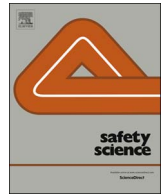




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Review

Bibliometric analysis of safety culture research

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ABSTRACT

The concept of safety culture is characterised by complexity. On the one hand, the concept is challenging content-wise, and on the other hand, is it a multi-dimensional and cross-disciplinary research domain. In this paper, bibliometric analysis has been applied to the field of safety culture to identify fundamental influences and to obtain a structured overview of the characteristics and the developments in this research domain. In total, 1789 publications published between 1900 and 2015 related to safety culture were identified in Web of Science. The 1789 publications cover 4591 authors, 775 journals, 76 countries or territories, and 1866 institutions. Two main research areas can be distinguished in the domain of safety culture: (1) organisational safety culture and (2) health-care and patient safety culture. The latter research area stands in a dominant position in safety culture research nowadays. Key publications are from Guldenmund (2000) and Sexton et al. (2006). Furthermore, 'Safety Science' is the key journal publishing on safety culture research, and the USA, England and China are the countries that dominate the publication production. It can be concluded that there is much collaborative research in the safety culture domain as multi-authored publications make up about three quarters of all publications. Also, safety culture research is characterised by a wide variety of research themes and multidisciplinary. Geographical inequality in the publication output is identified as a point of concern. A movement away from technical aspects towards more human aspects could be detected as a noteworthy change in research focus.

1. Introduction

The amount of scientific literature available on a specific research discipline or research topic is often overwhelming, which makes it challenging for researchers and practitioners to have a structured overview of relevant information (Rodrigues et al., 2014; Zhou et al., 2015). Bibliometric analysis is a technique which makes it possible to provide a macroscopic overview of large amounts of academic literature. Through a quantitative analysis of information on the publication history, the characteristics and the development of scientific output within a specific field of research can be mapped (Jia et al., 2014; Li and Hale, 2016). Bibliometric methods can be used to assess the performance and research patterns of authors, journals, countries and institutes, and can be used to identify and quantify cooperation patterns between them (Li and Zhao, 2015). Influential authors and

publications, and core journals, countries and institutions publishing on a specific topic can be identified. The number of different journals publishing on a specific topic and the subject categories allocated to publications can give an indication on the variety of research themes, and the multidisciplinary character of a research domain. Bibliometrics can reveal the latest advances, research directions and leading topics in a particular field of research (Wang et al., 2014). Bibliometric analysis also allows identification of current gaps in a certain research discipline, both content-wise as well as geographically (Gall et al., 2015). Furthermore, bibliometrics can play a crucial role in the decision-making process related to science. It is widely used to rank applications for academic positions, and to evaluate the performance of journals, countries and institutions. Bibliometric results can also be considered to support policy makers and funding agencies to allocate research funding (Ugolini et al., 2015).

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In this paper, bibliometric analysis has been applied to the field of safety culture research. The research topic of safety culture is a relative new one in terms of academic research. The concept was first used in 1986 in response to the Chernobyl disaster (EU-OSHA, 2011). From then on, an increased attention in the research area of safety culture can be observed. This increase is driven by the fact that, despite improvements over the years, disasters, accidents and incidents continue to persist in organisations, at home, and at all other levels of society. This has led to a continuously growing publication rate regarding safety culture, which makes it difficult to obtain a comprehensive overview on the topic.

This difficulty is enhanced by the complexity of the concept of safety culture. First of all, safety culture is a complicated topic based on its content. Many efforts have been devoted to develop and test models and theories to frame the concept. However, until today, little consensus has been reached on the definition, the cause and the consequences of safety culture (Guldenmund, 2000). Secondly, safety culture is a multidimensional research topic. As previously mentioned, the concept was first used in the nuclear organisational sector. However, the concept of safety culture is not only explored in the context of organisational safety, but is adopted for a wide variety of purposes. In health-care, for instance, safety culture is associated with patient safety, the quality of care and the occurrence of adverse events (Sammer et al., 2010; Weaver et al., 2013). Other contexts in which the concept of safety culture is used are, for example, railway traffic, aviation, road traffic, transportation, food industry, education, and home injuries. Thirdly, the complexity of safety culture is strengthened by the large variety of research disciplines engaging in safety culture research. The concept of safety culture has been studied by, amongst others, engineers, psychologists, sociologists, and anthropologists (Guldenmund, 2000; EU-OSHA, 2011). This cross-disciplinary focus has resulted in very different approaches for exploring and assessing safety culture (EU-OSHA, 2011). The complexity of safety culture and the continuously growing publication rate makes it an optimal topic for bibliometric analysis.

The goal of this descriptive paper is to provide a macroscopic overview on the main characteristics of safety culture publications based on a bibliometric analysis. The information presented in this paper provides a clear picture on the research progress achieved in the domain of safety culture research, and it can assist researchers and practitioners in identifying fundamental influences from authors, journals, countries, institutions, references and research topics.

2. Data and methods

The data for this study were retrieved from Web of Science on December 30, 2015. Web of Science was chosen as search engine because it is the most widely accepted and frequently used database for analysis of scientific publications (Yang et al., 2013). The term “safety culture” was used as search topic. This topic search means that the term “safety culture” is identified in the title, the abstract and/or in the keywords of the publications. Quotation marks have been included in the search term. This tighter condition ensures the robustness of the search results (Liu et al., 2013). The time span was set from 1900 to 2015 included. In Fig. 1, the search method can be found. As can be seen at the bottom of Fig. 1, the date on which the Web of Science database was last updated on the date of the search (i.e. December 30, 2015) was December 28, 2015. If the exact same search strategy is performed on a different date, it can be possible that the results slightly differ. These differences are due to the fact that Web of Science is continuously updated – also retrospective – which can lead to minor changes over time (Liu et al., 2013).

In total, 1789 publications related to safety culture were identified.

All types of publications were included in the search. Looking at the document types, the majority is article ($n = 1128$) and proceedings paper ($n = 344$). The other document types, such as meeting abstracts

and editorial material, are limited in numbers (all less than hundred).

Every publication in Web of Science contains many details, including publication year, authors, addresses of the authors, title, abstract, source journal, subject categories and references. These data of the 1789 publications stored in Web of Science were exported to Excel. Both Excel and IBM SPSS Statistics 23 were used to analyse the following topics: (1) publication output and growth trend, (2) authors and their cooperation, (3) journals publishing on safety culture, (4) geographical and institutional distribution and cooperation, (5) cited analysis, (6) citing and co-citation analysis, (7) subject categories, and (8) terms.

The freely available software program VOSviewer (www.vosviewer.com) (van Eck and Waltman, 2010) was used to analyse and visualise relationships between authors, countries, co-citations and terms. The VOS (Visualization Of Similarities) mapping method was used to calculate and locate each topic in a two-dimensional map in such a way that the distance between two items reflects the similarity or relatedness of the items as accurately as possible. The VOS clustering method was applied to cluster topics into different groups, where each cluster is marked with a different colour (van Eck et al., 2010; Waltman et al., 2010). The interpretation of the visualisations is explained in detail in the results section. In general, the interpretation is as follows: the size of the circles and the font of the label represents the number of occurrence, the colours represent clusters, and the distance between two circles reveals the relatedness and similarity between them (Rizzi et al., 2014; Khalil and Gotway Crawford, 2015). The x-axis and y-axis have no special meaning; the maps may be freely rotated and flipped (Khalil and Gotway Crawford, 2015).

