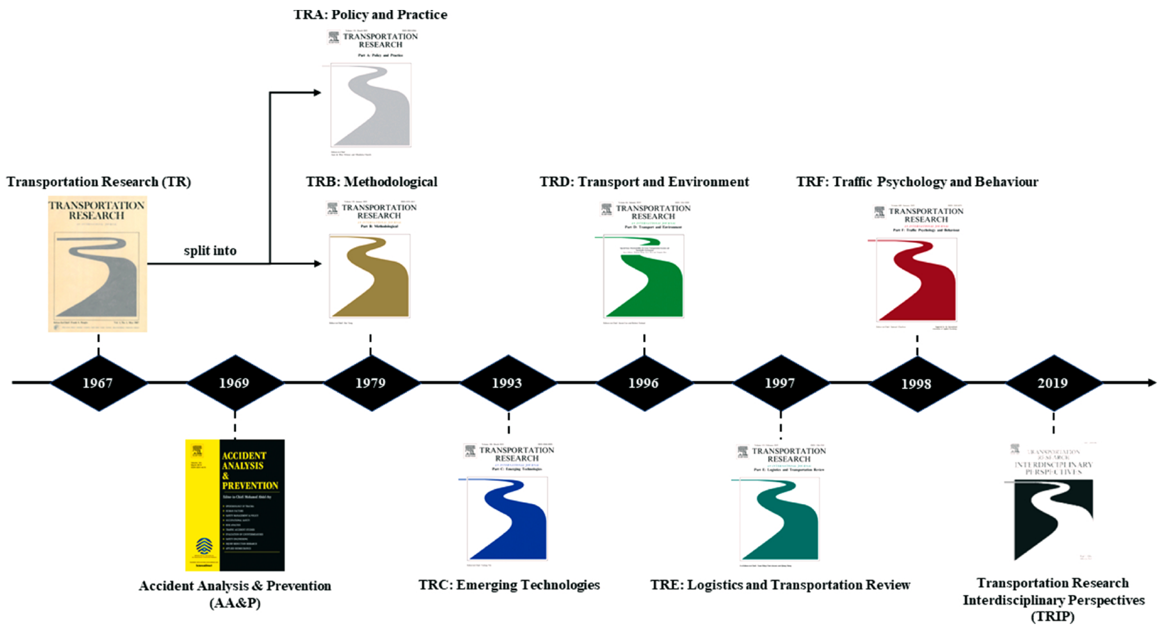


Fig. 1. Founding years of *AA&P* and the *TR* family.

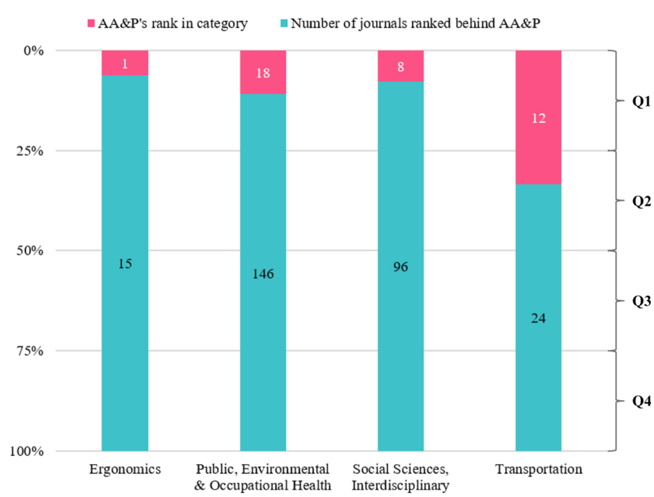


Fig. 2. Rankings of *AA&P* in different categories.

Fig. 3. Journal-citation network of road safety studies. Based on Zou et al. (2018).
Note: the node size depends on the number of publications, and the curved lines between nodes indicate citation relations.

multi-phases and multiple factors. After that, with the successful development of the Empirical Bayes (EB) approach (Hauer, 1997), the *Highway Safety Manual* (*HSM*; American Association of State Highway and Transportation Officials (AASHTO, 2010) came out as a milestone for evaluating the effects on safety of various factors for a variety of types of road entities. Human factors have been well-studied, and nowadays more and more proactive and real-time countermeasures are being tested and applied. The emerging of intelligent, connected and autonomous transportation systems is promising to re-define the field of road safety, and research should not be limited to civil, vehicular and

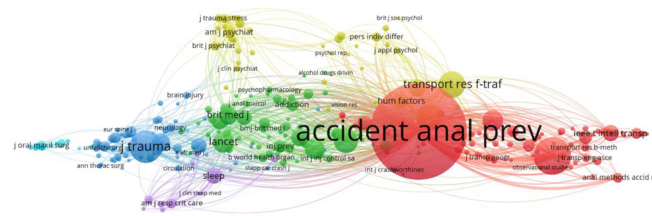


Fig. 4. Journal co-citation network of road safety studies.
Note:. the node size depends on the number of citations, and the curved lines between nodes indicate co-citation relations (the number of documents in the data set in which two journals co-occur in the reference list; the greater the number, the thicker the line).

ergnomics engineering, but extend to automation, information science and artificial intelligence technologies.

Scientific journals often celebrate their anniversaries by way of editorials (Rootzén et al., 2018; Gordon et al., 2018; Salter and Thoennessen, 2018) and special issues (Foley, 2019; Henson, 2019; Tumber and Zelizer, 2019). Many journals have also presented bibliometric overviews of their publications to celebrate their anniversaries (Laengle et al., 2017; Gaviria-Marin et al., 2018; Merigó et al., 2019). These analyses not only reveal the unique features of each journal but also indicatively reflect the overall scope of the scientific advancement in the fields covered by them. The use of traditional analysis to quickly and accurately identify changes in the discipline, the distribution of research authority, and the evolution of research hotspots is difficult due to the increasingly interdisciplinary nature of road safety science and the increase in the number of research branches and papers. Bibliometrics is an efficient tool for studying the distribution structure, changing rules, quantitative relationships, and management of document information. Below, we present a general overview of *AA&P* over its 50 years using bibliometric indicators.

The remainder of this paper is as follows: Section 2 describes the bibliometric methods used in the study; Section 3 presents the results through descriptive, document co-citation and reference burst detection analyses; and Section 4 summarizes the main findings and concludes the paper by proposing a revised Haddon matrix in the era of intelligent, connected and autonomous transportation systems.

Table 1
Time periods and their characteristic road safety paradigms

	1900-1920	1920-1950	1950-1970	1960-1985	1985/1990-now
Crash	Chance phenomenon, bad luck	Road devils, accident prone drivers	Road user or vehicle or road	Multi-causal approach	Result of integral road system
Research	What	Who	How: the cause	How: which causes, technical improvements	Multi-dimensional, economic analysis
Measures	On an ad hoc basis	Educate, punish	Choice from the three E's	Technical Solutions for vehicle & road	Adapt road system to road user

Soure: Hagenzieker et al. (2014)

2. Bibliometric and scientometric methodology

2.1. Data source and processing

The *WoS Core Collection* was retrieved and used as the source data for this study. The *Publication Name Index* function was used, and *Accident Analysis and Prevention* was input to find the journal. As a result of the above procedure, the exact keyword being used in the search is: ACCIDENT ANALYSIS "AND" PREVENTION.

The document types included *article*, *note*, and *review*. References to a total of 5,719 publications were collected, with the last update of the data taking place on March 11, 2019. The retrieved publications were saved in "plain text" with "full record and cited references." Note that the *WoS* only includes *AA&P* data dating from 1975. Therefore, to obtain earlier publications, we searched the journal website manually.

2.2. Analytical methods and tools

In this study, the main research methods used were bibliometric analysis and mapping knowledge domain analysis. Bibliometrics was developed by Pritchard (1969) to be "the application of mathematics and statistical methods to books and other media of communication." Taking literature as the object of study, the bibliometric method analyzes the quantitative characteristics of the literature and studies the structural distribution of, quantitative relationships within, and changing rules governing the information. It can be effective at determining the research trends in a given field and evaluating and forecasting the development of the discipline. Bibliometric indicators such as publications, citations, and citations per publication are used in this method, and the *h*-index (Hirsch, 2005), which combines citation and publication counts, is used in the assessment of the research output of countries, organizations, and researchers.

Mapping knowledge domain (MKD) analysis aims to reveal the development of knowledge and structural relationships and to present correlational research in a given field in the form of maps using visualized analysis. The network structures revealed by MKD analysis are maps of the information in a discipline that allow one to analyze the discipline's potential for evolution, explore the frontiers of its development, and present its key literature, research hotspots, and trends. MKD analysis is able to reveal not only the connections, structure, and interactions among knowledge units; it can also stimulate the creation of new knowledge in the overall knowledge groups. With visualization technology becoming increasingly mature, MKD analysis is increasingly being used to study the knowledge structures and their evolution while determining research hotspots and exploring research frontiers (Hosseini et al., 2018; Palmblad and van Eck, 2018; Chandra, 2018; Luo et al., 2019; Fergnani, 2019). VOSviewer (Visualization of Similarities Viewer) and CiteSpace (Citation Space) are software commonly used in MKD analysis.

1 CiteSpace, developed by Chen (2006) at Drexel University using Java language, is an information-visualization software based on citation-analysis theory. It is used to perform co-citation analysis of and path-finding calculations for the literature in a specific research field to construct knowledge-map paths for the evolution of knowledge in the field. CiteSpace can be used to gain insight into the evolution of and co-occurrence of knowledge units in the field and the frontiers of its development. This software is able to visualize and analyze the content of academic literature as well as the multivariate, time-sliced, and dynamic-citation data that are rapidly emerging in the era of scientometric data and information visualization.

2 VOSviewer, developed by van Eck and Waltman (2010) at Leiden University, is a software tool for constructing and visualizing bibliometric networks. This software is based on VOS (Visualization of Similarities) technology (van Eck and Waltman, 2007), and its

greatest advantage is the ability to visualize the knowledge units in research literature. Its strong graphical-presentation capability makes it suitable for analyzing large samples of data. It is primarily used for three types of browsing: network visualization, overlay visualization, and density visualization.

First, in this paper, a bibliometric approach is used to undertake a quantitative analysis of the data collected from the *WoS*. Next, the characteristics of and rules governing the evolution of *AA&P* with respect to its annual distribution, contributing countries, productive organizations, and core authors are explored. After that, the “dual-map overlays” tool in CiteSpace is used in combination with the “citing and cited journal data” tool in *JCR* to analyze the knowledge absorption and distribution structure of *AA&P* at the journal level. Finally, VOSviewer and CiteSpace are used to conduct document co-citation analysis and reference burst-detection analysis to create knowledge maps that reveal *AA&P*’s main topics, knowledge bases, research frontiers, and future trends.

3. Results

3.1. Descriptive analysis

3.1.1. Publication and citation structure of AA&P

The number of publications refers to the number of papers published by a certain journal over a certain period of time and is the main indicator of the ability of an academic journal to absorb and transmit information. Table 2 shows the annual publication and citation structure of *AA&P*. During the 50 years from 1969 to 2018, *AA&P* published 5,769 papers in 121 volumes, the average of which is 115.38 papers per year and 47.68 papers per volume. Based on the analysis of the annual distribution, shown in Fig. 5, those 50 years can be divided into three stages: exploratory stage (1969–1981), steady development stage (1982–2003) and rapid development stage (2004–2018). In order to reflect the research focuses at each stage, keyword co-occurrence networks are produced (Fig. 6).

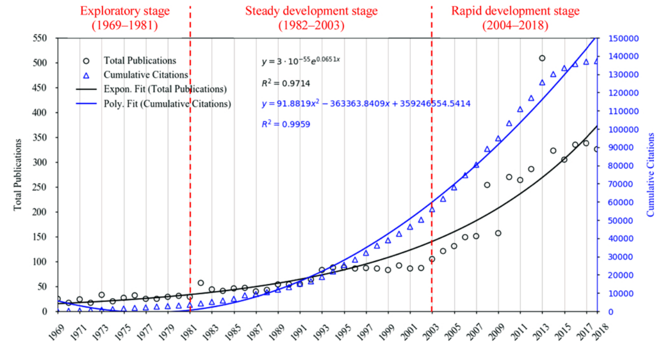


Fig. 5. Annual distributions of publications in and cumulative citations of *AA&P*, 1969–2018.

