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The history of road safety research: A quantitative approach ☆

Marjan P. Hagenzieker [a,b,*], Jacques J.F. Commandeur [c,a], Frits D. Bijleveld [a,c]

[a] SWOV Institute for Road Safety Research, PO Box 93113, 2509 AC The Hague, The Netherlands
[b] Transport and Planning Department, Faculty of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands
[c] VU University Amsterdam, Department of Econometrics and Operations Research, Faculty of Economics and Business Administration, Amsterdam, The Netherlands

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ABSTRACT

In this paper we provide a global description, in quantitative terms, of the developments in road safety research from the early 1900s until 2010. To this end, electronic databases have been searched and papers matching search criteria were selected for analysis. Word and co-word frequencies of key-words in all the titles and abstracts of these publications were collected and analysed. In this study, we explored the possibility to identify historical trends in road safety research topics. Furthermore we explored whether the important paradigms concerning the history of road safety research as presented in the literature can be confirmed on quantitative grounds. It is concluded that the first results are promising: varying trends over time could be identified in the selected topics, which are generally in line with the different road safety paradigms. Finally, a number of limitations of the present study are listed, including the incompleteness of the currently used dataset.

1. Introduction

Over time, a number of authors have provided overviews of road safety research. However, these reviews generally focussed on either a limited time period, or on specific areas of interest. None of these covered the history of road safety research in a comprehensive and quantitative way.

Early reviews of road safety and traffic research are provided by Glanville (1955) and Haight (1964). Glanville described the increase in numbers of vehicles and an increasing traffic flow, accompanied by a growth of road casualties between 1910 and 1953, and summarized several lines of research in the area of speeds and stopping times at intersections, pedestrian crossings, motorcycle helmets, and slippery roads. Haight (1964) compiled an annotated bibliography of scientific research in road traffic and safety, containing about 250 publications on road safety published between 1915 and 1964 on various topics but with a focus on mathematical modeling and methodologically and statistically oriented papers. Finally, Mom (2007) has looked into road safety issues that had been topics in PIARC (Permanent International Association of Road Congresses) conferences in the period 1908–1938.

The more general history of transport has been the topic of a number of reviews published during the past ten years. These include various transportation modes and automobility (Armstrong, 1998; Mom, 2003), but none of these overviews included road safety issues or the development of road safety research.

In OECD (1997, pp. 90–92) it is mentioned that "a review of past developments reveals that road safety work has mainly been practical in nature. Indeed, the need for theories, models and research methodologies originated from practice, where

☆ Editor's Note: This paper was invited and peer-reviewed for a special section on History of Traffic Psychology. The special section included a wide range of manuscript styles, from those typical of this journal to other styles just as important for sharing the discipline's history. Authors contributed reasoned viewpoints from experience and literature on where the discipline has come from and where it may be heading, to an investigation of trends and topics in the discipline since the early 20th century.

* Corresponding author at: SWOV Institute for Road Safety Research, The Hague, The Netherlands. Tel.: +31 703173333.
E-mail address: Marjan.Hagenzieker@swov.nl (M.P. Hagenzieker).

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the value of systematic knowledge is increasingly recognized. However, it is only relatively recently that systematic research based on theories and models has reached a recognized status in road safety work. (...) Historical perspectives can open a vision for the future. (...) Road safety research is now moving into an increasingly scientific and cross-disciplinary phase." Table 1 is inspired by and a condensed selection of a table in this OECD report providing an overview of the paradigms that were considered important in successive time periods of road safety research.

As the table indicates, during the early days of motorized transportation accidents were seen as a result of bad luck, and research was focused on describing 'what happened' and on collecting basic statistics. When the number of accidents started to increase the view that a small number of drivers could be responsible for the majority of accidents arose, and the term 'accident proneness' became in vogue (Shaw & Sichel, 1971). The term was introduced by Farmer (1925) and originates from the occupational safety field (see Swuste, van Gulijk, & Zwaard (2010) for a historical overview of dominant views and theories in the occupational safety literature). Research focussed on finding the characteristics of such accident prone drivers (and who were to blame for causing accidents) and a search for psychological testing as a predictor of accident prone drivers started. See Forbes (1922) for a very early example of this type of research. Solutions were sought in legislation and enforcement, punishment or (re-)education.

In the next period from roughly 1950 until 1970 the more dominant view can be characterized as looking for *the* cause of accidents. One cause per accident is postulated, either the road user, or the vehicle, or the road, and solutions were sought in a choice from the three E's: Engineering, Education, and Enforcement. In the 1960s, 1970s and 1980s more emphasis was put on technical improvements of vehicles and roads. As indicated in Table 1, this period is characterized by a multi-causal approach: it is not a single cause but a combination of factors that contribute to the occurrence of an accident. During this period the so-called Haddon Matrix (Haddon, 1972) was introduced, showing multiple factors and stages of the accident.

In more recent years crashes are viewed as the result of the integral road system. The view that the road system should be adapted to human capabilities and limitations becomes a more and more commonly recognized idea. Hakkert and Gitelman (this issue) characterizes the period from 2000 onwards by a better implementation of existing policies and the systems management perspective such as 'Sustainable safety' in the Netherlands (Wegman, Aarts, & Bax, 2008) and Vision Zero in Sweden (Tingvall & Haworth, 1999). Kimber (2003) points at the notion that the term 'system' replaces 'driver' for most failures in more recent thinking: the driver-vehicle–road system.

A similar time line as the one presented by OECD is presented by Elvik, Høye, Vaa, and Sørensen (2009, p. 88). They discuss five partly overlapping periods in which different accident theories are prominent, and add behavioral theory as characteristic for the most recent years – situated after systems theory: "During the last 15–20 years, it has become apparent, however, that not even systems theory can provide a fully satisfactory solution to the road accident problem". An example of behavioral theory mentioned by Elvik et al. (2009) is Wilde's risk homeostasis theory (Wilde, 1982), which figures prominently among the various behavioral accident theories that have been proposed after 1980.

