Identifying common grounds for safety and security research: a comparative scientometric analysis focusing on development patterns, similarities, and differences

Li, Jie; Goerlandt, Floris; van Nunen, K.L.L.; Reniers, G.L.L.M.E.

DOI
10.18757/jisss.2021.1.4638

Publication date
2021

Document Version
Final published version

Published in
Journal of Integrated Security and Safety Science

Citation (APA)
Li, J., Goerlandt, F., van Nunen, K. L. L., & Reniers, G. L. L. M. E. (2021). Identifying common grounds for safety and security research: a comparative scientometric analysis focusing on development patterns, similarities, and differences. *Journal of Integrated Security and Safety Science*, *1*(1), 5-33. https://doi.org/10.18757/jisss.2021.1.4638

IDENTIFYING COMMON GROUNDS FOR SAFETY AND SECURITY RESEARCH: A COMPARATIVE SCIENTOMETRIC ANALYSIS FOCUSING ON DEVELOPMENT PATTERNS, SIMILARITIES, AND DIFFERENCES

Jie Li [a], Floris Goerlandt [b], Karolien Van Nunen [c,d], Genserik Reniers [c,e,f,*]

a College of Safety Science & Engineering, Liaoning Technical University, Huludao, China

b Dalhousie University, Department of Industrial Engineering, Halifax, Nova Scotia B3H 4R2, Canada

c Safety and Security Science, Faculty of Technology, Policy and Management, Delft University of Technology, The Netherlands

d Research Chair Vandeputte, University of Antwerp, Belgium

e Antwerp Research Group on Safety and Security (ARGoSS), Faculty of Applied Economics, University of Antwerp, Belgium

f CEDON, KU Leuven, 1000 Brussels, Belgium

* Genserik Reniers, G.L.L.M.E.Reniers@tudelft.nl

DOI: https://doi.org/10.18757/jisss.2021.1.4638

Keywords

Safety
Security
Scientometrics
Bibliometrics
VOSviewer
Safety journals
Security journals

Abstract

Safety and security are often considered in complimentary or opposing terms. Discussions on their conceptual meaning have been put forward, and calls for an increased integration of these domains have been made. Nevertheless, there is currently no high-level empirical comparison of the development and contents of these research domains. In this article, the broad scientific literature of safety and security research obtained from Web of Science is analysed, aiming to obtain comparative insights in these respective fields, with a specific focus on the themes, topics and scientific areas where increased integration can be fruitful. Scientific publications are analysed in terms of research trends and geographic distribution, journals'

distribution, scientific categories, and focus topics of safety and security research in 2019. The results indicate a rapidly growing publication trend in both research domains, with an exponential growth since the 1990s. Safety research focuses on medicine/drug safety, patient safety and disease-related safety, with occupational health and safety and safety in socio-technical systems comparatively smaller research domains. Security research focuses on internet of things, physical layer security and cybersecurity/information security. Journals and scientific categories where significant contributions to both safety and security research are made relate mostly to industrial and transport safety and security, food safety, and public, environmental and occupational health. Apart from providing insights to academics and practitioners to the scope and focus areas of safety and security research, the findings also support delineating the scope and focus of the Journal of Integrated Security and Safety Science (JISSS), which aims to bolster connections and integration between these domains. Based on the findings, a focus on safety and security in industrial plants, transportation contexts, and industrially relevant aspects of public, environmental and occupational health, is found to be an appropriate target area for JISSS.

RESEARCH HIGHLIGHTS

- A scientometric comparison of safety and security research is presented.
- Safety and security publications are collected from Web of Science and analysed using VOSviewer.
- Comparisons focus on publication trends, core journals, scientific categories, and keywords.
- Results provide level insights in similarities and differences between safety and security research, identifying areas where synergies may be most fruitful.
- Safety research focuses mostly on health, medical, and food related issues, security research focuses primarily on food, cyber and information related topics.
- Opportunities for synergy between safety and security research are primarily in work on socio-technical and cyber-physical systems.