3. Results and discussion

3.1. Publication output and growth trend

The number of peer-reviewed publications is an important indicator to measure the development trend of a scientific research discipline or subject. As displayed in Fig. 2, the number of safety culture publications increased since 1990. There were only eight publications on safety culture in 1991. Until 2005, the publications on the topic remained limited (less than fifty publications each year). From 2006, an increasing number of publications could be observed every year, with exceptions in 2008 and 2010, where a decline could be observed. A peak of publications is reached in 2013 ($n = 225$), after which a declining trend occurs ($n = 191$ in 2014 and $n = 173$ in 2015). The question remains if this declining trend will continue during the following years. A possible explanation for the decline in the number of publications is not straightforward. An explanation can be found in Price’s law which evaluates the overall growth of scientific publications in a specific research domain (Price, 1963). According to this law, the growth of a research domain goes through four phases: (1) a precursors’ phase, where a small body of scientists begins to publish on a new field, (2) the proper exponential growth, where an increasing number of scientists is attracted by the many aspects of the subject that still have to be explored, (3) a consolidation of the body of knowledge and (4) a decrease in the number of publications (Dabi et al., 2016). This last phase reflects the inflection point of maturity where the research domains is saturated, resulting in a significant reduction of publications (Dabi et al., 2016). It is however questionable that this maturity point has already been reached in the domain of safety culture research. After all, this domain is, up to now, characterised by a lack of consensus on the definition, content and consequences of the concept of safety culture.

Looking at the cumulative number of publications in Fig. 2, it can be stated that the importance of safety culture research has increased. It took approximately twenty years (from 1991 until 2011 inclusive) to reach a total of 1000 publications on the topic of safety culture. The following four years (from 2012 until 2015 inclusive), this number

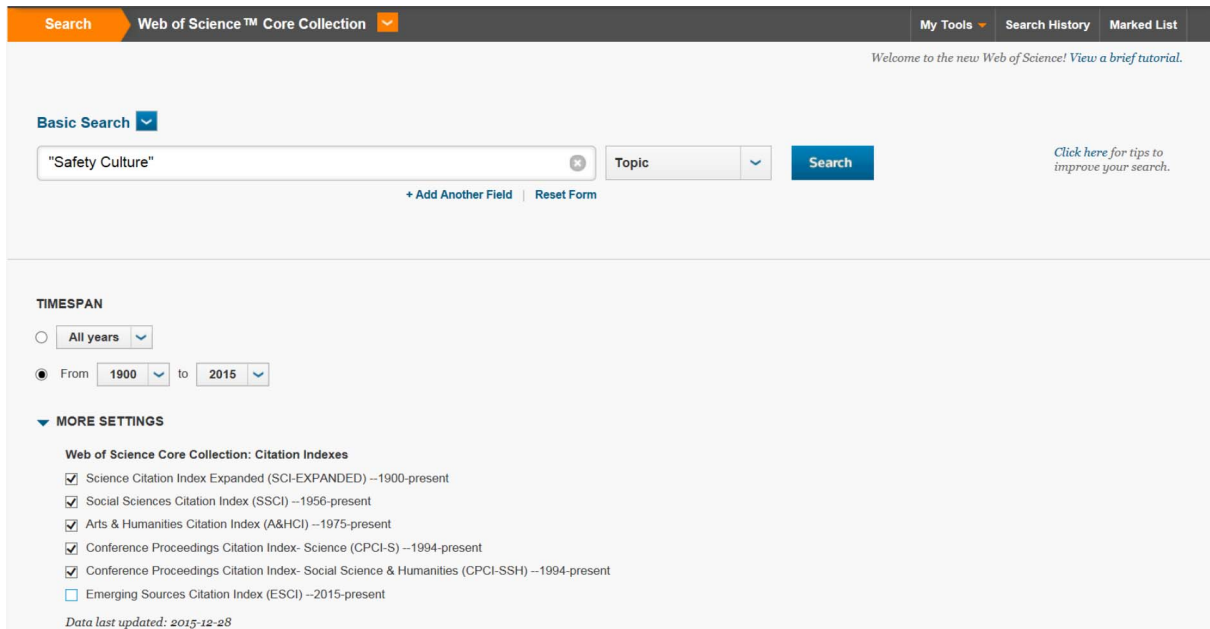


Fig. 1. Search method in Web of Science.

increased to a total of almost 1800 publications. The article from Li and Hale (2016) allows us to compare this increase pattern of safety culture publications with other safety related publications. Fig. 3 shows the cumulative number of safety related publications in six core safety journals from 1991 to 2013 (for more information on these six journals, the reader is referred to the original article from Li and Hale, 2016). Based on the comparison of the cumulative number of safety culture publications (Fig. 2) with the cumulative number of other safety related publications (Fig. 3), it can be stated that the publication output of safety culture research follows an exponential growth, where other safety related publications follow a more linear growth.

3.2. Authors and their cooperation

The 1789 publications were written by a total of 4591 different authors. The largest proportion of the authors (83.6%; n = 3,838/4591) is only credited in one publication on the topic of safety culture. 6.0% (n = 274/4591) is credited in at least three publications, and 0.2% (n = 9/4591) is credited in ten or more publications. It is

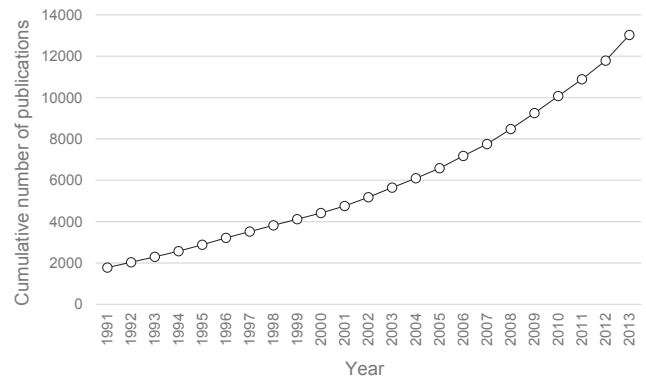


Fig. 3. Cumulative number of safety related publications in six core safety journals from 1991 to 2013 (figure). adapted from Li and Hale, 2016

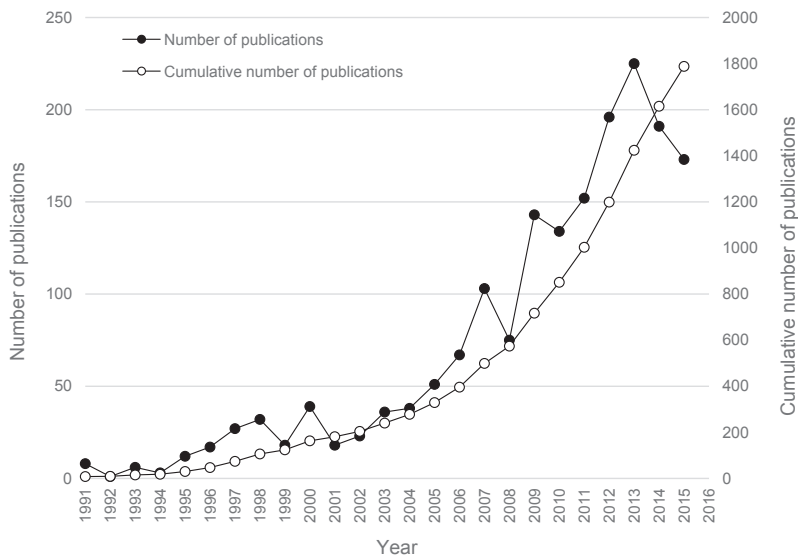


Fig. 2. Number of safety culture publications and cumulative number of safety culture publications by year.