These paradigms have only rarely been explored, and even then mostly at an anecdotal or qualitative level. Much anecdotal information is available of various developments in the field of road safety research. In addition, a number of narrative reviews are available on specialized topics. For example, some reviews describe developments from a human factors or psychological perspective (Barjonet, 1997; Haight, 2001; Lee, 2008; Rothengatter, 1997; Sivak, 1987), others review the history of vehicle design as a countermeasure to reduce occupant deaths and injuries (O'Neill, 2009; Wallis & Greaves, 2002), and still others focus on the development of road engineering and infrastructure (Bayliss, 2009; Proctor & Crowley, 2003). A number of reviews are restricted to specific countries; examples are Andreassen (1990, Australia), Sabey (1991, Great Britain), and Blasco (1994, Spain). Bax (2011) recently provided a historical institutional analysis of road safety policy and knowledge for the Netherlands. In the medical field reviews have been published for example focussing on the developments in research on alcohol and traffic safety (Jones, 2009, 2011; Luckin, 2010) and head injuries (Maartens, Wills, & Adams, 2002). Yet another type of review was provided by Waller (1994), who described the development of injury prevention and control activities since about 1940 from a more personal perspective. None of these publications, however, cover the history of road safety research in a comprehensive and quantitative manner.

The current explorative study investigates whether it is possible to describe developments in this field over time using a quantitative approach. Such a quantitative approach – also referred to as scientometrics or bibliometrics – refers to the study of quantitative aspects of information and scientific publications. A set of methods is available, such as content analysis and citation analysis as well as various statistical techniques (see Bar-Ilan (2008) and Zitt & Bassecoulard (2008), for general overviews). Such a quantitative approach has not yet been applied to the field of road safety. If it is possible to identify

Table 1
Time periods and their characteristic road safety paradigms, adapted from OECD (1997).

	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

historical developments using this approach, we might also use these results over time to investigate possible future trends or scenarios in road safety research.

In sum, in this paper we investigate whether it is possible to identify historical trends in research topics and whether road safety paradigms that have been identified in a qualitative form can be confirmed quantitatively. This was done by the analysis of keywords, and their use in titles and abstracts in journal articles written in English in the area of road safety research that were found in two electronic databases and were published in the period 1900–2010. Based on the paradigms displayed in Table 1 we expect to observe differential trends over time in the occurrence of relevant keywords for a selection of topics.

2. Data collection and analysis

In order to try and obtain a collection of all peer reviewed scientific papers concerned with road safety research, we started off by consulting the SCOPUS database of Elsevier (www.scopus.com). We searched for those records in the database whose "Title", "Abstract" and "Keyword" fields contained words that we considered relevant to road safety research. Based on a trial and error approach, and on our expert knowledge, we ended up with a list of keywords that seemed to select and cover the vast majority of scientific papers relevant to the field. Search terms included, e.g., "road safety", "traffic safety", "driver*", "driving", and various combinations with "accident*" or "crash", "car*", "automobile*", "auto", "vehicle*", "road user*", "pedestrian*", "bicycle*", "motorcycle*", "speed*". The asterisks after search terms are used as "wild cards" that indicate one or more unspecified characters.

At the same time, we discovered that papers collected with this procedure also included research that is actually irrelevant for the purpose of this study. As an example, we found that – as a result of the search keyword "bicycle" – papers were included discussing the effects of bicycle exercise for patients suffering from coronary or vascular diseases. Another example is that articles were sometimes included that reported on maritime or aircraft safety. Inspection of these irrelevant papers suggested new keywords that we could use to exclude papers from our search (in the former example, the exclusion keywords were "cardiology", "coronary disease", and "ergometer"). Combining the thus obtained in- and exclusion criteria, and also excluding records that were "Short Notes" or "Letters to the Editor", we ended up with a first selection of 26,519 articles from the SCOPUS database covering in principle both the oldest and most recent articles in the database, which was from 1900 until 2010.

Using these very same in- and exclusion criteria we then also consulted the ISI Web of Science database of Thomson Reuters (www.wokinfo.com) using its "Topic" and "Title" record fields. The two databases do not necessarily contain the same journal articles. We found quite some overlap in the selection of papers obtained from the two databases, an important difference however being that older articles on road safety research are better represented in the ISI Web of Science database than in the SCOPUS database. Considering our interest in historical changes in road safety research, we therefore decided to include only the papers selected from the ISI Web of Science database published before 1971 to our final dataset of all relevant scientific articles published between 1900 and 2010 and dedicated to the topic of road safety research. This resulted in a total of 651 articles from the ISI Web of Science database. Closer inspection of these combined 26,519 (SCOPUS) and 651 (ISI Web of Science) articles (making up a total of 27,170) revealed that 581 articles were not relevant, and that 53 articles had an unclear or unknown publication year; these were excluded. The final dataset therefore contained (27,170 − 581 − 53=) 26,536 scientific articles relevant to the topic of our research. Both databases were searched in April 2011.

We then made an inventory of all the distinct keywords that are mentioned in the "Keyword" field of these 26,536 articles, and found a grand total of 62,629 distinct keywords. Obviously, this number is completely unmanageable, and we therefore reduced these 62,629 keywords to a concise subset of only 18 sets of keywords based on the following three criteria:

- Synonyms, and singulars and plurals, should be treated as identical (e.g., automobile (singular) equals automobiles (plural), equals car (singular) equals cars (plural)).
- Keyword frequency of occurrence in the papers should make the top of this frequency list.
- In terms of content, each keyword set should make sense in light of the paradigms presented in Table 1.

The resulting 18 sets of keywords are listed in Table 4 of Appendix A.

As a next step, we checked for each of the 18 sets of keywords if, and if so, in how many of the 26,536 papers in our database this set of keywords occurred at least once. If it occurred at least once in the keyword, title and/or abstract field of a paper, this was considered a 'hit' and scored as a '1'; if it did not occur at all in a paper, this was considered a 'miss', and scored as a '0'. Note that this means that multiple 'hits' of a keyword set in one and the same paper is still scored as a single '1'.

During this process care was taken to ensure that combinations of keywords were only scored as a 'hit' when they were located side by side in a natural unit (e.g. the title or a sentence in the abstract) of the paper. As an example, consider the keyword combination "driver behavior" in keyword set number 1 shown in Table 4 of Appendix A. We made sure that these two keywords would only result in a 'hit' when found side by side within one and the same sentence of the abstract of the paper. When one sentence in the abstract happened to end with the word "driver", and the next sentence happened to start with the word "behavior", for example, then this was coded as a 'miss'.