1. Introduction

Like other concepts in safety and risk research (such as "hazard" and "risk"), "safety" and "security" are sometimes difficult to distinguish, whereas their scope and focus are not always intuitively clear. For example, in some languages these concepts are denoted by two different words, whereas in other languages the same word is used for referring to both concepts. For instance, in English the terms 'safety' and 'security' are used, in French safety is 'sécurité' and security is 'sûreté', and in Dutch these are 'veiligheid' and 'beveiliging'. In other languages, only one word covers different concepts, for example in Chinese, the word for both concepts is 'Anquan' (安全), in German it is 'Sicherheit', in Japanese it is 'Sekyuriti' (セキュリテ), and in Finnish the word is 'turvallisuus'.

We can understand the meaning of safety and security in different ways. In daily life, safety is often used in industrial environments or in relation to health: phrases like "safety first" are frequently used on construction sites or production lines, whereas occupational health and safety are innately connected in various regulations. Security is used intensely in public areas and organizational settings, for example "security checks" in airports or "security protocols" in relation to computer networks. Understanding the concepts of safety and security, and their implications of what is included in the respective research domains, is important for scientific communication, developments in practical and professional environments, and for practical problem-solving in contexts where safety and security may lead to conflicting requirements.

Questions about the similarities and differences between safety and security have already attracted several discussions in the scientific community (Burns et al., 1992; Aven, 2014; Foulquier, 2013; Parkinson, 2011; Albrechtsen, 2003; Barnes, 2005; van Nunen et al., 2018b). Idsø and Jakobsen from Norwegian University of Technology and Science (NTNU) have proposed following definitions of safety and security. Safety is considered as the protection against random incidents, which are unwanted incidents that happen as a result of one or more coincidences. They defined security as protection against intended incidents. Intended incidents happen due to a result of deliberate and planned acts (Idsø and Jakobsen, 2000). Albrechtsen (Albrechtsen, 2003) has compared safety and security by different factors of both concepts (including causes, threats/hazards, loss, surroundings, relevance and uncertainty), leading to the following definition of security: "A condition of being protected against planned, malicious and criminal incidents from a wide range of threats, where what is protected is all kinds of values to an organization/individual and incidents happen due to the wish for a wanted output/consequence for the attacker". Barnes, who is active in software-related work, proposed that "Safety is that the system must not harm the world, and security is that the world must not harm the system (Barnes, 2005)". Aven, a prominent risk research scholar, reviewed several safety definitions, where most of these defined safety being associated with low and acceptable risk. He regarded that "security relates to intentional situations and events (terrorist attacks, burglary, etc.) in contrast to safety, which covers the accident type of situations and events" (Aven, 2014). According to van Nunen et al., the main resemblance between safety and security is the focus on preventing undesirable events such as injury to people, material damage and environmental damage. The main difference is the origin of these undesirable events, being unintentional in the field of safety, and intentional in the field of security (van Nunen et al., 2018b).

Even though several papers have been published where discussions about the two concepts have been put forward, there is very limited empirical research on the respective scope and focus of the safety and security research domains. Definitional-focused work, like the work by (Aven, 2014), has its merits but does not provide empirical insights into how these terms are used in the scientific domains, or into what focus topic are associated with these.

In this manuscript, an empirically grounded approach provides insights into the high-level development patterns, and differences and similarities between the research domains of safety and security. A specific research focus is to obtain insights in what are the dominant themes, topics and scientific categories in which both security and safety is actively researched. Such knowledge is currently not explicitly available, whereas that is helpful for instance to delineate and justify a scope and focus themes for a journal like the Journal of Integrated Security and Safety Science (JISSS), which aims to bolster the connections between the safety and security research domains.

Consequently, the comparison between security and safety is approached on a very high level in the current work, by widely scoping the topics with which safety and security research is concerned. Aiming to contextualize the academic space in which the efforts to strengthen such connections between these research domains take place, this article maps the spaces of security and safety research in all their breadth. Apart from helping to delineate a scope and focus of JISSS, the work is intended as a starting point to further comparative analyses between subsets of these research domains.