1 ***Exploratory stage (1969–1981):*** In this stage, the research achievements are preliminary and emerging, with small annual numbers of publications (25.69 papers on average per year) and a slow growth rate (an average annual increase of only 0.33 papers). However, these research achievements laid the foundation for *AA&P*. Over this 13-year period, during which the research branches of *AA&P* were in the stage of exploration and gestation, 334 papers were published. At this stage, no clear frame of research work has been formed, and the studies in relation to alcohol, drug, and seat/safety belt use account for quite a considerable part.

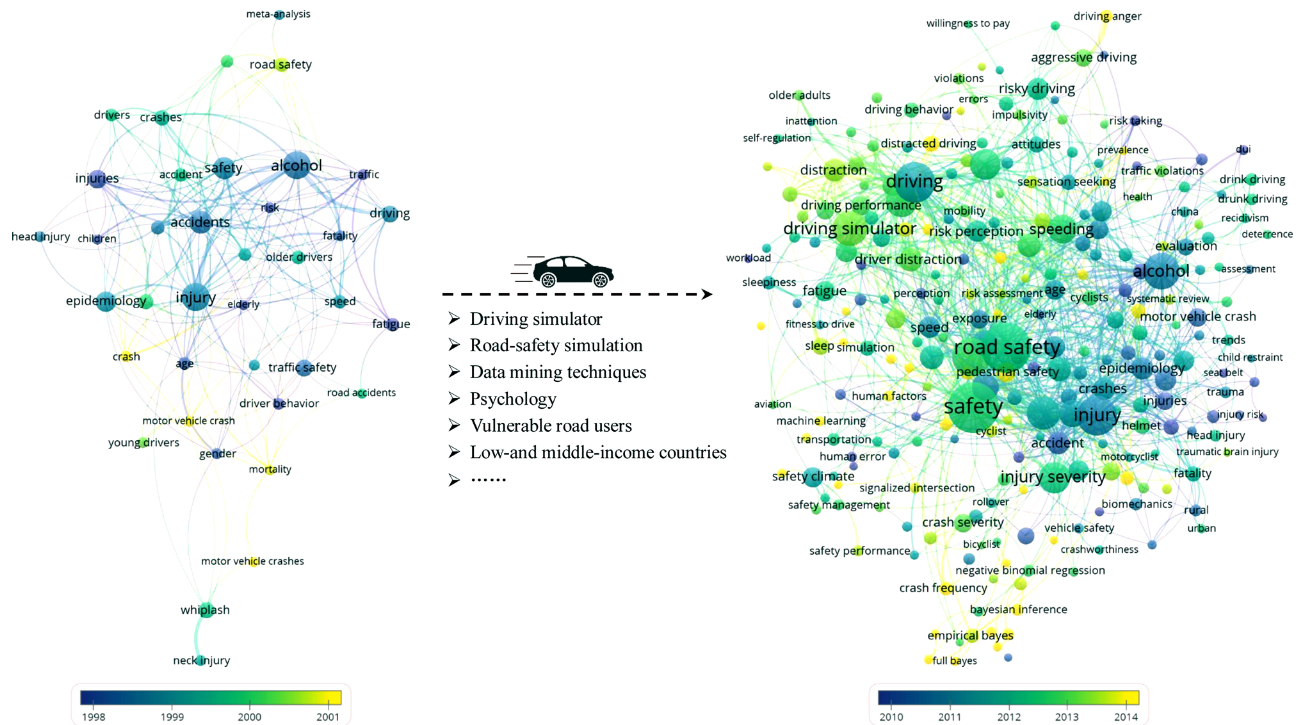
2 ***Steady development stage (1982–2003):*** In this stage, the increase in the number of publications in *AA&P* was steady. In 2003, for the first time, over 100 papers were published. Over this 22-year period, 1,516 papers were published (68.91 papers per year on average, with an average annual growth of 2.29 papers). *AA&P* gradually became a stable carrier of new research in the discipline of road safety; As shown in Fig. 6**(a)**, the common keywords include alcohol, epidemiology, whiplash, fatigue, older/young drivers, speed, driver behavior, risk, head/neck injury, and mortality, indicating that research on alcohol remain a hotspot at this stage, and the epidemiology of road traffic injuries, risky driver behavior (especially young and older drivers), and crash risks are all important research contents.

3 ***Rapid development stage (2004–2018):*** In this stage, many new research topics were explored in *AA&P*, and issues related to road

Table 2
Annual publication and citation structure of *AA&P*.

Exploratory stage (1969–1981)					Steady development stage (1982–2003)					Rapid development stage (2004–2018)				
Year	TP	TC	TC/TP	IF	Year	TP	TC	TC/TP	IF	Year	TP	TC	TC/TP	IF
1981	29	401	13.83	–	2003	105	5,791	55.15	1.075	2018	326	325	1	3.058
1980	31	302	9.74	–	2002	87	3,867	44.45	0.82	2017	338	1,267	3.75	2.584
1979	29	279	9.62	–	2001	86	3,848	44.74	0.754	2016	335	2,204	6.58	2.685
1978	25	458	18.32	–	2000	92	3,549	38.58	0.686	2015	305	3,308	10.85	2.07
1977	25	265	10.6	–	1999	83	2,955	35.6	0.844	2014	323	4,521	14	2.07
1976	32	364	11.38	–	1998	86	3,948	45.91	0.624	2013	509	8,539	16.78	2.571
1975	27	297	11	–	1997	87	3,731	42.89	0.598	2012	286	6,137	21.46	1.964
1974	20	353	17.65	–	1996	86	2,904	33.77	–	2011	264	7,694	29.14	1.867
1973	33	279	8.45	–	1995	88	3,550	40.34	–	2010	270	8,304	30.76	2.353
1972	17	181	10.65	–	1994	88	3,037	34.51	–	2009	157	5,797	36.92	1.647
1971	24	134	5.58	–	1993	83	2,378	28.65	–	2008	254	8,699	34.25	1.963
1970	17	126	7.41	–	1992	64	1,314	20.53	–	2007	151	5,758	38.13	1.586
1969	25	105	4.2	–	1991	55	1,875	34.09	–	2006	149	6,696	44.94	1.587
Total	334	3544	10.61	–	1990	54	1,377	25.5	–	2005	131	6,285	47.98	1.717
					1989	54	1377	25.5	–	2004	121	5,667	46.83	1.297
					1988	43	1,032	24	–	Total	3,919	81,201	20.72	–
					1987	40	697	17.43	–					
					1986	47	1,960	41.7	–					
					1985	46	898	19.52	–					
					1984	41	769	18.76	–					
					1983	44	855	19.43	–					
					1982	57	739	12.96	–					
					Total	1,516	52,451	34.60	–					

Note: TP = Total Publications; TC = Total Citations; TC/TP = Citations per Publication; IF = Impact Factor of the 2018 edition of *JCR*.



(a) 1982-2003

(b) 2004-2018

Fig. 6. Author keyword co-occurrence networks of *AA&P*.
Note: the node size and color depend on the number of occurrences and average publication year respectively; the curved lines between nodes indicate co-occurrence relations. Please note as keywords are not required in publications in earlier years, the network for the exploratory stage (1969–1981) is not included.

safety became prominent in academic circles. The number of publications rose in a wave-like fashion (261.27 papers per year, with an average annual growth of 14.64 papers). In 2013, the number of publications peaked at 509 papers, indicating that *AA&P* had entered a new stage of rapid development. The fast increase of paper numbers in this stage is mainly due to the rapid development of transportation systems especially in low- and middle-income countries as well as the increased attention to public health, along with rapid advances of transportation technologies. It can be seen from Fig. 6**(b)** that many more keywords appear at this stage, including driving simulator, driver distraction, perception, simulation, Bayesian inference, and so on. With the development and validation of driving simulators, they have been widely used as tools for researching traffic psychology (especially risk and hazard perception) and behavior related to road safety; futhermore, with advances in mathematics and computing, advanced data-mining techniques (such as artificial neural networks, Bayesian networks, decision trees and support-vector machines) and road-safety-simulation software (such as VISSIM, PARAMICS and AIMSUN), as well as the post-processor SSAM (Pu and Joshi, 2008), have been developed and utilized extensively by researchers whose work has been published in *AA&P*. In addition, since 2004, more and more studies have been conducted in low- and middle-income countries (Fig. 7), since 93% of traffic deaths occur in these countries, and approximately 60% of the world's vehicles can be found in them (World Health Organization (WHO, 2020).

The publications in the three stages account for 5.79%, 26.28% and 67.93%, respectively, of the total number of papers published during the research period. Since 2013, the annual number of publications by *AA&P* has increased exponentially, reflecting the fact that road safety has captured the attention of the international community. *AA&P* is continuing to attract high-quality researchers that publish high-impact papers, leading to continuous improvement in the quality of the

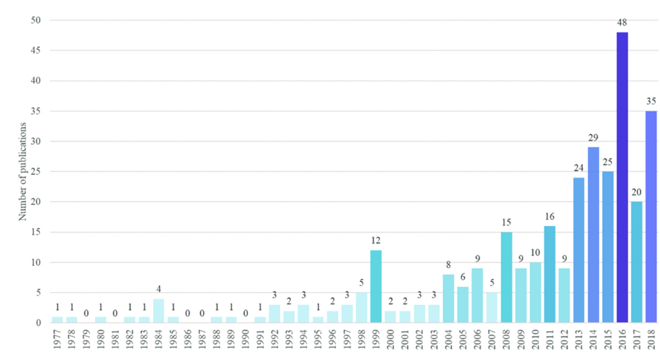


Fig. 7. Annual distribution of *AA&P*'s publications on low-and middle-income countries.
Note: The names of low- and middle-income countries are used as keywords in searching within *AA&P*'s publications. The list of the countries are from the World Bank: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

journal.

As indicated in Table 1, 5,769 papers were cited 137,196 times, with an average of 23.78 citations per publication. The highest number of citations of a single paper during the research period is 404. Moreover, the papers published in 2008 had the most citations, at 8,699, while those published in 2003 achieved the highest average, at 55.15 citations per paper. It should be noted that since the papers published in 2003 had more exposure than those published after, this average can be assumed to be temporary.

Papers published in earlier years have lower citation levels, which might be because electronic journals (e-journals) had not yet appeared. The 1990s witnessed the emergence of such journals (Kling and Callahan, 2003), which have now become fundamental research tools (Williams et al., 2010). Their growing popularity over the past two decades has significantly increased the availability and accessibility of publications other than print journals, enhanced the visibility of publications, and led to higher numbers of citations.

3.1.2. Highly Influential papers in AA&P

Highly cited papers are those that have had a strong influence in the field; they are believed to indicate research hotspots during certain periods. Table 3 presents list of the 50 most-cited ("top 50") papers in *AA&P*. We note that because citations accumulate over time, older papers have had time to gain more exposure. Thus, many of the top 50 papers were published around 2003 (Fig. 8), and their average number of citations is 244.08.

The most-cited paper is "Driving Speed and the Risk of Road Crashes: A Review" by Aarts and van Schagen (2006), with 404 citations. The review-based research of Jonah (1997) has the second-highest number of citations, followed by Zohar (2010). However, the

Table 3
Top 50 papers (the 50 most-cited papers) in *AA&P*.