These keyword counts were not only performed for each separate year of the time period 1900–2010, but also for the same data aggregated over time. The time aggregations that we used are shown in Table 2. They have the effect of smoothing out some of the uncertainty and therefore volatility contained in yearly publication data, especially for small counts. This also explains why we aggregated over longer time periods in the years 1900–1950: in these years the numbers of published articles were particularly small.

Letting f_{ti} denote the frequency of the number of keywords observed for set i ($i = 1, \ldots, 18$) in year or time period t, and letting n_t denote the total number of articles on road safety research published in year or time period t, we then computed the percentage p_{ti} of road safety research articles devoted to that particular set of keywords in year or time period t with

$$p_{ti} = 100\left(\frac{f_{ti}}{n_t}\right), \tag{1}$$

where $t = 1900, \ldots, 2010$ for yearly data, and $t = 1910, \ldots, 2007.5$ for aggregated data (see the labels in Table 2). The analysis finally consisted in obtaining graphs of the time series data for each of the 18 keyword sets defined in Appendix A obtained with formula (1).

3. Results

In general, the total number of journal articles dedicated to the topic of road safety research has increased exponentially over the years, as is shown in Fig. 1. In the early years (1900–1960) the searched databases contain only up to around 40 articles per year, and this number increased gradually to around 300–400 per year in the early 1990s. From then on an explosive increase can be seen, the number of journal articles on road safety research reaching a total of more than 2000 in 2010.

Roughly 50% of all articles fall in the SCOPUS subject areas of 'Medicine' (13,461) and 'Engineering' (12,443), and about 30% in the combined subject areas of 'Social sciences' and 'Psychology' (8013). Many articles have a combination of two or more subject areas.

Articles on road safety research are published in a large variety of journals. In Table 3 we present those journals in our database that published more than one hundred of such articles over the period of study. As the table indicates the large majority of these articles appear in the journal Accident Analysis and Prevention. Since 1969, the year that this journal was founded, over 3000 articles have been published on road safety. All other journals publish considerably less articles on road safety research. The journal Traffic Injury Prevention is third on this list, but it is a relatively new journal that only started publishing in 2002. Some other journals also started relatively recently, e.g., Safety Science (since 1991), the International Journal of Crashworthiness (since 1996), and Transportation Research Part F (since 1998). In road safety research many research backgrounds and disciplines are involved, as is witnessed by the journal titles shown in Table 3. It contains some medical and public health journals, some journals on road, traffic or vehicle engineering, as well as journals on psychological and behavioral research.

After presenting these very general aspects of our dataset we now focus on the observed developments in the following nine much more specific areas of road safety research:

1. Driver, vehicle, road, and system.
2. Policy and costs.
3. Law & enforcement, and education.
4. Speed.
5. Accident-prone drivers.
6. Accidents and crashes.

Table 2
Time aggregations used, and their labels.

Time period	Label
1900–1919	1910
1920–1950	1935
1951–1955	1952.5
1956–1960	1957.5
1961–1965	1962.5
1966–1970	1967.5
1971–1975	1972.5
1976–1980	1977.5
1981–1985	1982.5
1986–1990	1987.5
1991–1995	1992.5
1996–2000	1997.5
2001–2005	2002.5
2006–2010	2007.5

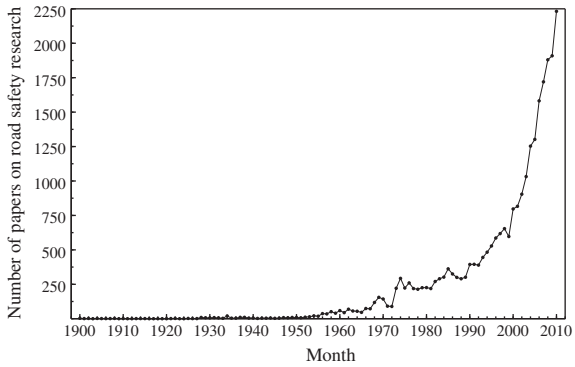

Fig. 1. Annual number of journal articles on road safety research in the period 1900–2010.

Table 3
Journals with more than 100 scientific articles on road safety in our dataset; frequencies and percentage of total number in dataset (n = 26,536) are shown.

	Journal	n	%
1	Accident Analysis and Prevention (since 1969)	3141	18.5
2	Journal of Safety Research (since 1969)	426	1.8
3	Traffic Injury Prevention (since 2002)	305	1.4
4	Journal of Trauma - Injury, Infection and Critical Care (since 1995)	296	1.1
5	Ergonomics (since 1958)	221	0.8
6	British Medical Journal	204	0.7
7	Safety Science (since 1991; its predecessor was the Journal of Occupational Accidents)	184	0.7
8	Human Factors (since 1968)	182	0.7
9	Transportation Research Record (since 1974)	182	0.7
10	Journal of Traffic Medicine (since 1975)	153	0.6
11	ITE Journal (Institute of Transportation Engineers) (since 1983)	151	0.6
12	Transportation Research Part F: Traffic Psychology and Behavior (since 1998)	144	0.5
13	International Journal of Crashworthiness (since 1996)	140	0.5
14	Pediatrics (since 1963)	132	0.5
15	Journal of the American Medical Association (129)	129	0.5
16	Journal of Trauma (since 1965)	122	0.5
17	Journal of Transportation Engineering (since 1983)	120	0.5
18	Traffic Engineering and Control (since 1974)	117	0.4
19	Annals of Emergency Medicine (since 1980)	116	0.4
20	Injury Prevention (since 1995)	113	0.4
21	American Journal of Public Health (since 1943)	105	0.4

7. Attention, distraction, and Advanced Driver Assistance (ADAS)/Intelligent Transport Systems (ITS).
8. Older drivers.
9. Alcohol and drugs.