Various scientometric analysis methods are applied to obtain insights in the research literature associated with both fields. Hence, this kind of analysis can be considered as a kind of meta-analysis of the research domains, to map what is included, how these domains have evolved, what academic communities have contributed to its development, and what topics have been in focus. To the best of the authors' knowledge, no earlier work has taken such a systematic approach to obtain high-level insights in the differences and similarities between the safety and security research domains. The use of scientometrics methods for understanding patterns in various subdomains of safety has attracted recent attention, with studies made on safety culture (van Nunen et al., 2018a), building information modeling in construction safety (Akram et al., 2019), resilient health care (Ellis et al., 2019), the Safety Science journal (Merigó et al., 2019) and process-safety related journals (Li et al., 2020a). Some bibliometric analyses have also been presented related to security, e.g. national security (Anwar et al., 2018) and cybersecurity in healthcare (Jalali et al.). However, comparative analyses between safety and security domains are currently lacking.

The remainder of this article is organized as follows. In section 2, the data retrieval process is described, and the specific research questions and associated methods used in the analysis are outlined. Section 3 presents the results, focusing on temporal and geographical trends in the research domains, the position of the research fields in the global journal and topic category maps, and hot research topics in the respective domains. The discussion and conclusions are presented in Section 4 and Section 5.

2. Data and method

2.1 Data retrieval process

Publications related to safety and security are retrieved from the online version of the Web of Science Core Collection (WoS). Web of Science is widely regarded to be one of the most comprehensive English-language databases of scientific works, with the highest information quality (Li et al., 2020b). Two sub-databases from WoS are included: Science Citation Index Expanded (SCI-EXPANDED)-1900 and Social Sciences Citation Index (SSCI)-1900. These two databases cover most of the world's high-quality journals articles: where over 8700 of the world's leading scientific and technical journals across 170+ disciplines are included in SCI, and more than 3000 of the world's leading social sciences journals across 50+ disciplines in SSCI (Carley et al., 2017). Web of Science and the SCI and SSI databases are widely used in the scientometrics domain.

The data used in this study is downloaded on 27 January 2020, whereas the last WoS database update was on 24 January 2020. To receive all relevant records of the safety and security research

domains, a title-based search strategy is applied during the data retrieval process. This means that any publication in SCI/SSCI will be obtained, if either the term 'safety' or 'security' appears in their title. The timespan of the data collection period is set as 1900-2019, i.e. the resulting dataset covers all SCI/SSCI articles up to and including 2019.

First, the title search strategy is used to obtain 190,963 papers where 'safety' has appeared at least once in the title of the paper. Using a similar strategy, 57,910 articles with 'security' in the title were obtained. Subsequently, based on the initial results of the dataset of safety and security papers, logical search operators (AND, OR, NOT) are used to extract more accurate records from the initial results. In the following, the label 'A' is used for the dataset corresponding to Title=(safety), and similarly the label B denotes the Title=(security) dataset. A series of derived datasets are developed, based on given set relation, which allows obtaining insights in similarities and differences between the safety and security research domains. In Table 1, each dataset used in the analysis of Section 3, is shown.

Table 1. Overview of datasets used for analysis, using title-based data retrieval process for 'safety' (A) and 'security' (B), based on SCI＆SSCI databases, period 1900-2019, retrieved 27 January 2020

NO.	Retrieval strategies	Data Set	Number of records	Periods	Data set used in each section
1	TI= (safety)	A	190,963	1900-2019	Not used in data analysis
2	TI= (security)	B	57,910	1900-2019	Not used in data analysis
3	TI= (safety) NOT TI=(security)	A, ~B	190,346	1900-2019	Section 3.1， 3.2
4	TI= (security) NOT TI= (safety)	~A, B	57,293	1900-2019	Section 3.1， 3.2
5	TI=(safety) AND TI= (security)	A∩B	617	1969-2019	Not used in data analysis
6	TI= (safety) OR TI=(security)	A∪B	248,256	1900-2019	Not used in data analysis
7	TI= (safety) NOT TI=(security)	2019∩ (A, ~B)	14,390	2019	Section 3.3
8	TI= (security) NOT TI= (safety)	2019∩ (~A, B)	3,198	2019	Section 3.3