Rank	Citations	Title	Author/s, Year	Citations per year
1	404	Driving speed and the risk of road crashes: a review	Aarts and van Schagen, 2006	28.86
2	382	Sensation seeking and risky driving: A review and synthesis of the literature	Jonah, 1997	16.61
3	335	Thirty years of safety climate research: Reflections and future directions	Zohar, 2010	**33.4**
4	328	Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory	Lord et al., 2005	21.8
5	317	The relationship between truck accidents and geometric design of road sections: Poisson versus negative binomial regressions	Miaou, 1994	12.19
6	308	Highway accident severities and the mixed logit model: An exploratory empirical analysis	Milton et al., 2008	25.67
7	306	Towards a general theory of driver behaviour	Fuller, 2005	20.4
8	290	Effect of roadway geometrics and environmental factors on rural freeway accident frequencies	Shankar et al., 1995	11.6
9	288	Modeling traffic accident occurrence and involvement	Abdel-Aty and Radwan, 2000	14.4
10	282	The effects of mobile telephoning on driving performance	Brookhuis et al., 1991	9.72
11	278	Driving avoidance and functional impairment in older drivers	Ball et al.,1998	12.64
12	277	The statistical analysis of highway crash-injury severities: A review and assessment of methodological alternatives	Savolainen et al., 2011	30.78
13	273	A note on modeling vehicle accident frequencies with random-parameters count models	Anastasopoulos and Mannering, 2009	24.82
14	267	A meta-analysis of the effects of cell phones on driver performance	Caird et al., 2008	22.25
15	267	Driving anger, sensation seeking, impulsiveness, and boredom proneness in the prediction of unsafe driving	Dahlen et al., 2005	17.8
16	265	Characteristics of crashes attributed to the driver having fallen asleep	Pack et al., 1995	10.6
17	264	The involvement of drugs in drivers of motor vehicles killed in Australian road traffic crashes	Drummer et al., 2004	16.5
18	263	Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance	Horberry et al., 2006	18.79
19	262	Changes in collision rates among novice drivers during the first months of driving	Mayhew et al., 2003	15.41
20	261	Accident risk and risk-taking behaviour among young drivers	Jonah, 1986	7.68
21	254	The effects of a mobile telephone task on driver behaviour in a car following situation	Alm and Nilsson, 1995	10.16
22	236	Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers	Li, et al., 2003	13.88
23	235	The observed effects of teenage passengers on the risky driving behavior of teenage drivers	Simons-Morton et al., 2005	15.67
24	233	Characteristics of traffic crashes among young, middle-aged, and older drivers	McGwin and Brown, 1999	11.1
25	232	Driver injury severity: an application of ordered probit models	Kockelman and Kweon, 2002	12.89
26	229	Models of driving behavior: a review of their evolution	Ranney, 1994	8.81
27	225	Monotony of road environment and driver fatigue: a simulator study	Thiffault and Bergeron, 2003	13.24
28	225	The effect of cellular phone use upon driver attention	McKnight and McKnight, 1993	8.33
29	217	The independent contribution of driver, crash, and vehicle characteristics to driver fatalities	Bédard et al., 2002	12.06
30	217	Bicycle helmet efficacy: a meta-analysis	Attewell et al., 2001	11.42
31	216	Young novice drivers: careless or clueless?	McKnight and McKnight, 2003	12.71
32	214	Cognitive load and detection thresholds in car following situations: safety implications for using mobile (cellular) telephones while driving	Lamble et al., 1999	10.19
33	213	Modeling vehicle accidents and highway geometric design relationships	Miaou and Lum, 1993	7.89
34	211	Traffic fatalities and economic growth	Kopits and Cropper, 2005	14.07
35	211	Perception of the risk of an accident by young and older drivers	Finn and Bragg, 1986	6.21
36	209	A mixed generalized ordered response model for examining pedestrian and bicyclist injury severity level in traffic crashes	Eluru et al., 2008	17.42
37	207	The link between fatigue and safety	Williamson et al., 2011	23
38	205	Bicyclist injury severities in bicycle–motor vehicle accidents	Kim et al., 2007	15.69
39	199	Traffic Accident involvement rates by driver age and gender	Massie et al., 1995	7.96
40	197	Impact of roadside features on the frequency and severity of run-off-roadway accidents: an empirical analysis	Lee and Mannering, 2002	10.94
41	197	The effectiveness of safety belts in preventing fatalities	Evans et al., 1986	5.79
42	196	Comprehensive analysis of vehicle–pedestrian crashes at intersections in Florida	Lee and Abdel-Aty, 2005	13.07
43	196	Psychoactive substance use and the risk of motor vehicle accidents	Movig et al., 2004	12.25
44	192	Using mobile telephones: cognitive workload and attention resource allocation	Patten et al., 2004	12
45	191	Safety climate and safety performance among construction workers in Hong Kong: the role of psychological strains as mediators	Siu et al., 2004	11.94
46	188	Differences in male and female injury severities in sport-utility vehicle, minivan, pickup and passenger car accidents	Ulfarsson and Mannering, 2004	11.75
47	188	Modeling accident frequencies as zero-altered probability processes: an empirical inquiry	Shankar et al., 1997	8.17
48	186	Probabilistic models of motorcyclists' injury severities in single- and multi-vehicle crashes	Savolainen and Mannering, 2007	14.31
49	186	Age differences in male drivers' perception of accident risk: the role of perceived driving ability	Matthews and Moran, 1986	5.47
50	182	Driving simulator validation for speed research	Godley et al., 2002	10.11

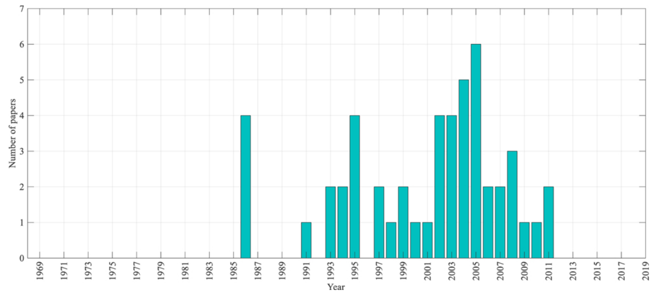


Fig. 8. Annual distribution of the top 50 papers.

paper with the highest number of citations per year is "Thirty Years of Safety Climate Research: Reflections and Future Directions" by Zohar (2010), which indicates that this paper has attracted significant attention from the academic community in a relatively short period. The paper "The Effectiveness of Safety Belts in Preventing Fatalities" (Evans, 1986) is the oldest paper in the top-50 list, while the youngest is "The Statistical Analysis of Highway Crash-injury Severities: a Review and Assessment of Methodological Alternatives" by Savolainen et al. (2011).

Review documents, incorporating many high-level papers, contain concentrated, refined, and optimized content. They not only play a role in terms of exchange of information and inheritance of knowledge but also have obvious advantages over other types of documents in terms of the quality and efficiency of communication. It can be seen that the three most-cited papers in *AA&P* are review papers (Aarts and van Schagen, 2006; Jonah, 1997; and Zohar, 2010), which provide substantial insights into issues including driving speed, sensation seeking, and the safety climate. In four of the remaining top 10 papers (Lord et al., 2005; Abdel-Aty and Radwan, 2000; Shankar et al., 1995; and Miaou, 1994), the authors develop and evaluate the performance of the Poisson, negative binomial (or Poisson-gamma), and zero-inflated Poisson models in "crash frequency modeling analysis." These four papers have laid a solid foundation and become core publications in this field. Two papers, by Fuller (2005) and Brookhuis et al. (1991), fall within the research field "effects of hazard and risk perception on driving behavior." The former details the task-capability interface (TCI) model and finds that perceived task difficulty is closely related to the feeling of risk, while the latter finds that cell-phone use while driving has a negative effect on driving performance. The final paper (Milton et al., 2008) falls within the research field "crash-injury severity modeling analysis".

As seen in Fig. 8, no top-50 papers were published before 1986. Furthermore, there are some years (especially 2005) in which many top-50 papers were published.

3.1.3. Leading countries, organizations and authors in AA&P

The number of publications by scholars from a given country reflects the degree and strength of the activity in the field in that country. Analysis of the sample data with respect to source country gives the spatial distribution of *AA&P* publications (Table 4). The cumulative percentage distribution of publications for the top 30 countries (or territories) is given in Fig. 9. The top 10 of these account for 75.5% of the publications, the top 20 for 89.6%, and the top 30 for almost all (95.6%) of the publications in *AA&P*. Not surprisingly, the USA is well ahead of other countries, dominating the list in terms of its total publications, total citations, and *h*-index. Its total-publications number is nearly triple that of Australia, which is in second place, while Canada and England hold the third and fourth positions, respectively. Turkey has the best performance in the "TC/TP" category, with 33.24 citations per publication, followed by Finland and Scotland. The most productive and influential region is Northern America (with 2,689 papers receiving 71,080 citations), followed by Northern Europe and Oceania. Each of these three regions has more than 800 papers and 20,000 citations.

Table 4
The 30 most productive and influential countries/territories contributing to *AA&P*.

Rank	Country/ Territory	Region	TP	TC	TC/TP	*h*-index
1	USA	Northern America	**2,165**	**58,194**	26.88	**100**
2	Australia	Oceania	729	16,870	23.14	60
3	Canada	Northern America	524	12,886	24.59	54
4	England, UK	Northern Europe	389	9,727	25.01	52
5	China	Eastern Asia	357	5,176	14.50	37
6	Sweden	Northern Europe	336	7,629	22.71	43
7	France	Western Europe	198	3,997	20.19	34
8	Netherlands	Western Europe	173	4,310	24.91	35
9	Norway	Northern Europe	173	4,177	24.14	38
10	New Zealand	Oceania	169	4,227	25.01	37
11	Israel	Western Asia	151	3,622	23.99	32
12	Germany	Western Europe	143	2,099	14.68	26
13	Spain	Southern Europe	137	1,984	14.48	24
14	Finland	Northern Europe	109	3,615	33.17	34
15	Taiwan, China	Eastern Asia	106	2,091	19.73	25
16	Italy	Southern Europe	92	2,156	23.43	26
17	Denmark	Northern Europe	83	1,700	20.48	24
18	Belgium	Western Europe	79	1,697	21.48	27
19	Republic of Korea	Eastern Asia	68	1,461	21.49	19
20	Japan	Eastern Asia	66	1,192	18.06	22
21	Greece	Southern Europe	58	1,243	21.43	20
22	Turkey	Western Asia	42	1,396	**33.24**	19
23	Singapore	South-eastern Asia	39	948	24.31	17
24	Scotland, UK	Northern Europe	37	1,025	27.70	20
25	Switzerland	Western Europe	36	429	11.92	12
26	Ireland	Northern Europe	35	771	22.03	14
27	Iran	Southern Asia	30	406	13.53	12
28	Brazil	South America	25	302	12.08	9
29	Austria	Western Europe	24	469	19.54	12
30	India	Southern Asia	23	432	18.78	12

Note: Abbreviations available in Table 2. The division of regions is based on the United Nations *M49 Standard*: https://unstats.un.org/unsd/methodology/m49/

With regard to the developing trend for the countries (Fig. 10), it can be seen that the USA ranked first over the past two decades, followed by Australia and Canada. China has shown strong growth in recent years, having surpassed Canada, and is likely to surpass Australia to become one of top 3 source countries of publications in *AA&P*.

By studying the distribution of contributing organizations, we can find the sources of knowledge production, dissemination, and evolution in the field of road safety. This helps assess the extent and strength of the involvement of organizations in research in the field, thereby providing a basis for recruiting talent and furthering professional development and academic cooperation in it. Table 5 shows the 30 most-productive organizations associated with *AA&P*. Among the top 30, 25 are universities and 5 are institutions of other kinds. The number of organizations located in the USA is the largest (13, or 43%), followed by Australia (5, or 17%) and Canada (3, or 10%). Monash University has the highest number of publications, followed by the Queensland University of Technology; both are in Australia. However, Purdue University (USA) received the most (55.37) citations per publication, while the Institute of Transport Economics (Norway) has the highest *h*-index, at 34.

Table 6 lists the top 30 most productive contributors to *AA&P*, reflecting the impact these authors and their groups have in the research field of road safety. Most of them (30%) are from the USA, which is consistent with the fact that most papers over the past 50 years have come from this country (Table 4) and that the USA is the dominant source of scholarship in this field.

Six authors have published at least 30 papers in *AA&P*. Professor Mohamed A. Abdel-Aty (University of Central Florida) tops the list with 82 papers and the highest *h*-index (29). In addition, he published two

Table 5
The 30 most productive and influential organizations in *AA&P*.