We selected these specific nine topics for discussion, either because they were associated with high key-word frequencies, or because they allowed us to find empirical evidence for the paradigm changes shown in Table 1, or for both reasons. In one case (alcohol), we decided to show the results because it is an example where our quantitative approach does not seem to work, i.e., does not lead to understandable results.

In the following sections, we first present the results of our analyses in quantitative terms, and also indicate if and how these results can be interpreted in the light of the various road safety paradigms presented in Table 1. Overall trends and findings of our study will be discussed in the final Section 4 of this article.

3.1. Driver–vehicle–road–system

In Fig. 2 the percentages of articles containing keywords from the keyword-sets "driver", "vehicle", "road", and "system" in the article titles are depicted for each five year period in the dataset. The upper left panel of this figure shows that around 15% of all articles in the period 2006–2010 had keywords from the "driver" keyword-set in their titles, which amounted to a total of 1,404 articles in this period. Similarly, the bottom right panel indicates that the term "system" does not show up in article titles in our dataset before the period 1966–1970; in the most recent period considered, 2006–2010, a total of 819 articles contained "system" in their titles, which amounts to almost 9% of all articles in this particular period.

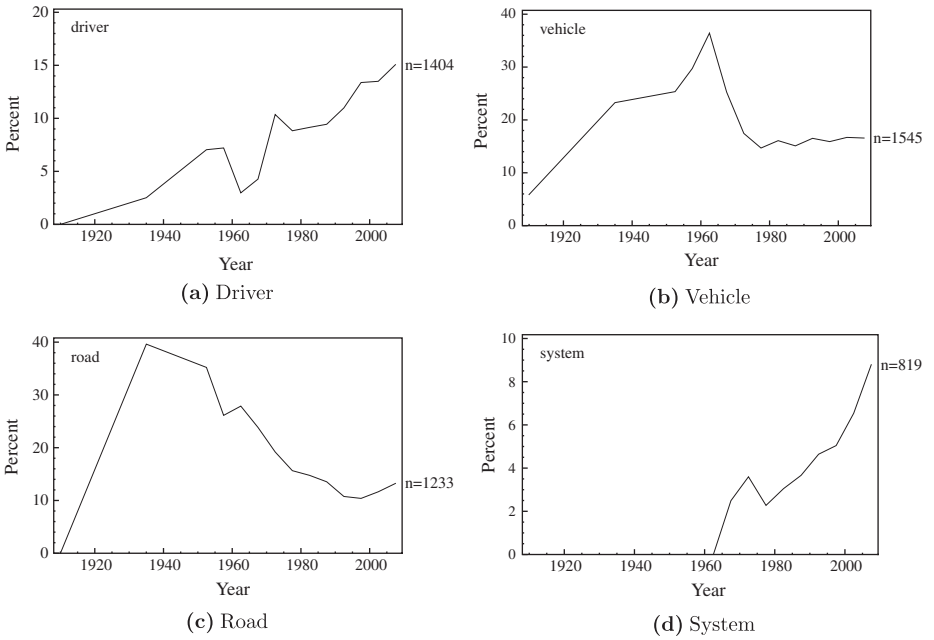

Fig. 2. Percentages of keywords "driver", "vehicle", "road", and "system" in article title.

Except for a dip in the 1960s, Fig. 2 shows a clear upward trend for articles that have "driver" in the title. This is in line with the noted trends in road safety paradigms (see Table 1), and the rise of psychology and driver behavior models over time (see Elvik et al., 2009). In this respect, Rothengatter (1997, p. 224) has pointed out that: "The study of road user behavior has not traditionally been the domain of psychologists – who tended to focus on driver selection (Blasco, 1994) – but was often carried out in the framework of engineering or ergonomics – in fact, one of the most recent volumes on road user behavior and traffic safety was written by a physicist (Evans, 1991, 2004). Only in recent years has psychology become more involved in this field of study, which is now called traffic psychology". Within the rise of traffic psychology over time Barjonet (1997) distinguishes three stages of development, from the beginning of the century (the 'psychometrics' stage, selection of drivers), to the 'psychology of road users', to more recently a focus on European research projects and the 'technical attendance' to car industry. On the other hand, Lee (2008) concludes – based on articles on driving safety published in the journal Human Factors in the past 50 years – that to a large extent, current and past driving research has explored similar themes and concepts. Many articles published in the first 25 years focused on issues such as driver impairment, individual differences, and perceptual limits. Articles published in this journal during the past 25 years address similar issues but also point toward the impact of vehicle technology on driver behavior.

Articles having "vehicle" or combinations with "vehicle" in the title show an upward trend until 1960s, then a steep decrease, levelling off to around 1500 papers in the most recent period (see Fig. 2). This is around the same amount as for "drivers". A look at the articles included in the dataset indicates that themes in vehicle safety research include the development of vehicle safety standards, safety belts, airbags, later – in the 1970s – followed by research using crash tests with dummies investigating the impacts and providing safety ratings for new vehicles for consumers. A major theme from the 1960s up to roughly 1990 is research on crashworthiness of vehicles.

The term "roads" in the title shows an increase in the early years until the 1940s followed by a continuous decrease (see Fig. 2). However, still over 1200 papers contain the term "road" in the title – only slightly less than for drivers and vehicles in the most recent period 2006–2010. Typical road engineering measures over the years include the development of standards and road infrastructure guidelines, design speed, traffic calming measures, safety audits, and the use of roundabouts and cycle tracks and lanes as safety measures (Elvik et al., 2009; Lamm, Psarianos, & Mailaender, 1999). In more recent years the EuroRAP approach is an example of a consumer-based approach to road safety where drivers are provided with information on the relative safety of routes (Proctor & Crowley, 2003).

The term "system" only first appeared around 1965–1970 and shows an increase since then, with around 800 publications in the period 2006–2010 (see Fig. 2). The start of the increase appears to coincide with papers on the application of systems analysis to road safety and Haddon's publication in 1972 introducing a matrix showing multiple factors and stages of the accident. The further steep increase in publications starting in the 1990s onwards resembles the introduction of concepts of self-explaining roads and sustainable safety in the Netherlands (see Theeuwes & Godthelp, 1995; Wegman et al., 2008), Vision Zero in Sweden (Tingvall & Haworth, 1999), and later on followed by the 'safe system approach' in Australia

(Corben, Logan, Fanciulli, Farley, & Cameron, 2010). These approaches share the same underlying concepts, but differ in elaboration and focus.