Table 1
Top-5 of most productive authors publishing on safety culture.

No. [*]	Author name	Country of author	Number of publications	Average citations per publication	Number of publications as first author
1	E.J. Thomas	USA	18	31.2	1
2	J.B. Sexton	USA	15	62.8	4
2	R. Flin	Scotland	15	51.3	2
4	K. Mearns	Scotland	14	31.2	6
5	C. Wagner	The Netherlands	13	9.5	1
5	T. Reiman	Finland	13	6.9	10

* Equally productive authors have the same ranking number.

consistent with observations in other fields (Liu et al., 2012), that only a small group of productive authors contributes to a significant share of publications on a specific topic.

Table 1 shows the top-5 of most productive authors publishing on the topic of safety culture. The ranking is based on the author's total number of publications and not on authorship order. Thomas is the most productive author on the topic of safety culture with eighteen publications, followed by Sexton and Flin with both fifteen publications. For the top-5 authors, a wide range can be seen regarding the average number of citations per publication (ranging from 62.8 to 6.9), and the number of publications as first author (one publication as first author for the firstly ranked author and ten publications as first author for one of the fifthly ranked authors).

The average number of authors per publication was 3.3. 23.6% (n = 422/1789) of the publications had single authorship, 22.3% (n = 399/1789) of the publications had two authors, 18.9% (n = 339/1789) had three authors, and 35.2% (n = 629/1789) had four or more authors (with a maximum of 21 authors). It can be concluded that there is much collaborative research in the safety culture domain, as multi-authored publications make up about three quarters of all publications. A high number of co-authored publications indicates a closer relationship among the authors within the same domain and a greater opportunity for future collaboration (Wang et al., 2014).

The cooperation pattern (i.e. co-authorship) of the authors publishing on safety culture was analysed with VOSviewer. The authors in the network published at least two papers on the topic. Authors who are not connected with other authors in the network are not included. The result of this authors cooperation network is presented in Fig. 4. The size of the circles represents the amount of publications, and the line between two authors represents the cooperation between them. The colours represent the collaboration clusters. In the cooperation network, nine major cluster of authors can be distinguished. The main researchers in the network are Pronovost, Sexton, and Thomas. Other researchers are linked to one of these main researchers.

Regarding the authorship, a possible bias should be noted. Authors with the same name could not be distinguished from each other. Also, authors using different names in their publications, e.g. due to marital changes, could not be merged. As recommended by others (e.g. Chiu and Ho, 2007), a mandatory allocation of a unique digital identity number when publishing the first paper as a researcher (such as ORCID), could provide a solution for this problem.

3.3. Journals publishing on safety culture

In total, the 1789 publications were published in 775 different journals. This high number indicates a wide variety of research themes, and the multidisciplinary character of safety culture research. Of the 775 journals, 503 journals (64.9%) published only one publication, and

113 journals (14.6%) published only two publications on the topic of safety culture. 27 journals (3.5%) published ten publications or more on the topic.

Table 2 gives information of the top-10 most active journals publishing on safety culture research. These ten journals (or 1.3% of all journals publishing on safety culture) have published more than one fifth of all safety culture publications (22.6%; n = 405/1789). Key journals in the field are 'Safety Science' and 'BMJ Quality & Safety', with 132 and 54 publications on the topic, respectively. The subject category 'Health care sciences & services' appears five times in the top-10 of most active journals. Most likely, publications on health-care and patient safety culture will be situated in these journals. Publications on organisational safety are more scattered in several subject categories of journals, ranging from 'engineering' to 'social sciences' (see Section 3.8 for more information on the division of safety culture publications in (a) organisational safety culture and (b) health-care and patient safety culture).

3.4. Geographical and institutional distribution and cooperation

Each publication was assigned to a country or territory, and to an institution based on the address(es) of the author(s) as listed in the Web of Science data. There were 86 publications without country or territory information and 95 publications without information on the institution. Hence, of all publications, 95.2% could be assigned to a country or territory and 94.7% could be assigned to an institution.

3.4.1. Countries and territories

Safety culture publications originate from 76 different countries or territories. Out of those 76, 32 are located in Europe, 23 in Asia, 7 in North America, 7 in South America, 5 in Africa, and 2 in Oceania. Fig. 5 shows the worldwide distribution of the contributing countries and territories. 46 countries or territories (60.5%) produced 10 or less publications, 21 countries or territories (27.6%) have produced between 11 and 50 publications, and 9 countries or territories (11.8%) have produced more than 50 publications on the topic of safety culture. The USA produced the most publications (n = 522), followed by England (n = 190) and China (n = 130). Fig. 6 shows the top-10 of most productive countries and territories on safety culture research. Economic development seems to contribute to scientific and academic investment, as all of the 7 major industrialised countries of the world (G7: USA, Japan, Italy, Germany, UK, Canada and France) were ranked in the top-14 of most productive countries publishing on safety culture research. The pattern of domination of the G7 has occurred in most scientific fields, reflecting the high economy activity and academic level of these countries (Liu et al., 2012; Yang et al., 2013).

The total count of countries and territories belonging to the 1703 publications with country or territory information was 1997 (one author can be affiliated to more than one country or territory, or a publication can be written by several authors from different countries or territories). In the extension of the information on countries and territories, a geographical inequality can also be seen when looking at the continents. Europe was assigned to 45.4% of the publications (n = 907/1997), North America to 30.4% (n = 606/1997), Asia to 15.9% (n = 318/1997), Oceania to 5.5% (n = 109/1997), South America to 1.9% (n = 39/1997), and Africa to 0.9% (n = 18/1997).

The cooperation network (i.e. co-authorship) between countries and territories publishing on safety culture was analysed with VOSviewer. The countries and territories in the network published at least ten publications on the topic. Countries or territories that are not connected with other countries or territories in the network are not included. The result of the cooperation network between countries and territories is presented in Fig. 7. The size of the circles represents the amount of publications, and the thickness of links represents the strength of collaborations. The colours represent the collaboration clusters. Two major clusters can be distinguished: one gathering around England