Rank	Organization	Country	TP	TC	TC/TP	*h*-index
1	Monash University	Australia	**165**	**3,953**	23.96	32
2	Queensland University of Technology	Australia	131	2,479	18.92	31
3	IFSTTAR – French Institute of Science and Technology for Transport, Development and Networks	France	118	2,203	18.67	27
4	Institute of Transport Economics	Norway	117	3,061	26.16	**34**
5	University of Michigan	USA	110	2,489	22.63	30
6	University of Central Florida	USA	108	3,470	32.13	33
7	Insurance Institute for Highway Safety	USA	106	3,362	31.72	32
8	University of New South Wales	Australia	86	1,720	20.00	22
9	University of Toronto	Canada	75	1,916	25.55	26
10	University of Washington	USA	72	2,706	37.58	25
11	Chalmers University of Technology	Sweden	66	669	10.14	15
12	University of Queensland	Australia	64	1,641	25.64	25
13	Virginia Tech – Virginia Polytechnic Institute and State University	USA	63	1,190	18.89	18
14	Harvard University	USA	60	1,307	21.78	23
15	University of Sydney	Australia	59	1,962	33.25	24
16	University of North Carolina at Chapel Hill	USA	58	2,010	34.66	23
17	Karolinska Institute (university)	Sweden	54	1,041	19.28	21
18	University of Otago	New Zealand	52	1,367	26.29	20
19	Purdue University	USA	51	2,824	**55.37**	26
20	University of Alabama at Birmingham	USA	51	2,005	39.31	19
21	Pennsylvania State University	USA	50	1,529	30.58	21
22	Technion – Israel Institute of Technology (university)	Israel	50	1,454	29.08	20
23	Tongji University	China	50	522	10.44	13
24	University of Helsinki	Finland	49	1,962	40.04	22
25	University of British Columbia	Canada	47	854	18.17	15
26	McGill University	Canada	47	769	16.36	16
27	Texas A&M University	USA	46	1,965	42.72	19
28	Pacific Institute for Research and Evaluation	USA	46	1,942	42.22	24
29	University of Nottingham	UK	43	1,134	26.37	17
30	General Motors Corp.	USA	42	1,804	42.95	24

Note: Abbreviations available in Table 2.

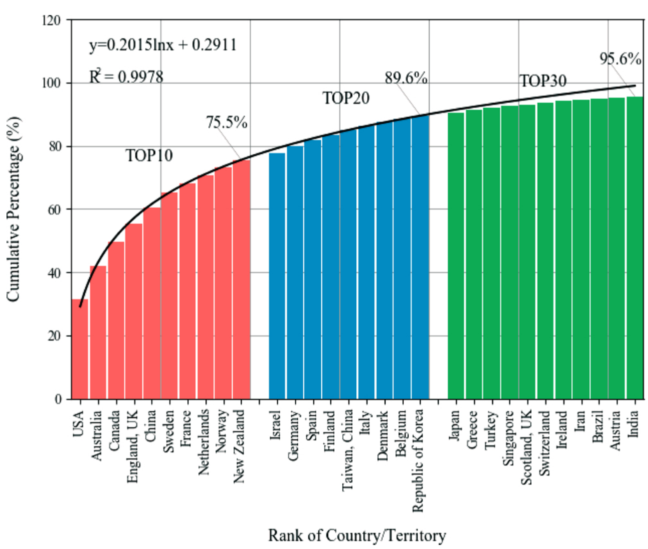


Fig. 9. Cumulative percentage distribution of publications from the top 30 countries/territories.

"top-50 papers." The next is Professor Rune Elvik (Institute of Transport Economics), with 77 papers that received 1,743 citations. Professor Fred L. Mannering (University of South Florida) ranks first in the categories of "TC" and "TC/TP" with a contribution of eight "top-50 papers", making him the most influential author published in *AA&P*.

Table 6 also shows that eight authors have received at least 40 citations per publication, and nineteen authors have received at least 23.78 citations per publication (the average number of citations per publication is 23.78, as shown in Table 1).

3.1.4. Knowledge communication between AA&P and other journals

Knowledge flow has two components: knowledge absorption and knowledge distribution. The former denotes the sources of innovation in a discipline, and the latter denotes the influence of these innovations within it. Their combination can be used to quantify the overall development of the discipline. The knowledge absorption process for *AA&P* was analyzed through the "dual-map overlays" function module embedded in CiteSpace (Chen and Leydesdorff, 2014), which shows how knowledge flows among journals through document-citation paths. The "z-score" function, which quantifies the connections among references, was also used to study the relationships among related

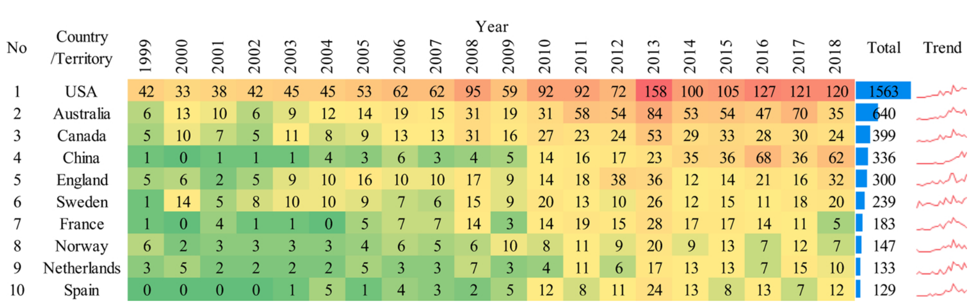


Fig. 10. Top-10 source countries and their annual distribution of publications in *AA&P* over the past two decades.

Table 6
The 30 most productive and influential authors contributing to *AA&P*

Rank	Author	Affiliation	Country	TP	TC	TC/TP	*h*-index	Most cited paper (representative work)			Top 50
								Author/s, Year	Title	Citations	
1	Mohamed A. Abdel-Aty	Univ. of Central Florida	USA	**82**	2,737	33.38	**29**	Abdel-Aty and Radwan, 2000	Modeling traffic accident occurrence and involvement	288	2
2	Rune Elvik	Inst. of Transport Economics	Norway	77	1,743	22.64	24	Elvik, 2009	The non-linearity of risk and the promotion of environmentally sustainable transport	154	–
3	Allan F. Williams	Allan F. Williams LLC	USA	47	1,908	40.60	26	Massie et al., 1995	Traffic Accident involvement rates by driver age and gender	199	1
4	Helai Huang	Central South Univ.	China	36	941	26.14	17	Huang et al., 2008	Severity of driver injury and vehicle damage in traffic crashes at intersections: A Bayesian hierarchical analysis	131	–
5	Dominique Lord	Texas A&M Univ.	USA	35	1,755	50.14	18	Lord et al., 2005	Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory	328	2
6	Fred L. Mannering	Univ. of South Florida	USA	30	**3,581**	**119.37**	27	Milton et al., 2008	Highway accident severities and the mixed logit model: An exploratory empirical analysis	308	8
7	Tarek A. Sayed	Univ. of British Columbia	Canada	29	585	20.17	12	El-Basyouny and Sayed, 2009a	Collision prediction models using multivariate Poisson-lognormal regression	112	–
8	Geert Wets	Hasselt Univ.	Belgium	26	620	23.85	14	Hermans et al., 2008	Combining road safety information in a performance index	73	–
9	Leonard Evans	Science Serving Society	USA	25	1,233	49.32	18	Evans, 1986	The effectiveness of safety belts in preventing fatalities	197	1
10	David Shinar	Ben-Gurion Univ. of the Negev	Israel	25	1,005	40.20	16	Shinar and Compton, 2004	Aggressive driving: an observational study of driver, vehicle, and situational variables	139	–
11	Xuesong Wang	Tongji Univ.	China	25	588	23.52	11	Wang and Abdel-Aty, 2006	Temporal and spatial analyses of rear-end crashes at signalized intersections	105	–
12	Barry Watson	Queensland Univ. of Technology	Australia	25	511	20.44	12	Walsh et al., 2008	Dialling and driving: Factors influencing intentions to use a mobile phone while driving	95	–
13	Tom Brijs	Hasselt Univ.	Belgium	25	432	17.28	12	Hermans et al., 2009	Benchmarking road safety: Lessons to learn from a data envelopment analysis	61	–
14	Heikki Summala	Univ. of Helsinki	Finland	24	1,264	52.67	14	Lamble et al., 1999	Cognitive load and detection thresholds in car following situations: safety implications for using mobile (cellular) telephones while driving	214	1
15	Adrian K. Lund	Insurance Inst. for Highway Safety	USA	24	648	27.00	17	Farmer et al., 1999	Changes in motor vehicle occupant fatalities after repeal of the national maximum speed limit	70	–
16	Simon P. Washington	Univ. of Queensland	Australia	23	1,270	55.22	18	Lord et al., 2005	Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory	328	1
17	Ted R. Miller	Pacific Inst. for Research and Evaluation	USA	23	831	36.13	16	Waehrer et al., 2007	Costs of occupational injuries in construction in the United States	121	–
18	Robert B. Voas	Pacific Inst. for Research and Evaluation	USA	23	816	35.48	16	Voas et al., 2003	Assessing the effectiveness of minimum legal drinking age and zero tolerance laws in the United States	108	–
19	Xuedong Yan	Beijing Jiaotong Univ.	China	23	618	26.87	12	Yan et al., 2008	Validating a driving simulator using surrogate safety measures	98	–
20	Michael G. Lenné	Monash Univ.	Australia	22	607	27.59	13	Lenné et al., 1997	Time of day variations in driving performance	109	–
21	Stuart V. Newstead	Monash Univ.	Australia	22	469	21.32	12	Cameron et al., 1994	Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia—An evaluation	109	–
22	George D. Yannis	National Technical Univ. of Athens	Greece	22	404	18.36	12	Theofilatos and Yannis, 2014	A review of the effect of traffic and weather characteristics on road safety	54	–
23	David C. Schwebel	Univ. of Alabama at Birmingham	USA	21	539	25.67	10	Schwebel et al., 2006	Individual difference factors in risky driving: The roles of anger/hostility, conscientiousness, and sensation-seeking	166	–
24	Sze Chun Wong	Univ. of Hong Kong	China	21	453	21.57	11	Sze and Wong, 2007	Diagnostic analysis of the logistic model for pedestrian injury severity in traffic crashes	102	–
25	Robert E. Mann	Centre for Addiction and Mental Health	Canada	21	379	18.05	11	Mann et al., 2001	The effects of introducing or lowering legal per se blood alcohol limits for driving: an international review	86	–
26	Wei Wang	Southeast Univ.	China	21	362	17.24	10	Xu et al., 2012	Evaluation of the impacts of traffic states on crash risks on freeways	68	–
27	Timo J. Lajunen	Norwegian Univ. of Science and Technology	Norway	20	876	43.80	16	Lajunen and Parker, 2001	Are aggressive people aggressive drivers? A study of the relationship between self-reported general aggressiveness, driver anger and aggressive driving	168	–

(*continued on next page*)

Table 6 (*continued*)

Rank	Author	Affiliation	Country	TP	TC	TC/TP	*h*-index	Most cited paper (representative work)			Top 50
								Author/s, Year	Title	Citations	
28	Orit Taubman – Ben-Ari	Bar-Ilan Univ.	Israel	20	586	29.30	12	Taubman-Ben-Ari et al., 2004	The multidimensional driving style inventory—scale construct and validation	137	–
29	David E. Crundall	Nottingham Trent Univ.	UK	20	528	26.40	11	Konstantopoulos et al., 2010	Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving	126	–
30	Richard Tay	RMIT Univ.	Australia	20	431	21.55	11	Tay, 2005	The effectiveness of enforcement and publicity campaigns on serious crashes involving young male drivers: Are drink driving and speeding similar?	83	–

Note: Abbreviations available in Table 2, except for Top 50 = Number of papers in the list of Table 3.

disciplines as reflected by *AA&P*. The base map in Fig. 11 was generated from 10,330 journals in the *JCR* (Leydesdorff et al., 2013); the left side represents the citing journals (knowledge carriers) and the right the cited ones (knowledge bases); the blue curves represent the citation curves (links). Based on the dual-map overlays, *AA&P* is in the journal cluster "6. Psychology, Education, Health" on the left side. By combining the citation curves, it can be seen that authors of papers in *AA&P* have often cited papers in journals in the cluster "7. Psychology, Education, Social" on the right side. The representative journals in this cluster include [986] *J Appl Psychol*, [641] *Pers Indiv Differ*, and [491] *J Pers Soc Psychol*; the figure in the square brackets indicates the number of citations. Furthermore, journals in many other fields, such as "1. Systems, Computing, Computer" (including [314] *J Am Stat Assoc* and [187] *Biometrika*), "5. Health, Nursing, Medicine" (including [1266] *Am J Public Health* and [792] *Jama-J Am Med Assoc*), and "12. Economics, Economic, Political" (including [647] *Transport Res A-Pol* and [463] *Transport Res C-Emer*), are also often cited by papers in *AA&P*. This shows the interdisciplinary nature of the research that is published in *AA&P*. The dual-map overlays shows the position of *AA&P* within the overall network of knowledge flow among all the scientific journals. Further, it illustrates that the paths and influences of knowledge absorption among these journals.