3.2. Costs and policy

Both "policy" and "costs" are emerging topics from the 1970–1980s onwards. In recent years (period 2006–2010) 4–8% of all published articles on road safety have keyword-sets "policy" or "costs" in the title and/or abstract, see Fig. 3. Before 1970 these terms are hardly used in articles on road safety research in the database; early examples are provided by Reynolds (1956) and Baker (1973). This trend is in line with the overview of paradigms over the years (see Table 1), with policy and costs as topics characterizing the most recent period.

3.3. Enforcement and education

Fig. 4 shows a steep increase from 1970 onwards with a peak in the period 1980–2000 with about 15% of all articles in these years containing enforcement or law in either title and or abstract. Since 2000 a decrease is notable. The research literature on traffic law enforcement encompasses a large variety of areas such as alcohol, speed, seat belts and signalized intersections (see, e.g., Zaal, 1994). Fig. 4 shows a somewhat erratic pattern of the number of articles on education and training in title and or abstract but generally indicating an upward trend over the years from 1950–1960 onwards. These trends are in line with (the choice of one of) the three E's in that period and the already earlier popularity of education as a theme (see Table 1). In recent years (2006–2010) about 8% of all articles contain keyword set "education" in title and/or abstract, and around 10% the keyword set "enforcement".

3.4. Speed

The theme speed has been an important topic in road safety research in all periods of time (see Fig. 5). Fig. 5 shows an ever increasing percentage of articles on this topic; from around 7.5% in the 1980s to over 15% in 2010 of all articles in our dataset. An early example of the consequences of high driving speeds is provided by Anon (1938). A large variety of topics associated with speed are included in research articles in this keyword-set, such as speed as a road accident factor (e.g., Wilmot & Khanal, 1999), speed limits (e.g., Kunna, 1980), speed reduction measures (e.g., Zaidel, Hakkert, & Pistiner, 1992), and ISA (e.g., Carsten & Tate, 2005). Literature reviews on the topic of speed and road safety clearly illustrate the importance of speed in road safety research; it encompasses all types of research and includes driver-, vehicle- as well as road-related research (see, e.g., Aarts & van Schagen, 2006; Anon, 1938; Lamm et al., 1999; McCarthy, 2001; Zaidel et al., 1992).

3.5. Accident-prone drivers

Fig. 6 shows that accident proneness is a recurring topic over the years. This finding is in line with literature pointing at the popularity of the theory on accident prone drivers in the early years (see, e.g., Burnham, 2009), and later became heavily criticized, and lost popularity: "Accident proneness theory failed because it was found that unequal accident liability was, in reality, a "club" with rapidly changing membership. In addition, attempts to find a clearly definable accident-prone personality proved fruitless" (Reason, 1990, pp. 198–199). However, it continues to return in the literature as an attractive idea (see for a recent example Herzberg, 2009; Visser, Pijl, Stolk, Neeleman, & Rosmalen, 2007). Unfortunately, our database only contains a very small number of articles on accident proneness (a total of 89 over all years, with 21 in 2006–2010). The problem is that particularly the (very) early years are underrepresented in electronic scientific literature databases, while these years have probably been the most popular period for this particular topic.

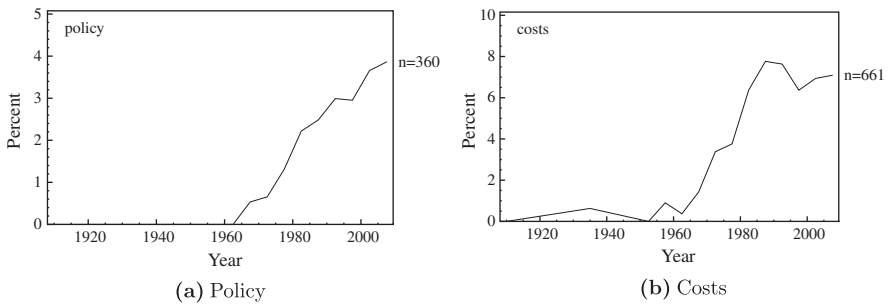

Fig. 3. Percentages of keywords "policy" and "costs" in article title or abstract.

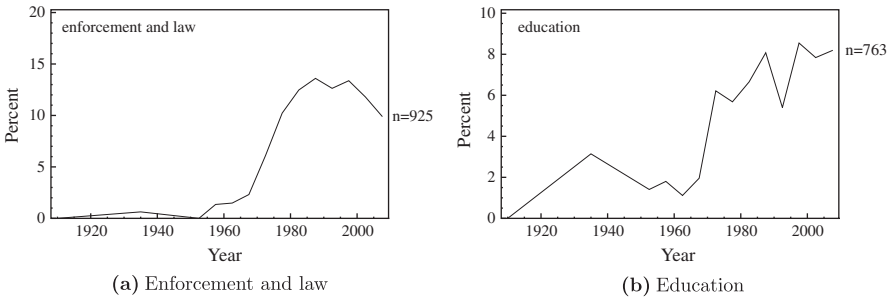

Fig. 4. Percentages of keywords "enforcement and law" and "education" in article title or abstract.

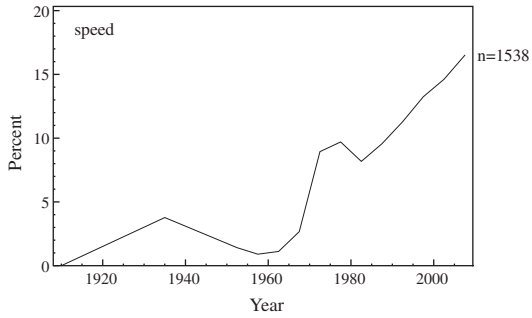

Fig. 5. Percentages of keyword "speed" in article title or abstract.