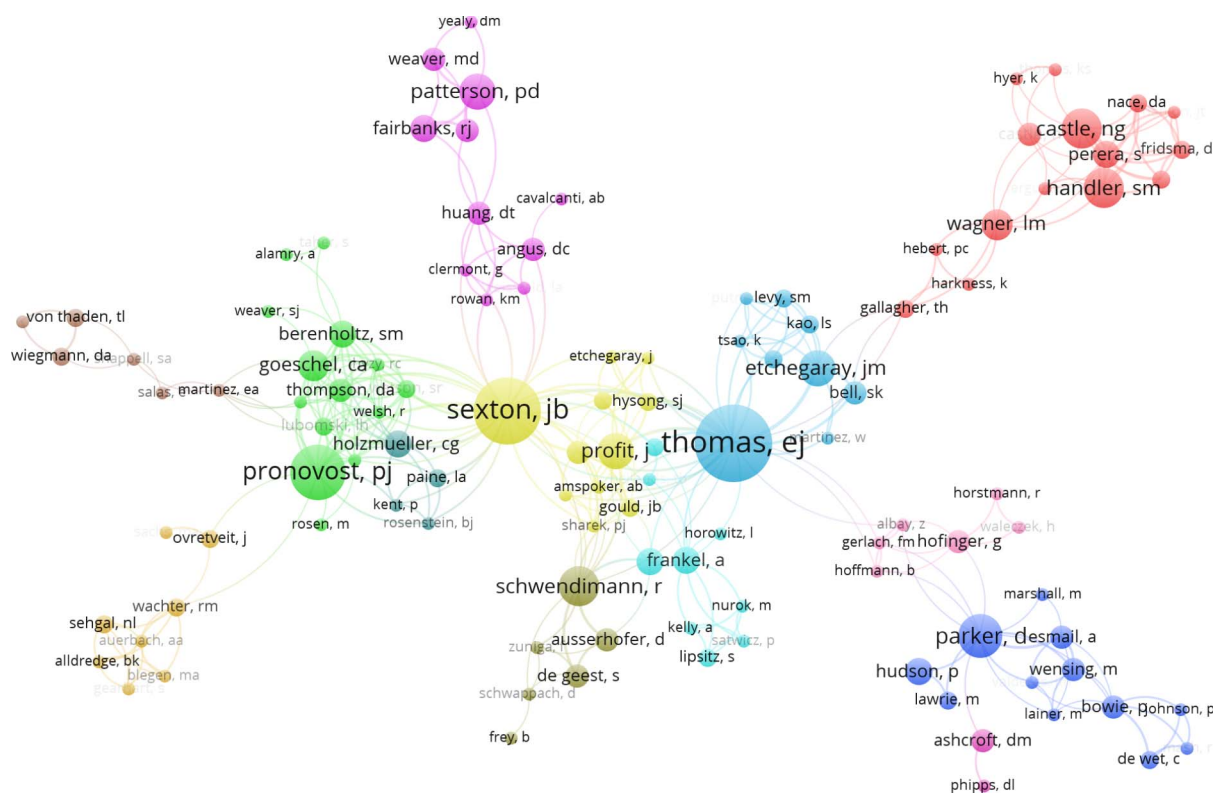


Fig. 4. Authors cooperation network in safety culture research.

Table 2
Top-10 of most active journals publishing on safety culture.

No.*	Journal title	Number of publications	Impact factor**	Subject category of the journal**
1	Safety Science	132	1.831	– Engineering, industrial – Operations research & management science
2	BMJ Quality & Safety	54	3.988	– Health care sciences & services
3	Quality & Safety in Health Care	37	2.160	– Health care sciences & services
4	Process Safety Progress	35	0.464	– Engineering, chemical
5	BMC Health Services Research	33	1.712	– Health care sciences & services
6	Journal of Safety Research	29	1.870	– Ergonomics – Public, environmental & occupational health – Social sciences, interdisciplinary
7	Journal of Loss Prevention in the Process Industries	22	1.406	– Transportation
7	International Journal for Quality in Health Care	22	1.756	– Engineering, chemical – Health care sciences & services
9	Journal of Patient Safety	21	1.492	– Health care sciences & services
10	Accident Analysis and Prevention	20	2.070	– Health care sciences & services – Ergonomics – Public, environmental & occupational health – Social sciences, interdisciplinary – Transportation

* Equally active journals have the same ranking number.

** Impact factors and subject categories were retrieved from the 2014 Journal Citation Reports®.

(green cluster, upper left), and one around the USA (red cluster, right). The cluster gathering around England mostly contains countries in Western- and Southern-Europe. The cluster gathering around the USA has three other major contributors: China, Australia and Canada. A third, smaller cluster contains the Scandinavian countries (blue cluster, bottom left). As found in other scientific research domains, collaborative countries tend to be geographically correlated, and centre around the most productive countries in terms of publication output (Zheng et al., 2016).

3.4.2. Institutions

1866 different research institutions participated in the 1694 publications with institution information (one author can be affiliated to

more than one institution, or a publication can be written by several authors from different institutions). Of all institutions, 72.9% (n = 1361) only participated in one publication, and 13.1% (n = 244) only participated in two publications. 29 organisations (1.5%) produced at least ten publications on the topic of safety culture. Table 3 gives information on the top-10 of most productive institutions publishing on safety culture. The five most productive institutions were located in the USA. The institution which published the most publications on the topic (n = 32) is the University of Pittsburgh. All of the top-10 institutions were universities.

It would be interesting to subdivide all 1866 institutions participating in safety culture research according to following categories: academic (colleges and universities), private organisation (e.g.

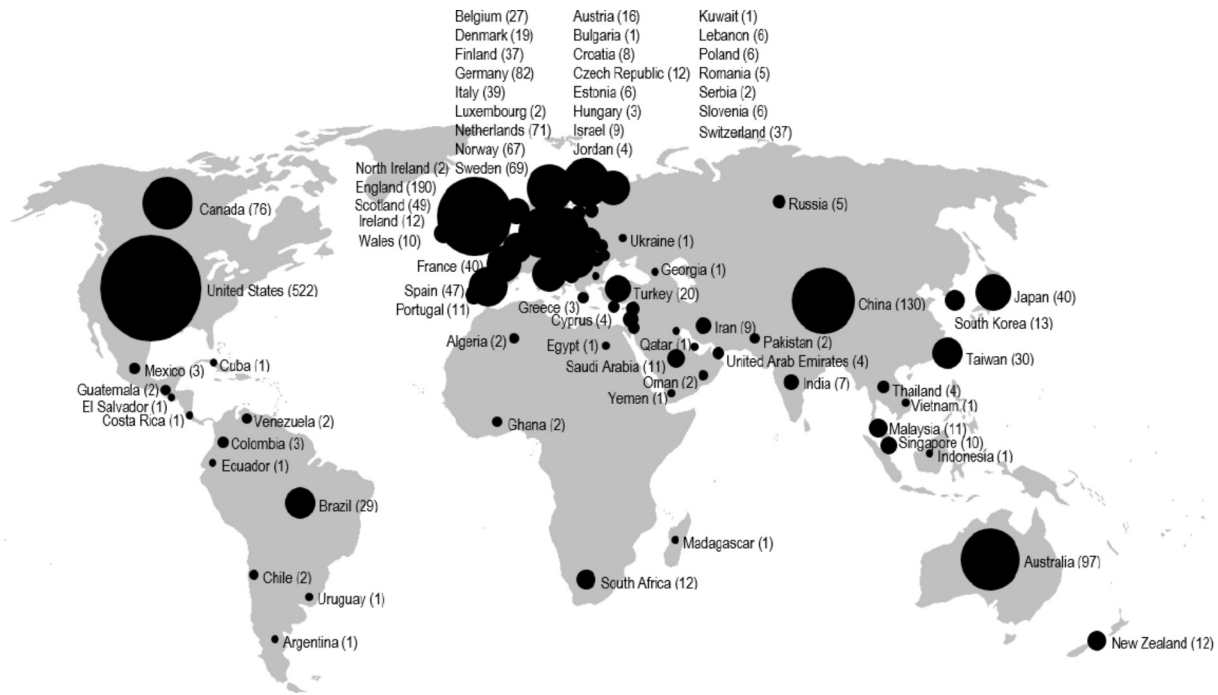


Fig. 5. The number of safety culture publications distributed by country or territory.