Fig. 12 shows the knowledge flows as reflected by *AA&P* based on the 2017 *JCR* database. In this database, the top 20 journals cited by *AA&P* are on the left side, while those citing *AA&P* are on the right. The cited journals on the left, which constitute the main knowledge inputs into the journal, are the knowledge bases of the papers *AA&P* has published. It can be seen that *AA&P* is the most cited and that it cites the most. Self-citation is quite common among journals, and here indicates that *AA&P* has published many high-impact papers and is continuing to make advances in its field. The cited journals in second and third places are *Transport Res Rec* (589) and *Transport Res F-Traf* (425), while the corresponding citing journals are *Transport Res F-Traf* (857) and *Traffic Inj Prev* (662). This indicates a strong pattern of mutual promotion and development between *Transport Res F-Traf* and *AA&P*. As shown in Table A1, 9 cited journals and 12 citing journals belong to the category of "Transportation Journals," including *Transport Res Rec*, *Transport Res F-Traf*, and *J Safety Res*. This indicates that *AA&P* has become an important platform of knowledge dissemination in the transportation research community. In addition, *AA&P* has widely cited and been cited in high-impact journals in other fields, such as Applied Psychology, Industrial Engineering and Clinical Neurology. This shows the interdisciplinary nature of *AA&P* and the attention it receives from distinguished journals in other fields.

3.2. Document co-citation analysis: main research topics and knowledge bases

The concept of co-citation was proposed by Small (1973), and in co-citation analysis, when two documents are simultaneously cited by a third paper, a co-citation relationship exists between them. Document co-citation analysis is the main approach for identifying the knowledge bases in a given field, since an important relationship exists between the co-cited documents and the research content of the papers. If a given paper is often cited by other papers in a field, the document can be assumed to be critical to this field. Mutual citation not only indicates the flow of knowledge within a field, but also reflects the cumulative processes of knowledge production and development. Document co-citation analysis of the documents published in *AA&P* therefore allows us to determine the journal's main research topics and knowledge bases.

Knowledge bases consist of co-cited documents, are the foundation of the evolution of knowledge in a research field and represent the evolution networks and co-citation trajectories of the cited scientific documents. Using VOSviewer, we conducted document co-citation analysis (van Eck and Waltman, 2010; van Eck and Waltman, 2009) to construct the document co-citation network for *AA&P* (Fig. 13). It can

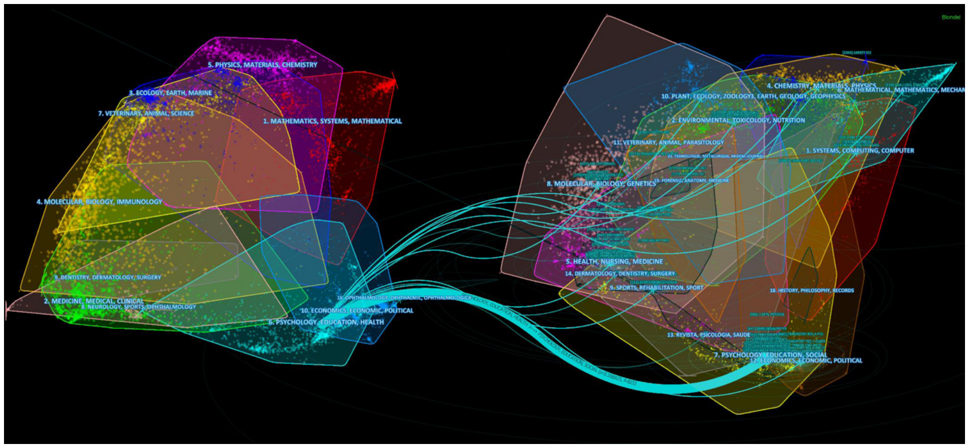


Fig. 11. Dual-map overlays of *AA&P*.

Fig. 12. Knowledge communication between *AA&P* and other journals in 2017.
Note: Full titles of journals are listed in Table A1.

be seen that the research published in *AA&P* can be divided into 5 main clusters, with detailed information about the top-5 documents (the documents with the highest numbers of co-citations in each cluster) is provided in Table 7. In this table, there are 20 classic documents (journal papers), three books, and two reports. Of the journals, 11 were published in *AA&P* itself and 9 in other prestigious journals, such as the *Journal of Safety Research, The New England Journal of Medicine*, and *Transportation Research Part A: Policy and Practice*.

3.2.1. Cluster 1 (red): Effects of hazard and risk perception on driving behavior

In this cluster, the classic document with the highest co-citations is “Hazard and Risk Perception among Young Novice Drivers” by Deery (1999), published in the *Journal of Safety Research*.

In the complex “human-vehicle-road-environment” system, the human factor dominates as the cause of traffic crashes. One key factor is the perception of hazards, that is, a driver’s ability to identify and react to potential traffic dangers (Deery, 1999). Hazard perception is closely related to crashes, because it not only distinguishes how different people drive but also relates to the types of crashes that drivers cause (Wells et al., 2008).

Deery (1999) proposed a model of processes underlying driving behavior in response to potential hazards to show how the concepts and functions of hazard and risk perception are different. Risk perception emphasizes a driver’s subjective assessment of danger and is often considered to be a “mediator” or “moderator” variable in research. In addition, Deery (1999) found that novice drivers have many disadvantages compared with experienced drivers, such as the fact that they have not developed the perception and cognitive skills to interact safely with the driving environment, and they often underestimate the risk of a crash and overestimate their driving skills. Deery’s findings laid the foundation for the appearance of factor analysis of risk perception (Lucidi et al., 2006; Rosenbloom et al., 2008) and hazard-perception training (Isler et al., 2009; Vidotto et al., 2011; Isler et al., 2011; Zeuwts et al., 2017a) and testing (Sagberg and Bjørnskau, 2006; Scialfa et al., 2012; Scialfa et al., 2013; Crundall and Kroll, 2018) in *AA&P*.

As early as Pelz and Krupat (1974) first undertook reaction-time measurement, requiring drivers to manipulate a handle to record the levels of danger they perceived while watching a video of traffic. This research laid the foundation for the subsequent development of hazard-perception tests (HPTs) used for driver evaluation, training and licensing. In the years that followed, scholars published a wealth of research in *AA&P* on areas including but not limited to:

1 determining the differences in hazard perceptions of novice and experienced drivers (Sagberg and Bjørnskau, 2006; Wallis and

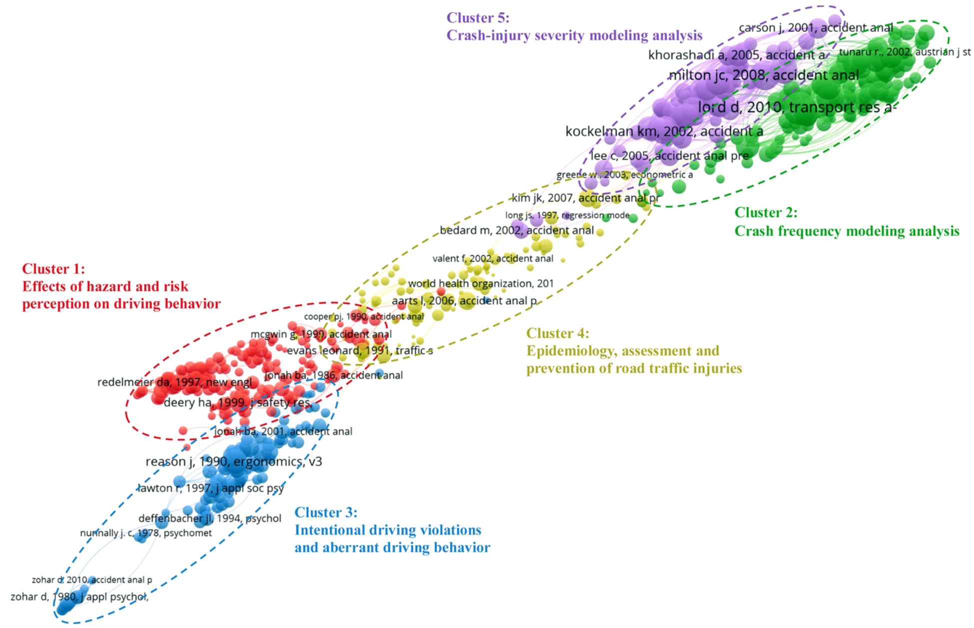


Fig. 13. Document co-citation network for *AA&P* and main research topics.

Horswill, 2007) or motorcycle riders (Hosking et al. 2010), as well as comparing accident-free motorcycle riders with those that had been involved in accidents (Cheng et al., 2011). Drivers of varying levels of experience were found to respond differently to different hazards (Crundall et al., 2012).

2 hazard-perception training, such as commentary measures (Isler et al., 2009; Crundall et al., 2010), which turned out to be beneficial even for highly experienced drivers (Horswill et al., 2013).
3 factors affecting hazard perception, such as sleepiness (Smith et al., 2009), age, and skill (Borowsky et al., 2010).
4 development of HPTs (Wetton et al., 2010; Scialfa et al., 2012), especially for novice drivers (Scialfa et al., 2011) and for use in driver licensing (Wetton et al., 2011), as well as for predicting crash involvement (Horswill et al. 2015).

In recent years, more focus has been put on vulnerable road users (Ābele et al., 2018), especially child bicyclists, in terms of hazard perception test (Zeuwts et al., 2017b) and training (Lehtonen et al., 2017; Zeuwts et al., 2018), perception of risk in different traffic situations (Moller and Hels, 2008), as well as crash-probability estimation through assessments of the abilities of drivers to perceive hazards (their risk-response times) (Li et al., 2018a). Useche et al. (2018) have measured bicyclists' risk perception from a psychometric perspective and suggested that risk perception was significant for risky cycling behaviors. Moran et al. (2019) conducted a systematic review of HPT methodologies, in which a high level of heterogeneity was found, and the authors highlighted the importance of resolving the inconsistencies and developing gold standards, such as categorization of drivers by age and experience, and the selection criteria for types of hazards, as well as developing methodologies for assessing the hazard-perception skills of vulnerable road users.

3.2.2. *Cluster 2 (green): Crash frequency modeling analysis*

In this cluster, the classic document with the highest co-citations is "The Statistical Analysis of Crash-frequency Data: A Review and Assessment of Methodological Alternatives" by Lord and Mannering (2010), published in *Transportation Research Part A: Policy and Practice*.

Crash-frequency model is an essential tool in traffic safety analysis. Numerous studies have been conducted to evaluate the safety level of various types of road entities, to identify hotspots or sites with promise, and to find appropriate countermeasures (*HSM*; American Association of State Highway and Transportation Officials (AASHTO, 2010). A variety of statistical and econometric models have been developed at both the road entities/micro level and, in the past decade under the context of transportation safety planning, the zonal/macro level. Since the earliest work, "The Distribution and Prediction of Driver Accident Frequencies" by Peck et al. (1971), to use Poisson analysis, the traditional multiple-linear-regression, Poisson regression (Miaou and Lum, 1993; Miaou, 1994), negative binomial (Poisson-gamma) regression (Miaou, 1994; Shankar et al., 1995; Abdel-Aty and Radwan, 2000; Carson and Mannering, 2001; Noland and Quddus, 2004; Lord, 2006), multivariate Poisson log-normal model (Ma et al., 2008; El-Basyouny and Sayed, 2009a), and the controversial zero-inflated Poisson and negative binomial (ZIP and ZINB) models (Miaou, 1994; Shankar et al., 1997; Carson and Mannering, 2001; Lee and Mannering, 2002; Lord et al., 2005) are all well-established techniques in analyzing crash frequency.