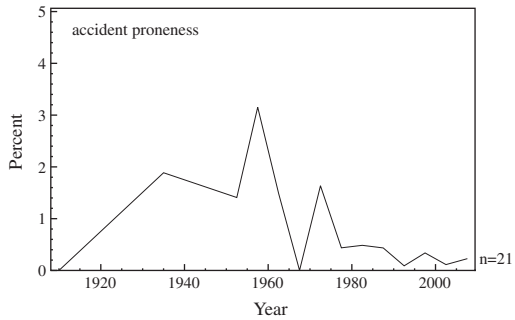

Fig. 6. Percentages of keyword "accident proneness" in article title or abstract.

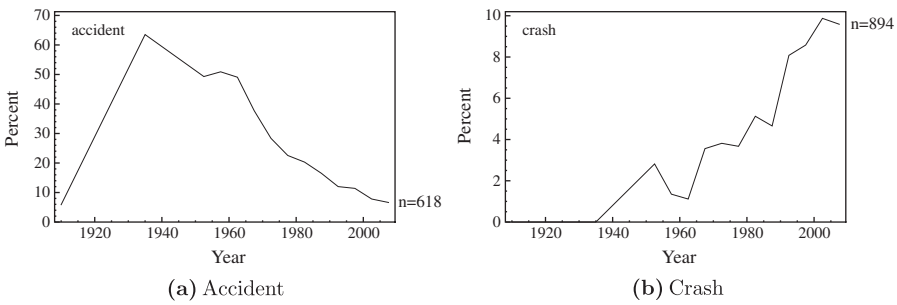

Fig. 7. Percentages of keywords "accident" and "crash" in article title.

3.6. Accidents and crashes

Fig. 7 indicates a decreasing use of "accident" since the 1940–1950s. At the same time an increasing use of the term "crash" is seen. "Crash" is now used more often than "accident". Still, the term "accident" is used in more than 600 article titles in the period 2006–2010. The different trends in the usage of these two specific terms is more than a linguistic issue, and is attributable to the development of road safety paradigms. The discussion on the use of the terms crash or accident stems from a medical and injury prevention background. Some researchers and organizations favor the term crash over accident, because the former emphasizes that such events can be avoided, whereas "accident" imply random events. This is why the *British Medical Journal* decided to ban the word accident about 20 years ago. In an editorial, Evans, 1993; cited in Davis & Pless (2001)) explained why "motor vehicle crash" is an appropriate expression but "motor vehicle accident" is not: "The word crash indicates in a simple factual way what is observed, while accident seems to suggest in addition a general explanation of why it occurred without any evidence to support such an explanation." Evans also argued that "accident" is inappropriate in reference to medical errors (as in medical accidents) and that "its use in medical settings continues to mislead" (Davis & Pless, 2001, p. 1320). Although the term crash definitely shows a rapid increase in the literature, the term accident is still favored by many researchers and organizations. It is interesting to see that this debate is clearly reflected in our results.

3.7. Attention, distraction, and Advanced Driver Assistance Systems (ADAS)

Fig. 8 shows that the term "distraction" has not been used until the 1970s; "ADAS" and "distraction" are emerging topics, and the number of publications in our database shows a steep increase since the 1990s. The keyword set ADAS (Advanced Drivers Assistance Systems) also includes other ITS (Intelligent Transport Systems) and navigation systems. Recently, distraction has emerged as an important factor in driving safety and the term distraction is often associated with research on mobile phone use (see, e.g., Caird, Willness, Steel, & Scialfa, 2008) and the possible distracting effects of roadside advertising (e.g., Bendak & Al-Saleh, 2010; Crundall, Loon, & Underwood, 2006). In earlier periods the term "attention" is already a notable research item, then mostly related to visual attention and selection processes (see, e.g., Cole & Hughes, 1988).

3.8. Older drivers

The keyword set "older drivers" shows an increasing trend since the late 1970s – early 1980s, and then levels off (see Fig. 9). This clearly reflects a demographic trend as the growing numbers of older people also make up a larger share of the driving population (see, e.g., Sivak & Schoettle, 2012). The overall vulnerability of older road users, fitness to drive, functional limitations, and how to assist the older driver are typical topics of study (Davidse, 2007).

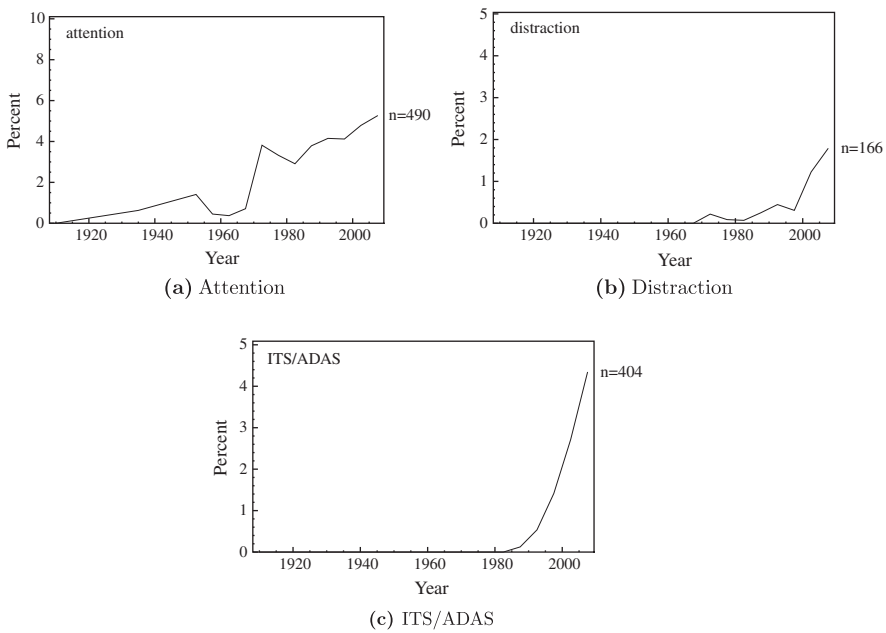

Fig. 8. Percentages of keywords "attention", "distraction", and "ITS/ADAS" in article title or abstract.