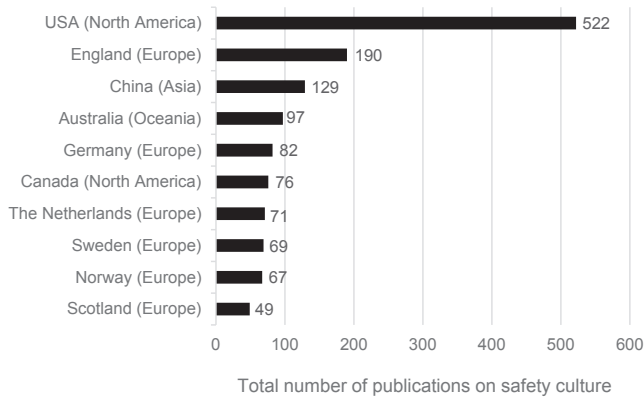


Fig. 6. Top-10 of most productive countries or territories publishing on safety culture research.

Table 3

Top-10 of most productive institutions publishing on safety culture.

No.	Institution	Country	Number of publications
1	University of Pittsburgh	USA	32
2	Harvard University	USA	28
3	University of Michigan	USA	25
4	Stanford University	USA	24
5	Johns Hopkins University	USA	23
6	University of Manchester	UK	22
6	University of Aberdeen	UK	22
8	University of Toronto	Canada	18
9	University of California, San Francisco	USA	16
10	Griffith University	Australia	15
10	Delft University of Technology	The Netherlands	15

* Equally productive institutions have the same ranking number.

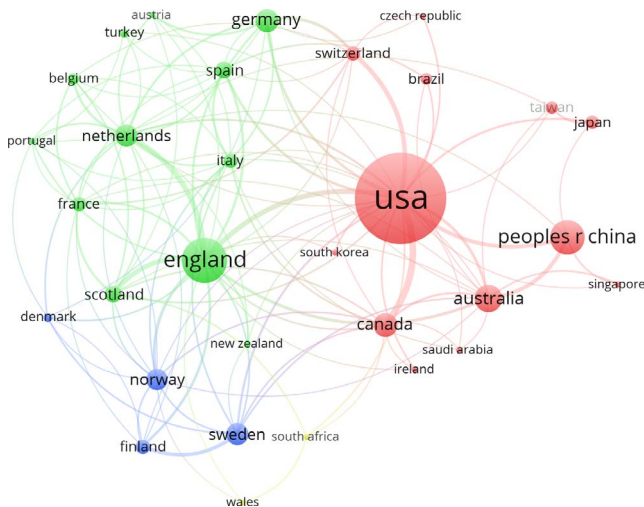


Fig. 7. Cooperation network between countries and territories in safety culture research.

industry, hospital), or governmental organisation (policy makers). Based on this division, it could be identified if safety culture research is squarely situated in the world of academia, and it can shed a light on stakeholder involvement and policy focus (Gall et al., 2015). However, this division is very time consuming, as this information is not registered in Web of Science, and it has to be searched one by one manually.

3.5. Cited analysis

Citation is a two way process. Firstly, it covers the knowledge input, i.e. the citing behaviour in a publication (the references that are used in the publication), which is called the ‘citing analysis’ (Li and Hale, 2015). This aspect will be covered in the next section. Secondly, it covers the knowledge output, i.e. the citing of a publication by others (other publications that use the publication as a reference), which is called the ‘cited analysis’ (Li and Hale, 2015). This aspect will be covered in this section.

The cited analysis gives the number of times the publications on safety culture has been cited by other publications listed in Web of Science. In total, all 1789 publications were used 14,485 times as a reference in other publications. The average citation per publication is

Table 4
Top-10 of most frequently cited publications on safety culture.

No.	Title	Author(s)	Country of first author	Journal name (journal impact factor [*])	Published year	Times cited	Average citations per year	Main topic
1	The nature of safety culture: a review of theory and research	F.W. Guldenmund	The Netherlands	Safety Science (1.831)	2000	410	25.6	Organisational safety
2	The Safety Attitudes Questionnaire: psychometric properties, benchmarking data, and emerging research	J.B. Sexton et al.	USA	BMC Health Services Research (1.712)	2006	319	31.9	Health-care & patient safety
3	Towards a model of safety culture	M.D. Cooper	UK	Safety Science (1.831)	2000	207	12.9	Organisational safety
4	Safety culture: philosopher's stone or man of straw?	S. Cox et al.	UK	Work and Stress (2.386)	1998	167	9.3	Organisational safety
5	The culture of safety: results of an organisation-wide survey in 15 California hospitals	S.J. Singer et al.	USA	Quality & Safety in Health Care (2.160)	2003	162	12.5	Health-care & patient safety
6	Role of hand hygiene in healthcare-associated infection prevention	B. Allegranzi et al.	Switzerland	Journal of Hospital Infection (2.544)	2009	138	19.7	Health-care & patient safety
7	The structure of employee attitudes to safety: a European example	S. Cox et al.	UK	Work and Stress (2.386)	1991	128	5.1	Organisational safety
8	Improving patient safety in intensive care units in Michigan	P.J. Pronovost et al.	USA	Journal of Critical Care (1.995)	2008	123	15.4	Health-care & patient safety
9	Man-made disasters: why technology and organisations (sometimes) fail	N. Pidgeon et al.	UK	Safety Science (1.831)	2000	115	7.2	Organisational safety
10	The development of a measure of safety climate: the role of safety perceptions and attitudes	A.M. Williamson et al.	Australia	Safety Science (1.831)	1997	112	5.9	Organisational safety

* Impact factors were retrieved from the 2014 Journal Citation Reports[®].

8.1. 42.4% (n = 759/1789) was cited zero times at the time of the data extraction. Of the 1789 publications on safety culture, 3.6% (n = 65/1789) was cited 50 times or more, and 1.0% (n = 18/1789) was cited 100 times or more.

It should be noted that there is a general assumption that the number of citations reflects a publication's influence and notoriety and, hence, its quality (Smith, 2007; Ugolini et al., 2015). However, some authors (e.g. Walter et al., 2003; Chiu and Ho, 2007) state that the times a publication has been cited by others does not actually indicate the quality of a publication, but that it measures its visibility. Also, there is a growing recognition that open access journal publications are increasingly cited more (Whipple et al., 2013).

Table 4 shows the ten most frequently cited publications. The most cited paper is 'The nature of safety culture: a review of theory and research' from Guldenmund. The paper has been cited 410 times since its publication in 2000 (until December 29, 2015). The paper with the highest average citations per year is 'The Safety Attitudes Questionnaire: psychometric properties, benchmarking data, and emerging research' from Sexton et al. Since its publication in 2006, the paper has been cited on average 31.9 times per year. Looking at the ten most frequently cited publications, the UK is best represented as country of first author with four publications, followed by the USA with two publications. Cox is the only first author occurring twice in the list. The journal 'Safety Science' is best represented with four publications, followed by 'Work & Stress' with two publications. If the content of the ten most frequently cited publications is examined, it can be seen that six of the publications cover safety culture in organisations and four cover health-care and patient safety culture (see Section 3.8 for more information on the division of safety culture publications in (a) organisational safety culture and (b) health-care and patient safety culture).