However, in the presence of unobserved heterogeneity, zero-inflation, multilevel and spatiotemporal correlations of crash data, traditional approaches could result in biased and inefficient parameter estimations, and in turn lead to inaccurate inferences and predictions. To address these issues, more advanced methods with better goodness-of-fit and predictive performances have been applied, including but not limited to

1 random parameters models to deal with the unobserved heterogeneity issue (Anastasopoulos and Mannering, 2009; El-Basyouny and Sayed, 2009b; Anastasopoulos et al., 2012; Dong et al., 2014).
2 Bayesian hierarchical, spatial and temporal models to adjust multilevel and spatiotemporal heterogeneities in model residuals by accounting for structured data characteristics, including spatial analysis (Levine et al., 1995a, 1995b), generalized estimating equations model (Wang and Abdel-Aty, 2006), multilevel model (Huang and Abdel-Aty, 2010); spatial model (Aguero-Valverde and Jovanis, 2006; Quddus, 2008a; Siddiqui et al., 2012), time series model (Quddus, 2008b); spatial joint model (Zeng and Huang, 2014a), spatio-temporal interaction model (Dong et al., 2016; Wang et al., 2016; Zhou et al., 2019), spatially varying coefficients model (Xu et al., 2017); semi-parametric geographically weighted Poisson model (Xu and Huang, 2015); the multivariate spatial model (Jonathan et al., 2016), etc.
3 finite mixture/state switching models to resolve unobserved

Table 7
Classic documents with high co-citations in *AA&P*.

Cluster (color)	Author/s (year)	Classic document (knowledge base)	Published in	Co-citations
1 (red)	Deery (1999)	Hazard and risk perception among young novice drivers	*Journal of Safety Research*	831
	Redelmeier and Tibshirani (1997)	Association between cellular-telephone calls and motor vehicle collisions	*New England Journal of Medicine*	516
	Horswill and McKenna (2004)	Drivers' hazard perception ability: Situation awareness on the road	*A Cognitive Approach to Situation Awareness: Theory and Application* *(Book)*	482
	Williams (2003)	Teenage drivers: Patterns of risk	*Journal of Safety Research*	470
	Finn and Bragg (1986)	Perception of the risk of an accident by young and older drivers	*AA&P*	456
2 (green)	Lord and Mannering (2010)	The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives	*Transportation Research Part A: Policy and Practice*	2,291
	Anastasopoulos and Mannering (2009)	A note on modeling vehicle accident frequencies with random-parameters count models	*AA&P*	1,449
	Shankar et al. (1995)	Effect of roadway geometrics and environmental factors on rural freeway accident frequencies	*AA&P*	1,314
	Miaou (1994)	The relationship between truck accidents and geometric design of road sections: Poisson versus negative binomial regressions	*AA&P*	1,213
	Abdel-Aty and Radwan (2000)	Modeling traffic accident occurrence and involvement	*AA&P*	1,207
3 (blue)	Reason et al. (1990)	Errors and violations on the roads: A real distinction?	*Ergonomics*	1,252
	Parker et al. (1995)	Driving errors, driving violations and accident involvement	*Ergonomics*	897
	Ajzen (1991)	The theory of planned behavior	*Organizational Behavior and Human Decision Processes*	819
	Jonah (1997)	Sensation seeking and risky driving: A review and synthesis of the literature	*AA&P*	763
	Lawton et al. (1997)	The role of affect in predicting social behaviors: The case of road traffic violations	*Journal of Applied Social Psychology*	704
4 (yellow)	Aarts and van Schagen (2006)	Driving speed and the risk of road crashes: A review	*AA&P*	708
	Evans (1991)	Traffic Safety and the Driver	*(Book)*	582
	WHO (2004)	World Report on Road Traffic Injury Prevention	*(Report)*	474
	Evans (2004)	Traffic Safety	*(Book)*	470
	WHO (2013)	Global Status Report on Road Safety 2013: Supporting a Decade of Action	*(Report)*	439
5 (purple)	Milton et al. (2008)	Highway accident severities and the mixed logit model: An exploratory empirical analysis	*AA&P*	1,862
	Lee and Mannering (2002)	Impact of roadside features on the frequency and severity of run-off-roadway accidents: An empirical analysis	*AA&P*	1,548
	Kockelman and Kweon (2002)	Driver injury severity: An application of ordered probit models	*AA&P*	1,358
	Shankar and Mannering (1996)	An exploratory multinomial logit analysis of single-vehicle motorcycle accident severity	*Journal of Safety Research*	1,260
	Savolainen et al. (2011)	The statistical analysis of highway crash-injury severities: A review and assessment of methodological alternatives	*AA&P*	1,259

Note: For brevity, only the first authors are shown if there are more than two.

heterogeneity or “zero-inflation” problem (Park and Lord, 2009; Malyshkina and Mannering, 2010).

4 machine and deep learning methods to handle high-dimension and non-linear relationship, including the support vector machine (Dong et al., 2015), and neural network (Xie et al., 2007; Zeng et al. 2016), etc.

3.2.3. Cluster 3 (blue): Intentional driving violations and aberrant driving behavior

In this cluster, the classic document with the highest co-citations is “Errors and Violations on the Roads: A Real Distinction?” by Reason et al. (1990), published in *Ergonomics*.

Reason et al. (1990) developed the pioneering Manchester Driver Behavior Questionnaire (DBQ), a self-reporting instrument. By investigating 520 drivers and analyzing the completed DBQ, Reason et al. (1990) determined that there are three contributing factors to aberrant driving: violations, dangerous errors, and harmless lapses. Based on the Manchester DBQ, Parker et al. (1995) defined the three types of aberrant driving more clearly and created a simplified version of the DBQ while also verifying the three-factor structure established by Reason et al. (1990). The DBQ has been widely used by *AA&P* scholars to investigate aberrant driving in a variety of countries, including Greece (Kontogiannis et al., 2002), Denmark (Martinussen et al., 2013), France (Guého et al., 2014), Qatar, and the United Arab Emirates (Bener et al., 2008), and by various driver groups, including women drivers (Dobson et al., 1999), elderly drivers (Parker et al., 2000), and young novice drivers (Lucidi et al., 2010; Hassan and Abdel-Aty, 2013). The DBQ has also been modernized (Cordazzo et al., 2016) and extended to create the Motorcycle Rider Behavior Questionnaire (Elliott et al., 2007; Cheng and Ng, 2010; Özkan et al., 2012; Stephens et al., 2017), Pedestrian Behavior Questionnaire (Deb et al., 2017) and Cycling Behavior Questionnaire (Useche et al., 2018).

In *AA&P*, studies of the relationship between “risky driving behavior and driving violations” and “road accidents” have a long history, especially in relation to younger drivers (Jonah, 1986; Parker et al., 1992). The most important contributions of *AA&P* scholars relate to assessments/predictions of aggressive and risky driving as well as negative driving outcomes (accidents or violations) on the basis of driving anger and personality traits (especially sensation-seeking and the Big Five personality traits: neuroticism, extraversion, openness, agreeableness and conscientiousness) (Arnett et al., 1997; Jonah, 1997; Jonah et al., 2001; Dahlen et al., 2005; Schwebel et al., 2006; Constantinou et al., 2011; Dahlen et al., 2012). Other important factors include gender (Lonczak et al., 2007; Prato et al., 2010), the driving behavior/styles of parents (Bianchi and Summala, 2004; Prato et al., 2010; Miller and Taubman - Ben-Ari, 2010), and driving experience (Tao et al., 2017). Extensive work has also been done on the application and validation of DBQ for measuring self-reported aberrant driving in a variety of countries, including Turkey (Sümer, 2003), Finland and the Netherlands (Lajunen et al., 2004), Israel (Shahar, 2009), Italy (Lucidi et al., 2010), Australia (Stephens and Fitzharris, 2016), and China (Shi et al., 2010; Tao et al., 2017), as well as in different driver groups (Martinussen et al., 2013) and in simulated driving (Helman and Reed, 2015).

3.2.4. Cluster 4 (yellow): Epidemiology, assessment and prevention of road traffic injuries

In this cluster, the classic document with the highest co-citations is “Driving Speed and the Risk of Road Crashes: A Review” by Aarts and van Schagen (2006), published in *AA&P*.

Road-traffic injury (RTI) is a non-negligible worldwide social-safety and public-health concern that leads to more than 3,000 fatalities every day (World Health Organization (WHO, 2004). Reports on RTI published by the WHO (2004)andWHO (2013) have motivated researchers to conduct research on the epidemiology, assessment and prevention of RTI that focusses on vulnerable road users (Jacobsen, 2003; Kim et al., 2007).

From an epidemiological point of view, RTI is considered to be a type of “social disease”. Through analytical investigation of injury patterns and characteristics, risk factors, injury severity, and treatment and prevention of traffic crashes and RTI, the patterns of occurrence of RTI can be better understood. The roles of and relationships among social causes, natural environments and crash management, and treatment processes are explored and preventive strategies are put forward, thereby providing a scientific basis for road safety management, the prevention and reduction of RTI, and its treatment. Speeding is the most important single cause of casualties due to the greater likelihood and severity of injury associated with it. The faster the speed, the less able the driver, who has a reaction time of between 1.5 and 4.0 s (Evans, 1991), is to respond, the greater the distance required for braking, and the more likely the driver is to make mistakes. Aarts and van Schagen (2006) conducted a comprehensive review of the relationship between speed and crash rate. They concluded that the relationship is exponential at the individual-vehicle level, while the average speed has a power-function relationship with the crash rate at the road-section level. Based on their findings, studies of the effects of speed-related control measures, such as average-speed enforcement (Soole et al., 2013), speed-limit restrictions (De Pauw et al., 2014), and point-to-point speed enforcement (Montella et al., 2015) have also been conducted.

High-quality data sources and databases are extremely important for assessing the risk factors behind RTIs, and developing interventions to reduce them. In *AA&P*, based on the construction of an RTI database (Ferrante et al., 1993), considerable related work has been conducted, and produced valuable results. It has included comparisons of hospital and police RTI data (Rosman and Knuiman, 1994; Aptel et al., 1999), linkages between hospital and police records (Rosman, 1996; Rosman, 2001), and assessments of under-reporting of RTI data (Alsop and Langley, 2001; Amoros et al., 2006; Watson et al., 2015; Huang et al., 2017; Ahmed et al., 2019). It should be noted that issues of under-reporting (especially for less-severe injuries) affect both crash-frequency and crash-injury severity analyses (clusters 2 and 5), since omitting minor crashes, and having a bias toward severity in the model parameters, could lead to erroneous inferences (Yamamoto et al., 2008; Yasmin and Eluru, 2013; Mannering and Bhat, 2014). In addition, epidemiological (distribution and mechanism) analyses of RTIs (Plasència et al., 1995; Petridou et al., 1997; Harruff et al., 1998; Mock et al., 1999; Híjar et al., 2004), evaluation of RTI-prevention programs (Ytterstad and Wasmuth, 1995; Lindqvist et al., 2001; Carnis and Blais, 2013) and laws/regulations (Ichikawa et al., 2003; Miller et al., 2018), and the after-effects of RTIs, such as financial consequences (Haukeland, 1996), work disability (Berecki-Gisolf et al., 2013) and quality of life (Rissanen et al., 2017; Monárrez-Espino et al., 2018), are all important research subjects. In addition, some studies have focused on assessing the health burden of RTIs using indicators like disability adjusted life years (DALY; Dhondt et al., 2013; Polinder et al., 2015) and years lived with disability (YLD; Weijermars et al., 2018).

In recent years, more findings have shed light on the RTIs of bicyclists In *AA&P*. Based on databases from police records, traffic departments, hospitals and insurance companies, epidemiological studies have been done on exploring the patterns of crashes, the environment-related factors (Chen and Shen, 2016; Loo and Tsui, 2010; Schepers et al., 2011; Pulugurtha and Thakur, 2015; Twisk and Reurings, 2013; Wang and Nihan, 2004; Wood et al., 2009), describing the characteristics of injured bicyclists (Martínez-Ruiz et al., 2015; Simon-Tov et al., 2012). More focus has been put on young bicyclists including children and adolescent (Mcadams et al., 2018; Vanparijs et al., 2016). In addition, Wegman et al. (2012) concluded the interventions to reduce risks and severity of bicycle injuries, such as wearing bicycle helmets, taking infrastructure measures and improving poor cyclist behaviour by education and enforcement.