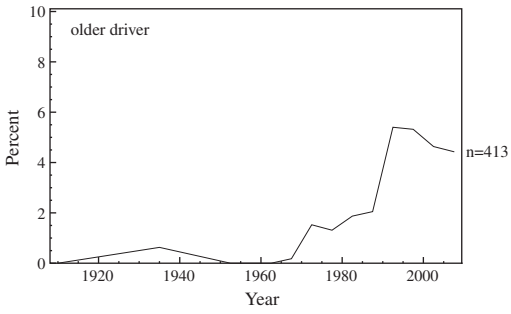

Fig. 9. Percentages of keywords "older driver" in article title or abstract.

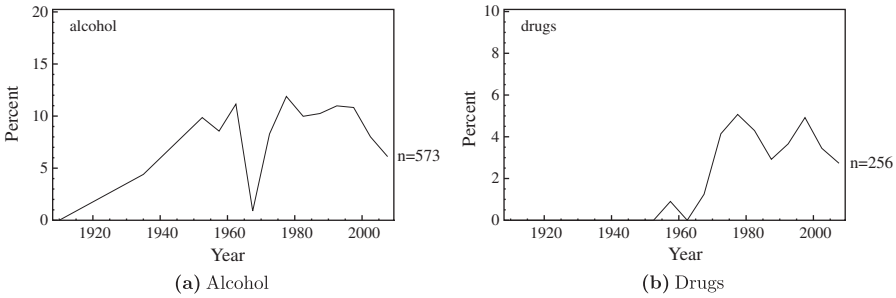

Fig. 10. Percentages of keywords "alcohol" and "drugs" in article title or abstract.

3.9. Alcohol and drugs

Fig. 10 depicts the number of articles on the themes "alcohol" and "drugs". Our dataset contains a sharp dip for the number of articles regarding "alcohol" around 1970 which we cannot explain. Literature reviews, e.g., by Jones (2009, 2011), Luckin (2010), and Mathijssen (2005), do not provide clues as to why such a dip would be present. The theme "drugs" shows a steep increasing trend since the 1970s (see reviews by Brookhuis, this issue; Orriols et al., 2009).

4. Conclusions and discussion

In this explorative study we used a quantitative approach to investigate the developments in the history of road safety research, and this yielded promising first results. Varying trends in the selected research topics were identified, in directions that are mostly consistent with the changes in road safety paradigms presented in the literature.

Road safety is a small field, which is illustrated by the fact that a substantial part of all journal articles on road safety research are published in only one journal. The journal Accident Analysis and Prevention is by far the most frequently published in: nearly 20% of all articles in our database are from this journal. Nevertheless, an explosive increase of published journal articles can be seen during the last 10 years. The annual number of journal articles on road safety research being published is presently over 2000 (in 2010).

Road safety research is also a multidisciplinary field – with origins in medicine, engineering, and social science and psychology, which is illustrated by the fact that road safety research is published in a large variety of journals.

The multidisciplinary nature of road safety research makes searching for relevant documents a difficult process, because of the different use of keywords in various disciplines, journals, and databases. There is not one specific topic or straightforward (set of) search terms that can be used to find the relevant publications we were looking for. In addition, different search criteria are in use for the SCOPUS and ISI Web of Science electronics databases. The results show that the SCOPUS database contains more journal articles on road safety research. On the other hand, the Web of Science contains more early-years papers and more medically oriented papers. In recent years the selections of both databases appear to look more similar.

When we compare the keyword sets in terms of general percentage of occurrence, we see that research on vehicles, roads, drivers, and speed have overall been the most important themes over the years, while the system approach, and themes associated with road safety policy and costs have become more prominent in recent years. Although other – more specific – topics such as older drivers, distraction and ADAS show an increasing occurrence in the literature in recent years, they still make up only a small percentage of the body of research in this field.

The time developments in frequencies of various word combinations in keywords, titles and abstracts are found to have different trends. First, clear *upward trends* are seen for the themes "driver", "system", "policy" and "costs". This is in line with

the noted trends in road safety paradigms (see Table 1) with policy and costs as topics characterizing the most recent period, and with the continuous rise of psychology and driver behavior models over time (see Elvik et al., 2009). Other emerging topics are distraction and ADAS, both showing a steep increase in the number of publications in our database since the 1990s. The number of articles on "older drivers" also displays an increasing trend since the late 1970s–early 1980s, which then stabilizes over time. This clearly reflects a demographic trend as the growing numbers of older people also make up a larger share of the driving population (see, e.g., Davidse, 2007; Sivak & Schoettle, 2012).

On the other hand, the number of articles on the theme "vehicle" shows an upward trend until the 1960s, then a *steep decrease*, and finally levels off to around 1500 papers in the most recent period. Yet another development is noticeable for the term "roads" which first shows an *increase* in the early years until the 1940s followed by a *continuous decrease*.

Finally, the results also show examples of more *erratic patterns* and trends that are more *difficult to interpret*. An example of this are articles on the theme of "education". A somewhat erratic pattern of the number of articles on education is seen although it still seems to show a generally upward trend over the years from 1950–1960 onwards. Such a trend can be viewed as in line with (a choice of one of) the three E's in that period and the already earlier popularity of education as a theme (see Table 1).

An interesting finding is the decreasing use of the term "accident" since the 1940–1950s, accompanied by an increasing use of the term "crash". This reflects more than a mere linguistic issue, and is in line with the development of road safety paradigms. The discussion on the use of the terms crash or accident stems from a medical and injury prevention background. The term crash is often favored over accident because the former emphasizes that such events can be avoided, whereas 'accidents' imply random events. "Crash" is now used more often than "accident". Although the term crash definitely shows a rapid increase in the literature, the term accident is still favored by many researchers and organizations. It is interesting to see that this debate is clearly reflected in our results (see also Loimer & Guamieri, 1996).

A final type of trend is observed for the theme of "accident proneness" which appears to be a recurring topic over the years. This finding is in line with literature pointing at the popularity of the theory on accident prone drivers in the early years (see, e.g. Burnham, 2009), which later became heavily criticized, and lost popularity (Reason, 1990). However, it continues to return in the literature as an attractive idea (see for recent examples Herzberg (2009) and Visser et al. (2007)).