The number of times a publication has been cited is highly correlated with the length of time since its publication (Qui and Chen, 2009). Obviously, older publications have more chance to be already cited than newer publications, but this does not preclude recent publications from having an important impact in the field (Milfont and Page, 2013). For example, the most recent published article in the top-10 was published in 2009 and has been cited 138 times, compared to the earliest published article in 1991 that has been cited 128 times.

3.6. Citing and co-citation analysis

The citing analysis gives the number of references used by the 1789 publications on safety culture. In total, 50,790 references were used, which is the total number of references. The number of unique references is 31,776.

Co-citation analysis focuses on the relationship or interaction between two publications, and gives an overview of publications that have been cited together in other publications. The more two publications are cited together, the more similarities between them can be assumed (Li and Hale, 2015).

As mentioned in the citing analysis, 31,776 unique references were used in the 1789 publications on safety culture. VOSviewer was used to analyse and visualise the co-citations. To be included in the co-citation map, a reference had to be used in the bibliography of the 1789 safety culture publications at least twenty times. Of the 31,776 unique references, 156 met this threshold.

The result of the co-citation analysis is presented in Fig. 8. The size of the circles represents the number of citations, i.e. the larger a circle, the more a publication has been cited in the safety culture publications. A smaller distance between two publications suggests a stronger relation and a higher similarity between them. Circles with the same colour suggest a similar topic among these publications. The co-citation map shows how the references of the safety culture publications cluster together, and clearly illustrates three distinct clusters, where each cluster represents a field of safety culture research: a blue cluster (upper left), a green cluster (bottom left) and a red cluster (right). Green and blue are

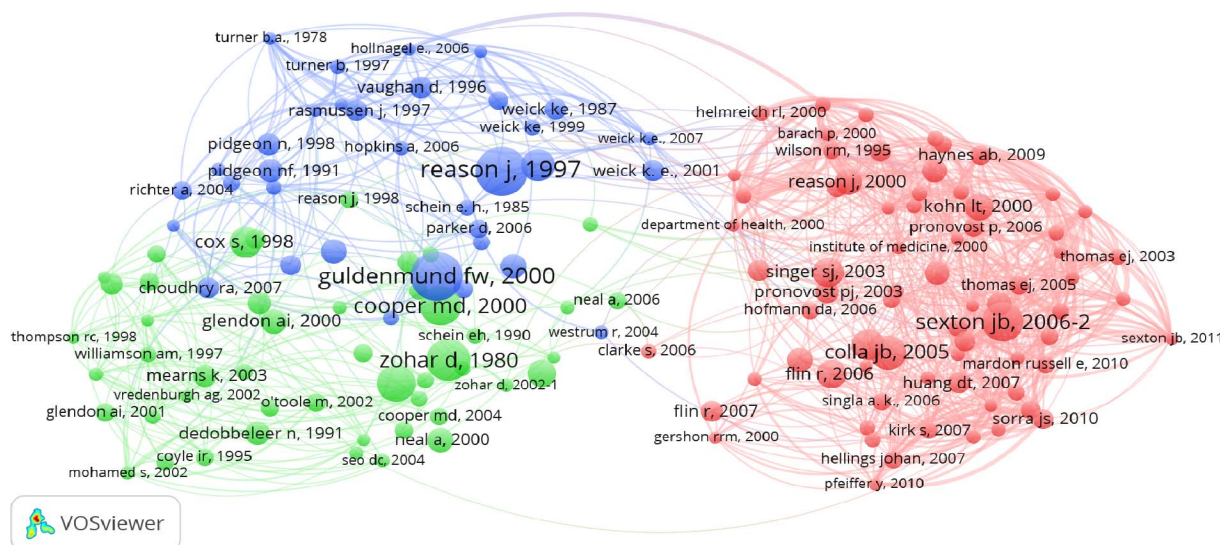


Fig. 8. Co-citation analysis of highly-cited references used in publications on safety culture.

more intermingled with each other, while the red cluster stands more alone.

Based on the examination of the titles of all individual publications in the three clusters, an appropriate label could be assigned to each of them. The red cluster is clearly separated from the two other clusters, and represents the subfield of health-care safety. Not only patient safety is included in this cluster (although this is the majority), but also, amongst others, safety in surgical interventions, intensive care units and the health-care system in general. The green and blue clusters are more intermingled, as they both represent publications on organisational safety. Publications in the green cluster focus on occupational safety, and more specific on safety climate, attitudes and behaviour. Publications in the blue cluster focus on disaster prevention and models of safety culture. The blue cluster is more theoretical, whereas the green cluster contains more practical-oriented publications.

The highly-cited references used in publications on safety culture can be divided in two groups: (1) a group of references that is a part of the 1789 safety culture publications and (2) a group of references that belongs to another main research domain than safety culture, but of course has an interrelatedness with the concept. Looking at the second group of references, important influences in safety culture research can be identified. In the cluster of health-care safety, *Measuring patient safety climate: a review of surveys* from Colla et al. (2005) can be seen as an important influence that does not belong to the main domain of safety culture, but belongs to the main domain of safety climate. The most influential publication in the cluster of occupational safety is *Safety climate in industrial organisations: Theoretical and applied implications* from Zohar (1980), also belonging to the main domain of safety climate research. Important influences in the cluster of disaster prevention and models of safety culture are two books from Reason: *Human error* (1990) and *Managing the Risks of Organisational Accidents* (1997).

3.7. Subject categories

Every journal covered by Web of Science is assigned to at least one subject category. The subject categories reflect a particular field of research. Web of Science comprises approximately 250 subject categories. All articles published within a journal will inherit the journal's subject categories designation.

The total count of the subject categories belonging to the 1789 publications on safety culture was 3094. A great diversity in subject categories can be seen, as there were 153 different Web of Science

subject categories related to the research of safety culture. Just like the high number of different journals publishing on safety culture, the high number of subject categories indicates a wide variety of research themes, and the multidisciplinary character of safety culture research. Out of these 153 subject categories, 28 subject categories (18.3%) contained only one publication, and 19 subject categories (12.4%) contained only two publications. 56 subject categories (36.6%) contained at least ten publications.

Fig. 9 shows the top-10 of most frequently assigned Web of Science subject categories to the safety culture publications and the division over time. The legend gives the names of the top-10 subject categories, along with the total number of safety culture publications belonging to these categories. The subject category containing the most publications on the topic of safety culture was *Health Care Sciences & Services* with 252 publications, followed by *Public, Environmental & Occupational Health* with 243 publications.

The division of safety culture research in two main clusters (see Section 3.8) – (a) organisational safety culture and (b) health-care and patient safety culture – is also represented in the subject categories belonging to the publications. For example, the categories *Health Care Sciences & Services* and *Health Policy & Services* can be clearly assigned to the cluster 'health-care and patient safety culture', and the categories *Engineering, Industrial* and *Engineering, Chemical* can be clearly assigned to the cluster 'organisational safety culture'.

The distribution of the subject categories over 5-year intervals (Fig. 9) helps us to see the level of research that is spent during a given period on a given subject, and it can uncover subjects that gained more attention over time. For example, during the last five years, a doubling of publications on safety culture could be observed in the subject categories *Transportation* and *Ergonomics*. The category *Nuclear Science & Technology* even counted a fourfold increase of safety culture publications the last 5 years. The nuclear disaster in Fukushima in 2011 can provide an explanation on this matter.