Table 8
Top 30 references with the strongest citation bursts in *AA&P*

Rank	Author/s (year)	Title	Published in	Strength	Begin	End
1	Lord and Mannering (2010)	The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives	*Transportation Research Part A: Policy and Practice*	39.33	2013	2019
2	Evans (1991)	Traffic Safety and the Driver	*(Book)*	31.49	1991	1999
3	Mannering and Bhat (2014)	Analytic methods in accident research: Methodological frontier and future directions	*Analytic Methods in Accident Research*	27.52	2015	2019
4	Mannering et al. (2016)	Unobserved heterogeneity and the statistical analysis of highway accident data	*Analytic Methods in Accident Research*	25.97	2017	2019
5	WHO (2015)	Global Status Report on Road Safety 2015	*(Report)*	25.08	2016	2019
6	WHO (2013)	Global Status Report on Road Safety 2013: Supporting a Decade of Action	*(Report)*	24.87	2014	2019
7	Savolainen et al. (2011)	The statistical analysis of highway crash-injury severities: A review and assessment of methodological alternatives	*AA&P*	24.29	2013	2019
8	AASHTO (2010)	Highway Safety Manual	*(Book)*	22.70	2012	2019
9	WHO (2009)	Global Status Report on Road Safety 2009: Time for Action	*(Report)*	21.51	2011	2015
10	Milton et al. (2008)	Highway accident severities and the mixed logit model: An exploratory empirical analysis	*AA&P*	17.64	2009	2015
11	Lord et al. (2005)	Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: Balancing statistical fit and theory	*AA&P*	17.51	2007	2013
12	Washington et al. (2003)	Statistical and Econometric Methods for Transportation Data Analysis (First Edition)	*(Book)*	17.40	2006	2011
13	Elvik et al. (2009)	The Handbook of Road Safety Measures (Second Edition)	*(Book)*	16.65	2012	2017
14	Washington et al. (2010)	Statistical and Econometric Methods for Transportation Data Analysis (Second Edition)	*(Book)*	16.27	2015	2019
15	Savolainen and Mannering (2007)	Probabilistic models of motorcyclists' injury severities in single- and multi-vehicle crashes	*AA&P*	15.01	2010	2015
16	WHO (2004)	World Report on Road Traffic Injury Prevention	*(Report)*	14.94	2007	2012
17	Anastasopoulos and Mannering (2009)	A note on modeling vehicle accident frequencies with random-parameters count models	*AA&P*	14.90	2010	2017
18	Xu and Huang (2015)	Modeling crash spatial heterogeneity: Random parameter versus geographically weighting	*AA&P*	14.14	2016	2019
19	Eluru et al. (2008)	A mixed generalized ordered response model for examining pedestrian and bicyclist injury severity level in traffic crashes	*AA&P*	13.94	2010	2016
20	Elvik and Vaa (2004)	The Handbook of Road Safety Measures (First Edition)	*(Book)*	13.61	2006	2010
21	Klauer et al. (2014)	Distracted driving and risk of road crashes among novice and experienced drivers	*New England Journal of Medicine*	13.40	2015	2019
22	Huang and Abdel-Aty (2010)	Multilevel data and Bayesian analysis in traffic safety	*AA&P*	13.26	2013	2019
23	de Winter and Dodou (2010)	The Driver Behaviour Questionnaire as a predictor of accidents: A meta-analysis	*Journal of Safety Research*	13.18	2013	2016
24	Aarts & van Schagen (2006)	Driving speed and the risk of road crashes: A review	*AA&P*	13.01	2012	2014
25	Siddiqui et al. (2012)	Macroscopic spatial analysis of pedestrian and bicycle crashes	*AA&P*	13.00	2015	2019
26	Huang et al. (2010)	County-level crash risk analysis in Florida: Bayesian spatial modeling	*Transportation Research Record*	13.00	2015	2019
27	Lee and Mannering (2002)	Impact of roadside features on the frequency and severity of run-off-roadway accidents: An empirical analysis	*AA&P*	12.86	2004	2010
28	Caird et al. (2008)	A meta-analysis of the effects of cell phones on driver performance	*AA&P*	12.71	2013	2016
29	Ulfarsson and Mannering (2004)	Differences in male and female injury severities in sport-utility vehicle, minivan, pickup and passenger car accidents	*AA&P*	12.22	2007	2011
30	Chen and Chen (2011)	Injury severities of truck drivers in single- and multi-vehicle accidents on rural highways	*AA&P*	12.08	2014	2019

Note: For brevity, only the first authors are shown if there are more than two.

3.2.5. Cluster 5 (purple): Crash-injury severity modeling analysis

In this cluster, the classic document with the highest co-citations is "Highway Accident Severities and the Mixed Logit Model: An Exploratory Empirical Analysis" by Milton et al. (2008), published in *AA&P*. It can be seen that this cluster is closely related to Cluster 2, "Crash frequency modeling analysis" (Fig. 13), indicating that there are many studies whose topics overlap and influence one another.

The purpose of research on traffic crashes is not only to decrease crash frequency, but also reduce crash-injury severity. Through research on the distribution of related variables and their influence on the severity of crash injuries, solutions can be proposed to reduce this severity and enhance overall safety. In crash-injury severity modeling analysis, the traditional practice is to classify the casualties into two or more classes of severity (such as "no injury", "minor injury", and "severe injury") and then analyze the variables of discrete-outcome models by assessing their parameters for various types of crashes.

In *AA&P* publications, a variety of important methodological approaches for analyzing crash-injury severity have been established and developed, especially discrete-choice (logit/probit) models including:

1 logistic regression models (Bédard et al., 2002; Al-Ghamdi, 2002; Yau, 2004; Sze and Wong, 2007)
2 multinomial logit models (Shankar and Mannering, 1996; Carson and Mannering, 2001; Ulfarsson and Mannering, 2004; Khorashadi et al., 2005; Kim et al., 2007)
3 nested logit models (Shankar et al., 1996; Chang and Mannering, 1999; Lee and Mannering, 2002; Savolainen and Mannering, 2007)
4 ordered probit models (Kockelman and Kweon, 2002; Zajac and Ivan, 2003; Yamamoto and Shankar, 2004; Abdel-Aty and Keller, 2005; Lee and Abdel-Aty, 2005; Zhu and Srinivasan, 2011)
5 mixed (random parameters) logit models to address unobserved heterogeneity (Milton et al., 2008; Gkritza and Mannering, 2008; Kim et al., 2010; Moore et al., 2011; Anastasopoulos and Mannering, 2011; Chen and Chen, 2011; Kim et al., 2013; Shaheed et al., 2013; Wu et al., 2014; Zhao and Khattak, 2015).

However, due to the limitations of traditional regression models (i.e. pre-defined underlying relationships between target (dependent) variable and predictors (independent variables), as well as limitations in analysis of high-order interactions between explanatory variables and rankings of variable importance), advanced data-mining techniques, such as neural networks (Zeng and Huang, 2014b), Bayesian networks (Chen et al., 2015a; Chen et al., 2016a; Prati et al., 2017), decision trees (Prati et al., 2017), support-vector machines (Chen et al., 2016b), and classification and regression tree (CART) models (Chang and Wang, 2006; Huang et al., 2018), were developed and advocated. Still, unobserved heterogeneity remains a significant issue in predicting crash-injury severity, and needs to be carefully addressed (Mannering et al., 2016). In relation to this, random parameters models and finite-mixture (latent-class) models are two major types that are widely used (Zou et al., 2013; Pahukula et al., 2015; Haleem et al., 2015; Gong and Fan, 2017), as along with models including the hierarchical Bayesian model (Huang et al., 2008; Chen et al., 2015b; Meng et al., 2017), and the random-effects generalized ordered probit (REGOP) model (Anarkooli et al., 2017).

3.3. Reference burst-detection analysis: hotspots and trends

The influence of a paper on a given field can be measured by its citation frequency, but the latter cannot determine the influence of the paper over a certain period of time. Through reference burst-detection analysis, references with the strongest citation bursts (a burst represents how frequently the reference is cited (Chen, 2019)) over given periods are identified to better determine the frontiers of research in *AA&P*.

Burst literature is an important type of literature that is able to quantify sudden boosts in the citation frequency of papers. Such literature, which is characterized by innovation, usually represents a rise or turn in a particular research field, and the topics of papers classified as burst literature are often at the forefront of the field. A sudden increase in citation frequency also indicates that the value of the paper or papers in question has been noted in the field. Using the "burst detection" function in CiteSpace, which is based on Kleinberg's algorithm (Kleinberg, 2003), the 30 papers with the strongest citation bursts in *AA&P* were obtained, with detailed publication information provided in Table 8.

Key literature with high burst strength is literature that has received extraordinary attention over a certain period of time. It is often at the forefront of research in its discipline, and its research area is generally a hot topic during that time. Key literature with a burst strength higher than 20 is discussed in the following.

As shown in Table 8, the paper with the highest burst strength is "The Statistical Analysis of Crash-frequency Data: A Review and Assessment of Methodological Alternatives" by Lord and Mannering (2010), with a burst strength of 37.26 since 2013. As discussed in Section 3.2.2., this paper is fundamental to "crash frequency modeling analysis", which indicates that the paper has been a strong force in the evolution of research on this topic and that research in this area will continue to attract the most interest from the *AA&P* community.

The paper with the second highest burst strength is *Traffic Safety and the Driver* by Evans (1991), with a burst strength of 31.49 and a burst period from 1991 to 1999. This classic book analyzes the engineering, environmental, and human factors contributing to crashes, discusses the effectiveness of occupant-protection devices and corresponding laws, and presents traffic safety within the contexts of safety, mobility, and other values. The book has been highly recommended by many prestigious journals, including *AA&P* (Hutchinson, 1992), *Journal of the Operational Research Society* (Shea, 1992), *Risk Analysis* (White, 1993), *Journal of the American Planning Association* (Kim, 1993), and *Ergonomics* (Fuller, 1993), as is evidenced by the fact that it has been cited 1,657 times in Google Scholar (recorded on April 19, 2019). The book exerted great influence on publications in *AA&P* in the 1990s. Although the book has not been as influential recently as it was in the past, it will remain a theoretical cornerstone of road safety studies.

In the third and fourth places are two recent masterworks by Mannering and Bhat (2014) and Mannering et al. (2016), titled "Analytic Methods in Accident Research: Methodological Frontier and Future Directions" and "Unobserved Heterogeneity and the Statistical Analysis of Highway Accident Data," respectively; both were published in *Analytic Methods in Accident Research*, founded in 2014 by Professor Fred Mannering. The former paper, based on the work of Lord and Mannering (2010) and Savolainen et al. (2011), reviews the evolution of methodological approaches in both crash-frequency and crash-injury-severity research. Issues such as unobserved heterogeneity, multivariate models, and endogeneity are identified as the methodological frontiers. In the second paper, Mannering et al. (2016) highlights the importance of addressing unobserved heterogeneity in traffic-crash analysis and gives a detailed discussion of the methods for unobserved heterogeneity. These two papers provide profound insights and new directions for *AA&P* scholars working on crash-frequency and injury-severity studies.

In the fifth, sixth and ninth places are reports in the series *Global Status Reports on Road Safety*, published by the WHO (2009; 2013; 2015). These reports, focusing on RTI prevention from a global perspective, constantly update data on the road safety situations in approximately 180 countries. The reports have always motivated *AA&P* scholars from around the world to produce more effective research and propose better safety measures. The latest report, *Global Status Report on Road Safety 2018* (World Health Organization (WHO, 2018), shows that crash fatalities are continuing to increase, reaching 1.35 million in 2016, which indicates that traffic crashes remain a serious problem globally.

In addition to the 2010 review of "crash frequency modeling

Table 9
Modified Haddon matrix for level-4 HAVs (highly automated vehicles) and level-5 FAVs (Fully automated vehicles).