We also notice various limitations to our approach in the identification of historical trends in road safety research. Not all of our findings can be interpreted easily. A possible reason for this is that the dataset that we compiled for the purpose of this explorative study is not complete. Two examples illustrate the incompleteness of the current dataset. One example concerns the number of articles in our database on the theme "alcohol" that displays a sharp dip in the early 1970s (even to zero) which we cannot explain. A likely reason is that the search criteria we used were insufficient to find all the relevant articles in the two electronic databases (SCOPUS and ISI Web of Science) that we have consulted. Furthermore, the current dataset is not suitable to study early trends. This is illustrated by the results on the theme "accident proneness". Although the analysis indicates that this is a recurring topic over the years, the results are not very convincing because they are based on very small numbers. The current dataset contains only small numbers of publications in the first decades of the 20th century, while these have been the most popular period for this particular topic (Burnham, 2009).

A general problem of the type of quantitative analyses we performed is that early years are underrepresented in electronic databases, because computerized literature databases have only been developed since the early 1970s. Another drawback is the fact that research reports are not included in such databases. Unlike peer-reviewed literature gray literature usually cannot be found in mainstream databases (Schöpfel & Farace, 2010). The term gray literature usually refers to scientific or technical output such as technical reports, conference proceedings, and doctoral theses. Road safety research is traditionally more commonly published in technical research reports and conference proceedings than in journals. Also worth mentioning here - and related to the previous points – is that the electronic databases hardly contain articles in other languages than English.

As a follow-up to the present study, we therefore first of all intend to enhance the current dataset by adding search results from other available databases, such as the International Transport Research Documentation (ITRD) and the Transportation Research Information Services (TRIS) database (recently combined into TRID: Transport Research International Database). These two databases also have the advantage of containing a lot more publications in the field of road safety research in general, as well as much more gray literature than SCOPUS and ISI Web of Science. Second, we need to develop more refined and better-tailored search criteria. Third, in a future study it would be interesting to investigate how trends have developed for various research disciplines separately; these might show different patterns over time in the keywords and topics studied. Fourth, we could analyse these time series of keyword frequencies with state space methods, see Durbin and Koopman (2012), Bijleveld (2008), and Commandeur and Koopman (2007), and then obtain estimates of future developments in the specific areas of road safety research that we investigated in this paper.

Finally, the word count analyses themselves could also be further elaborated and refined. In the present study we have investigated changes in frequencies of relatively simple word set combinations in titles and abstracts as derived from keywords. It is also possible to count how often keywords occur *together* in publications. The frequency of co-occurrence of two keywords can interpreted as a measure of similarity between the two keywords, a high frequency of co-occurrence implying that the two corresponding keywords are very similar, or have a lot in common, a low frequency of co-occurrence implying that they are very different, or do not have much in common.

Since frequencies of keyword co-occurrences in the road safety literature can be interpreted as measures of similarity between keywords, multidimensional scaling of all these frequencies can be used to obtain two- or higher-dimensional con-

Table 4
Keywords sets and keywords.

Keyword set	Keyword pattern	Matching keywords
1	Driver∗; Behav∗	Driver; drivers; behavior; behaviorism; behaviors; behavior
2	Vehicle; vehicles; car; cars; automobile∗	Automobile; automobiles; car; cars; vehicle; vehicles
3	Road; roads; roadside; roadsides; roadspace; roadway; roadways	Road; roads; roadside; roadsides; roadspace; roadway; roadways
4	System∗	System; systematization; systemic; systems
5	Policy	Policy
6	Cost∗	Cost; costeffectiveness; costs
7	Police∗; enforcement∗; law; laws; legislation∗	Enforcement; enforcements; police; law; laws; legislation
8	Education∗; training∗; learner∗; instruction∗	Education; instruction; instructions; learner; training
9	Speed; speeding; speeds	Speed; speeding; speeds
10	Prone∗	Proneness
11	Accident; accidents	Accident; accidents
12	Crash; crashes	Crash; crashes
13	Attention∗	Attention
14	Distraction∗	Distraction; distractions
15	Adas∗; intelligent trans∗; telemat∗; driv∗ assist∗ sys∗; nav∗ sys∗; guide∗ sys∗	Adas; intelligent transport; intelligent transportation; telematic; telematics; driver assistance system; driver assistance systems; driver assistant system; driver assistant systems; driver assistent systems; drivers assistant systems; driving assistance system; driving assistance systems; driving assistant system; driving assistant systems; navigation system; navigation systems
16	Old∗ ∗; elder∗ ∗; excluding: old road; old vehicles; elderly care; elderly housing	Elder driver; elder people; elderly driver; elderly drivers; elderly drives; elderly motivation; elderly pedestrians; elderly people; elderly persons; elderly population; elderly subjects; elderly transportation; elderly travel; elderly women; old age; old ages; old drivers; old people; older adult; older adults; older driver; older drivers; older female; older occupants; older pedestrian; older pedestrians; older people; older peoples; older persons; older population; older women; older worker; older workers
17	Alcohol∗; dui; dwi; drink driv∗; drunk∗	Alcohol; alcoholism; alcohols; dui; dwi; drink drive; drink driver; drink drivers; drink driving; drunk; drunkenness
18	Drug∗; psycho∗ substance∗	Drug; drugs; psychoactive substance; psychoactive substances

figurations or "maps" of all the relevant topics in road safety research (see, e.g., Borg & Groenen (2010) for details on multidimensional scaling techniques). In such a configuration or "map" each keyword is represented as a point, and the distance between each pair of points is a function of the similarity between the two corresponding keywords: a small distance indicates that two keywords often occur together, while a large distance reflects that their co-occurrence frequency is very small. The axes of such configurations or "maps" can then be interpreted as important dimensions or latent factors in the evolution of road safety research.

By producing one such map for all historical periods simultaneously, and then allowing the dimensions of this common "map" to have different weights for different periods in time (with a multidimensional scaling technique called INdividual Differences SCALing (INDSCAL), see again Borg & Groenen (2010)), it becomes possible to investigate whether the paradigms in Table 1 are reflected in the different values of the dimension weights assigned to each different time period (see Rikken, Kiers, & Vos (1995), for an application of this approach to the dynamic mapping of the evolution in scientific research concerning the adverse reactions to drugs).

Appendix A

See Table 4.

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