3.8. Terms analysis

An analysis of the terms that are used in the titles and abstracts of safety culture publications can provide insight in main topics and research trends in the domain of safety culture.

VOSviewer was used to analyse and visualise the terms. First, all noun phrases were extracted from the titles and abstracts of the 1789 safety culture publications. Terms with a general meaning, such as 'article' and 'conclusion', were not included. Terms with a different

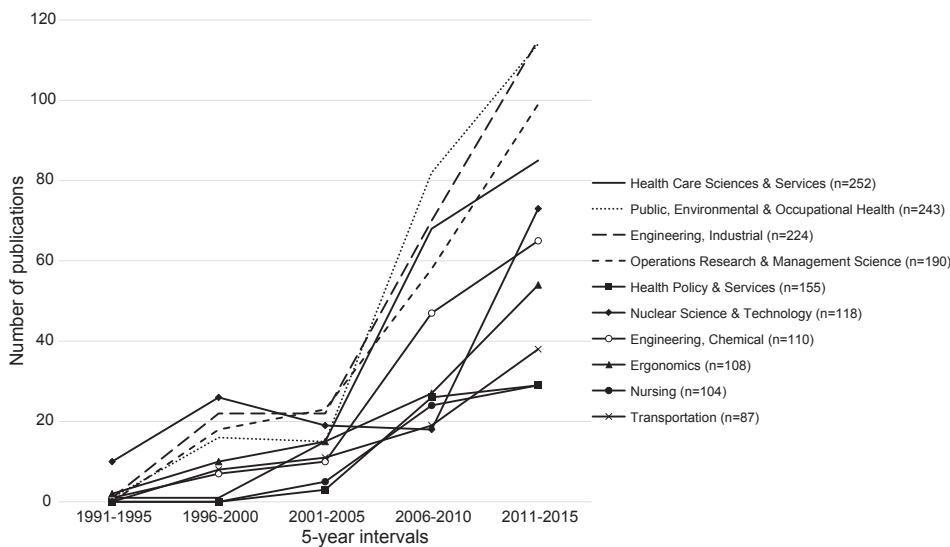


Fig. 9. Top-10 of most frequently assigned Web of Science subject categories to the publications on safety culture by 5-year intervals.

spelling, such as ‘safety behavior’ and ‘safety behaviour’, were merged. Only terms that occur in at least ten publications were considered. 493 terms met this threshold.

The result of the terms analysis is presented in Fig. 10. The size of the circles represents the occurrence of a term, i.e. the higher the size, the higher the occurrence of a term in the abstracts and titles of the safety culture publications. The overall distance between terms provides information on their relatedness. The shorter the distance between terms, the stronger their relation. The relatedness of terms is determined by counting the number of times that terms occur together in the titles and abstracts (Rodrigues et al., 2014). The colours are used to distinguish different clusters.

The terms map shows how the terms of the safety culture publications cluster together, and clearly illustrates two distinct clusters: a red cluster (left) and a green cluster (right). The most common keywords in the red cluster are: risk, accident, industry, concept, and company. The most common keywords in the green cluster are: patient safety, hospital, survey, patient safety culture, and questionnaire. The red cluster seems to entail publications on organisational safety. Terms such as

‘concept’ and ‘framework’ suggest a more theoretical focus. The green cluster seems to entail the health-care and patient safety culture publications with a more practical-oriented emphasis. Terms such as ‘survey’ and ‘questionnaire’ strengthen the latter presumption.

Fig. 11 shows the terms analysis of the safety culture publications, but with time information. The colour of a term indicates the term's average publication year. The average publication year of a term is calculated by taking the average of the publication years of all publications that have the term in their title or abstract. Terms that are used more towards 2015 are shown in red (the right of Fig. 11), while terms that are used more towards 2006 are shown in blue (the left side of Fig. 11).

Looking at the time periods, most research around 2006 was conducted in the content area of nuclear safety (corresponding terms such as nuclear power plant, reactor, nuclear technology). Most research around 2008 focussed on organisational safety, and more specific on the technical and organisational aspects (corresponding terms such as risk, accident, industry, technology, safety management, safety management system). Around 2010, a lot of safety culture research focussed

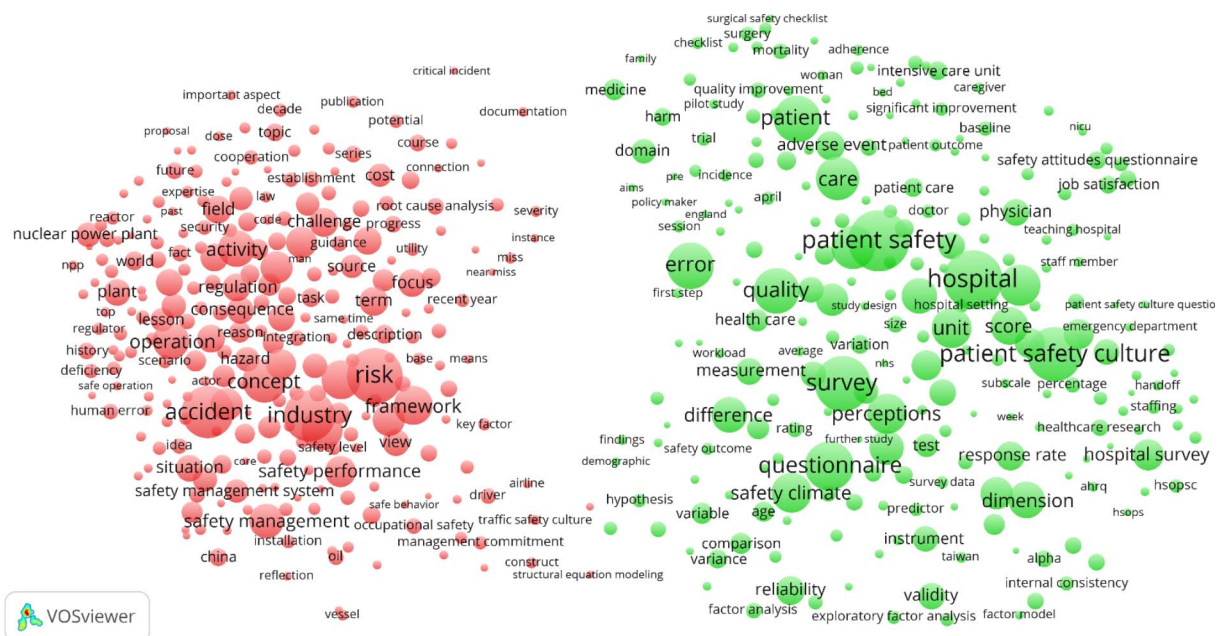


Fig. 10. Terms analysis of safety culture publications.