Factor Phase		Human	Vehicle/Equipment		Physical environment		
			Software	Hardware	Information-communication networks	Transportation infrastructure	
Pre-crash	Crash prevention	Driver state recognition, perception enhancement, and action suggestion* Driver timing choice of deploying autonomous mode* Ability to take over control in challenging situations* Driver licensing system for AVs*	Handle heavy workloads Intention recognition and trajectory prediction (in relation to other road users) Critical scenerio library and risk mitigation algorithms Instant update, periodic testing and security SOTIF	Vehicle design and Functional Safety HMI with occupants and other road users AV computer and sensor capability Defined and standardized ODD Sensor detection of ODD Training and testing of OEDR capabilities Vehicle alert system Security of computer system Vehicle status monitoring and display system	Efficiency and security of connected vehicle infrastructure Cybersecurity HMI with vehicle monitoring center	Maintenance of road paint and other markings Safe road design, layout and signages meeting the requirements of ODD Intelligent intersections and roundabouts Environmental conditions	AV adoption and behavior change due to new mobility options AV market penetration and its impact Education about AV and future mobility Ethics regulation and policies
Crash	Injury severity minimization during the crash	Machine-driven moral decisions and related ethics Best brace positions for occupants	Capacity to function as normal and take control of the vehicle (or alert driver*) Vehicle proactive/passive response strategies with ethical rules	Protocol for reaching safety after failure Advanced restraint and protection systems Vehicle safety ratings (crash aggressivity and crashworthiness)	Speed and reliability of communications networks Disseminate to road users around	Guard systems to reduce impact	Impact of mixture of AVs and conventional vehicles
Post-crash	Life sustaining and future improvements	Ability to call for help Ability to perform first-aid Warning triangle placement Patient perceptions on the use of autonomous ambulances	Automatic decision-action algorithm Record the detail and re-enact the crash circumstances Algorithm modification/ improvement/sharing	Automatic collision notification Capability to detect EMS vehicles and automatically pull over Vehicle fire resistance Difficulty of entering/exiting the vehicle	Fault-tolerant cooperative motion planning Signal preemption for EMS vehicles HMI with vehicle rescue center Improved information contents and security	Vehicle-monitoring and rescue center Competent EMS staff Distance to trauma care Rehabilitation programs	Improved EMS systems Address AV induced trauma Educating drivers for yielding to EMS vehicles Data sharing for burden assessment Liability and compensation (hospital, medical and rehabilitation expenses)

Note: Aspects relevant for level 4 but not level 5 are denoted with *. EMS = emergency medical services, HMI = human machine interface, ODD = operational design domain, SOTIF = safety of the intended functionality, OEDR = object and event detection and response (Thorn et al., 2018; ISO, 2019).

analysis" by Lord and Mannering, a review of "crash-injury severity modeling analysis" was conducted by Savolainen et al. (2011). The paper has a burst strength of 24.29 during the period from 2013 to the present. In this paper, the authors analyze the characteristics of crash-injury-severity data and methodological issues, discuss binary, ordered discrete, and unordered multinomial discrete outcome models, and provide future methodological directions. The sustained burst strength of this document indicates that crash-injury severity will remain an important research focus of *AA&P*.

4. Summary and Future Directions

4.1. Summary

Since its appearance in 1969, *Accident Analysis & Prevention* has become the top journal in the field of road safety and has published the most influential research in the field. The year 2018 marked the 50th anniversary of *AA&P*, which motivated us to conduct a bibliometric and scientometric overview using the *WoS Core Collection* database of the journal's evolution since its inception. In our research, we collected bibliographic information, determined bibliometric indicators, and performed document co-citation analysis and reference burst-detection analysis to create knowledge maps of the main research topics, hotspots, and trends in *AA&P*. The present study reveals the following.

1 Based on the number of publications appearing annually in the journal, the evolution of *AA&P* has gone through an exploratory stage (1969–1981), a stage of steady development (1982–2003), and a rapid-development stage (2004–present) and has grown exponentially. During the study period, the USA was the most active source country, with a total of 2,165 publications and 58,194 citations, followed by Australia, Canada, the UK, and China, in that order. Monash University (Australia) was the most productive (165 publications) and influential (3,953 citations) source organization, followed by the Queensland University of Technology (Australia) and IFSTTAR (France) in terms of total publications, and the University of Central Florida (the USA) and Insurance Institute for Highway Safety (the USA) in terms of total citations. Professor Mohamed A. Abdel-Aty (University of Central Florida) ranks at the top of the list of contributors, with 82 publications and the highest h-index (29), while Professor Fred L. Mannering (University of South Florida) received the most citations (3581). Other scholars making remarkable contributions include Professors Rune Elvik (Institute of Transport Economics), Allan F. Williams (Allan F. Williams LLC), Helai Huang (Central South University), Dominique Lord (Texas A&M University), and Tarek A. Sayed (University of British Columbia).

2 Through knowledge-flow analysis, it can be seen that *AA&P* most often cited journals located in the "Psychology, Education, Social" cluster, and that it widely assimilated knowledge from journals in other categories, such as the "Systems, Computing, Computer" and "Health, Nursing, Medicine" categories, showing the highly interdisciplinary nature of the journal. In addition, *AA&P* has close connections with *Transportation Research Record*, *Transportation Research Part F: Traffic Psychology and Behaviour*, *Traffic Injury Prevention*, *Journal of Safety Research*, and *Analytic Methods in Accident Research*.

3 Through document co-citation analysis, it was determined that the main research topics appearing in *AA&P* include "effects of hazard and risk perception on driving behavior", "crash frequency modeling analysis", "intentional driving violations and aberrant driving behavior", "epidemiology, assessment and prevention of road traffic injuries", and "crash-injury severity modeling analysis." Papers by Deery (1999), Lord and Mannering (2010), Reason et al. (1990), Aarts and van Schagen (2006), and Milton et al. (2008), which are the most highly co-cited, are fundamental to the field of road safety and are important for establishing the basis of the discipline and the research consensus in the field.

4 Through reference burst-detection analysis, papers by Lord and Mannering (2010), Evans (1991), Mannering and Bhat (2014), Mannering et al. (2016), and the WHO (2015) are seen to have the strongest citation bursts, indicating that these papers played or have been playing pivotal roles in advancing research and *AA&P* evolution. Furthermore, it is evident that the research on crash frequency and crash-injury severity are and will continue to be important topics in *AA&P*.

4.2. Future Directions

With rapid advances in the technologies of intelligent, connected and autonomous vehicles (CAVs or ICVs), safety becomes the first-priority subject of research for the new generation of transportiona systems. Capable of real-time monitoring themselves and their surroundings for hazards, and communicating with other vehicles and road infrastructure, CAVs can achieve collision avoidance, route optimization, and crash reduction. In the last two years, some studies on CAV safety have appeared in *AA&P* on topics such as sleepiness, fatigue and distraction in CAVs (Vogelpohl et al., 2018; Matthews et al., 2018), CAV disengagements (Favarò et al., 2018), the impacts of cyber-attacks on CAVs (Li et al., 2018b), safety impact evaluation of CAVs (Papadoulis et al., 2019), and collision-risk assessment for CAVs (Katrakazas et al., 2019). Research on CAV safety will become increasingly crucial and diverse. Based on the existing review studies (e.g., Li et al., 2012; Bonnefon et al., 2016; Ryerson et al., 2019), herein we propose a modified Haddon matrix for CAVs (Table 9) to provide insights into road safety studies involving CAVs.

There is still a great deal of work to be done before fully automated driving (level 5) is achieved. For example, it is expected to be preceded by highly automated driving (level 4) being introduced to roads in the next 10 to 20 years, and drivers will still be needed to take control of (take over) vehicles swiftly when automatic-driving systems fail, or traffic conditions are encountered which they cannot handle. Therefore, research on CAV alert and backup systems, and training for drivers to take over in challenging situations, are necessary. Before CAVs completely replace conventional vehicles, a mix of the two on roads will be a great safety issue; therefore, increasing market penetration of CAVs, and especially enhancing public trust and acceptance of them, as well as modifying driver behavior appropriately (for example, teaching how CAVs and conventional vehicles should interact), are important to explore. In addition, CAVs should not only be able to perceive other road users (especially cyclists and pedestrians), they should also be able to identify their gestures and even predict their behaviors in order to make better-informed decisions and reduce risks.

It should be noted that the results of this study are dynamic, and that newer papers could lead to new topics. Therefore, for future work, we suggest a periodic update of this study using new bibliometric indicators (Tu and Seng, 2012; Jarić et al., 2014) and criteria (Wang, 2018) to better detect emerging research topics in *AA&P*.

Author Statement

Xin Zou: Develop the concept and methodology, collect data, conduct analysis and write the manuscript. **Hai L. Vu**: Discuss and contribute to the concept development, discuss results, review & edit the manuscript. **Helai Huang**: Discuss and contribute to the concept development, discuss results, review & edit the manuscript.

Appendix A

Table A1
JCR Abbreviations.

JCR Abbreviation	Title	IF (2018)	Categories
Accident Anal Prev	Accident Analysis & Prevention	3.058	Ergonomics Public, environmental & occupational health Interdisciplinary social sciences Transportation
Am J Public Health	American Journal of Public Health	5.381	Public, environmental & occupational health
Anal Methods Accid R	Analytic Methods in Accident Research	9.333	Public, environmental & occupational health Transportation
Appl Ergon	Applied Ergonomics	2.610	Industrial engineering Ergonomics Applied psychology
Biometrika	Biometrika	1.641	Biology Mathematical & computational biology Statistics & probability
Ergonomics	Ergonomics	2.181	Industrial engineering Ergonomics Psychology Applied psychology
Hum Factors	Human Factors	2.649	Behavioral sciences Industrial engineering Ergonomics Psychology Applied psychology
IEEE T Intell Transp	IEEE Transactions on Intelligent Transportation Systems	5.744	Civil engineering Electrical & electronic engineering Transportation science & technology
Injury	Injury	1.834	Critical care medicine Emergency medicine Orthopedics Surgery
Injury Prev	Injury Prevention	2.987	Public, environmental & occupational health
Int J Env Res Pub He	International Journal of Environmental Research and Public Health	2.468	Environmental sciences Public, environmental & occupational health
Int J Inj Control SA	International Journal of Injury Control and Safety Promotion	0.870	Public, environmental & occupational health
J Adv Transport	Journal of Advanced Transportation	1.983	Civil engineering Transportation science & technology
J Am Stat Assoc	Journal of the American Statistical Association	3.412	Statistics & probability
J Appl Psychol	Journal of Applied Psychology	5.067	Management Applied psychology
J Safety Res	Journal of Safety Research	2.401	Ergonomics Public, environmental & occupational health Interdisciplinary social sciences Transportation
J Sleep Res	Journal of Sleep Research	3.432	Clinical neurology Neurosciences
J Transp Eng	Journal of Transportation Engineering	1.520	Civil engineering Transportation Transportation science & technology
J Transp Eng A-Syst	Journal of Transportation Engineering, Part A: Systems	0.641	Civil engineering Transportation science & technology
J Transp Health	Journal of Transport & Health	2.583	Public, environmental & occupational health Transportation
J Transp Saf Secur	Journal of Transportation Safety & Security	1.191	Transportation
Jama-J Am Med Assoc	JAMA	51.273	Medicine, general & internal
Pers Indiv Differ	Personality and Individual Differences	1.997	Social psychology
PLOS ONE	PLOS ONE	2.776	Multidisciplinary Sciences
Psychol Bull	Psychological Bulletin	16.405	Psychology Multidisciplinary psychology
Safety Sci	Safety Science	3.619	Industrial engineering Operations research & management science
Sleep	Sleep	4.571	Clinical neurology Neurosciences
Sustainability-Basel	Sustainability	2.592	Environmental sciences Environmental studies Green & sustainable science & technology
Traffic Inj Prev	Traffic Injury Prevention	1.465	Public, environmental & occupational health Transportation
Transport Res A-Pol	Transportation Research Part A: Policy and Practice	3.693	Economics Transportation Transportation science & technology
Transport Res C-Emer	Transportation Research Part C: Emerging Technologies	5.775	Transportation science & technology

(*continued on next page*)

Table A1 (*continued*)

JCR Abbreviation	Title	IF (2018)	Categories
Transport Res F-Traf	Transportation Research Part F: Traffic Psychology and Behaviour	2.360	Applied psychology Transportation
Transport Res Rec	Transportation Research Record	0.748	Civil engineering Transportation science & technology
Transportmetrica A	Transportmetrica A: Transport Science	1.988	Transportation Transportation science & technology
J Pers Soc Psychol	Journal of Personality and Social Psychology	5.919	Social psychology

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