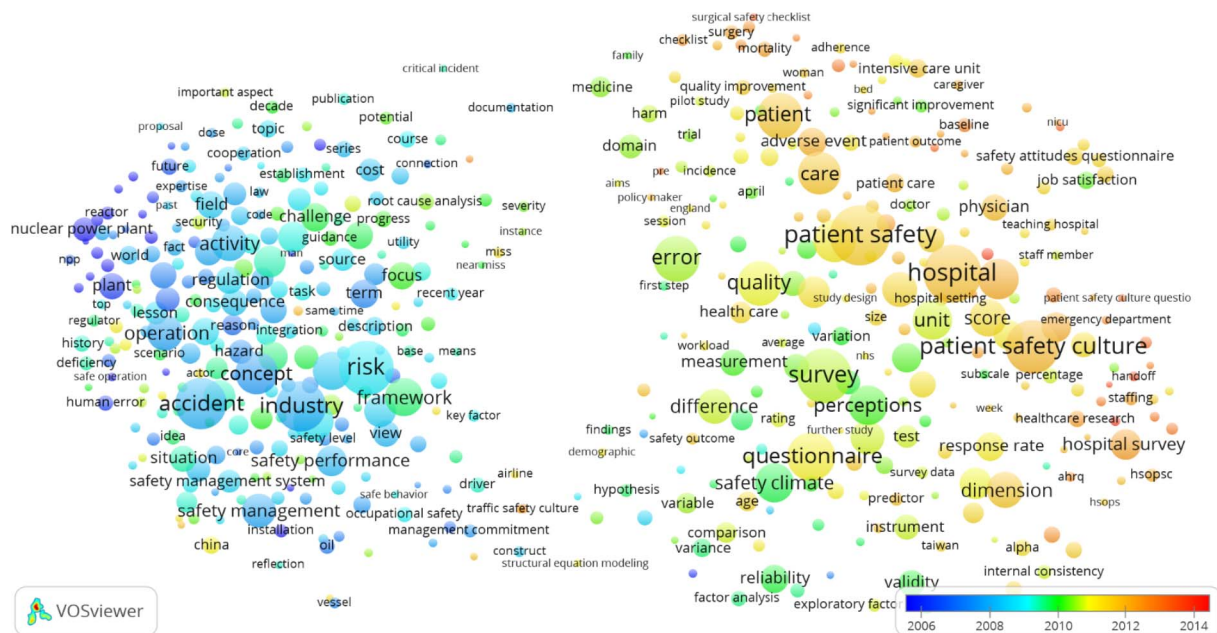


Fig. 11. Terms analysis of safety culture publications with time information.

on safety climate and perceptions. Finally, the map shows an increasing trend in publications related to health-care and patient safety, as the corresponding terms (patient safety, nurse, hospital, patient safety culture, care, etcetera) are mostly used in recent years.

To summarise, the time map of terms shows a movement away from organisational safety culture in general, and a movement away from more technical factors in particular. Along with the development of safety culture, human aspects such as perceptions, safety climate, workload, and job satisfaction, were given greater importance than technology. The movement away from the more technical factors could reflect the more classically dominant division between the human (social science and medicine) and technical worlds (Li and Hale, 2015). Publications on health-care and patient safety stand in a dominant position in safety culture research nowadays. It should be noted that this does not mean that lesser attention is being paid to organisational culture – a lot of research on this topic is still being performed, and needed – but that publications on health-care and patient safety culture gain the upper hand.

4. Conclusions

In this paper, an evaluation on the global research trends in safety culture publications from 1900 to 2015 is given. The topic of safety culture has been a field of extensive research during the last ten years and its publication output is characterised by an exponential growth. Nevertheless, latest trends suggest a saturation of scientific output in this field. The next few years will enlighten if this declining trend in publication output will remain. The study includes 1789 publications on safety culture covering 4591 authors, 775 journals, 76 countries or territories, and 1866 institutions.

Two main research areas can be distinguished in the domain of safety culture: (1) organisational safety culture and (2) health-care and patient safety culture. The research area of organisational safety culture seems to be a more theoretical, where the research area of health-care and patient safety culture has a more practical-oriented emphasis. The research in the subdomain of health-care and patient safety culture stands in a dominant position in safety culture research nowadays.

The power-law distribution, which has also been discovered by bibliometric studies in other fields (Li and Zhao, 2015), applies to many aspects of safety culture publications:

- The largest proportion of the authors (83.6%) is only credited in one publication, and a small group of productive authors contributed to a significant share of publications in safety culture research (6.0% of all authors published at least three articles).
- Of all journals publishing on the topic, 79.5% only published one or two publications. A small proportion of the journals (1.3%) is responsible for about one fifth of the safety culture publications.
- Of the countries or territories publishing on safety culture, 60.5% produced ten or less publications. 11.8% of the contributing countries or territories produced more than fifty publications on the topic.
- 72.9% of the institutions only participated in one publication, and 1.5% of the contributing institutions produced at least ten publications on the topic of safety culture. Universities (and not private or governmental organisations) were the predominant contributors.
- A large proportion of the safety culture publications (42.4%) was not (yet) cited by others, and only a small proportion of the publications (3.6%) was cited fifty times or more.

The analyses also provided information on who is standing on the frontier of this research area:

- Thomas and Sexton are the most productive authors. They are spill figures in the cooperation network of authors, which means that other authors are linked (directly or indirectly) to one of them. Both authors are affiliated to the USA and publish in the research area of health-care and patient safety culture.
- The most cited paper is from Guldenmund (2000), and the paper with the highest average citations per year is from Sexton et al. (2006).
- The journal ‘Safety Science’ is the key journal publishing on safety culture research.
- The USA, England and China are the countries and territories dominating the publication production. In the cooperation network, other countries and territories are linked (directly or indirectly) to one of these main contributing countries. Europe and North America are the continents dominating the publication production.
- The leading institution is the University of Pittsburgh (USA). The top-5 of most productive institutions were located in the USA.
- Important influences from other main research domains on the

safety culture research come from Colla et al. (2005), Zohar (1980) and Reason (1990, 1997).

Some positive aspects could be derived from the bibliometric analysis. Firstly, it can be concluded that there is much collaborative research in the safety culture domain, as multi-authored publications make up about three quarters of all publications. Secondly, many different journals publish on the topic and a wide range of subject categories is assigned to the safety culture publications, which indicates a wide variety of research themes, and the multidisciplinary character of safety culture research.

Also, some points of concern could be concluded. Firstly, a geographical inequality, which is related to economic development, can be seen in safety culture research. The share of Oceania, South America and especially Africa is very limited. Secondly, regarding organisational safety culture, it seems that there is a movement away from technical aspects towards more human aspects. Human aspects are important when safety culture is addressed, however, it should be acknowledged that technological aspects remain important. As argued by several authors (e.g. Reiman and Rollenhagen, 2014; van Nunen et al., 2016), safety culture represents a holistic, comprehensive term that comprises a totality of technological, organisational and human factors.

Finally, some limitations of this bibliometric study should be addressed. First of all, the search was limited to publications listed in Web of Science. Although Web of Science is among the largest global databases, it does of course not contain all publications in the field of safety culture research. Other international databases such as PubMed or Scopus could have been used. However, Web of Science is the most widely accepted and frequently used database for analysis of scientific publications (Yang et al., 2013). Secondly, bibliometric analysis uses quantitative methods. Hence, the content or the quality of publications cannot be interpreted (Dunk and Arbon, 2009). This can imply that some of the publications were included in the analyses notwithstanding they address a different topic than safety culture; they can address for example the topic of safety climate.

Another limitation of bibliometrics is that analysis can only be done for the existing classifications included in Web of Science. This leads to the omission of other valuable information, such as the distinction between theoretical and empirical papers and more details on the context in case of empirical research (for instance the sectors or the countries in which the study was conducted). Based on these limitations characterising bibliometric analysis, a deeper content analysis is recommended for further research.

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