Note: A U B: joint dataset with articles from dataset A and B
~A: articles from the dataset are excluded
A ∩ B: dataset with articles found both in dataset A and B

2.2 Research questions and analysis methods

As outlined in the introduction, this article aims to provide insights into the differences and similarities between the safety and security research domains, aiming to delineate a thematic and applications-oriented domain for which increased integration of safety and security research can be fruitful. This is approached using empirically based scientometric analysis methods. The following research questions will be answered:

i) What are the temporal development trends of the research domains?
ii) How is the research on safety and security distributed geographically?
iii) What are the core journals publishing on safety and security topics?
iv) How are the journals associated with safety and security research distributed on the global journals map?
v) What categories of scientific domains are associated with safety and security research?
vi) How are the research domains situated in the global map of the sciences?
vii) What are currently key research topics in these domains?

To answer these questions, a series of scientometric analysis approaches and tools are applied. In the following, only a brief outline of the applied methods is given for reasons of brevity. These brief outlines of the adopted methods are provided later in this section, whereas the reader is

referred as well to Li et al. (Li et al., 2020b) where an overview of scientometric methods is given and their rationale is further elaborated.

Research questions i) and ii), i.e. the temporal evolution and geographical distribution, are answered using the 'analyse' functions in WoS, augmented with descriptive statistics and regression analysis, and subsequently visualized using MS Excel and Tableau software. The relevant datasets ('A, ~B' and '~A, B') (see Table 1) are analysed in two aspects. The yearly output of safety and security publications are used to analyse the research activity from a temporal perspective. The countries/regions output distributions of the research domains are used to show how the research production is distributed around the world.

Research question iii), i.e. the core journals, is answered using Bradford's Law. This law was first introduced by Bradford (Bradford, 1934), and become well-known after he published a book on the topic (Bradford, 1948). The idea underlying the law is that publication outputs on a given topic are not balanced between different journals. Hence, different journals can be classified into different zones based on the total articles they publish on a given topic. According to the Bradford law, there is a similar number of publications in each zone, while the number of journals in each zone is different. The stratification of journals in the different Bradford zones follows a power relationship, where the articles associated with different journals are stratified into three groups of approximately the same size. According to Okoroiwu et al. (Okoroiwu et al., 2018), the group constituting of journals which contain most publications on the given topic can be considered the "core zone", whereas the other two groups are known as "peripheral zones". In the present work, Bradford's Law is applied to identify core journals in safety and security research.

Research questions iv) and v), i.e. scientific categories associated with safety and security science, and where these and the journals are located in the global science map, are answered by obtaining the journal name and categorizations of the articles by scientific domains from WoS, and mapping these on the global science map. The layers of the map were created by Leydesdorff and his colleagues (Leydesdorff et al., 2013a; Rafols et al., 2010; Leydesdorff et al., 2013b; Leydesdorff and Rafols, 2009). These map layers are free for scientific purposes. The data ('A, ~B' and '~A, B') associated with safety and security research is mapped on these global science map layers using the VOSviewer software (van Eck and Waltman, 2010). The mapped scientific categories and journal locations provide an indication of the core knowledge areas where there are active safety and security research. In this study, Leydesdorff's overlay tools are used to extract categories and journals from the downloaded data, and then map them to the layer. In the category analysis, the DIV* diversity metric proposed by Rousseau (Rousseau, 2019) based on an earlier proposal by Leydesdorff et al. (Leydesdorff et al., 2019) is calculated, providing an indication of the level of interdisciplinarity of the safety and security research domains. The DIV* metric operationalizes and aggregates metrics of variety, balance, and disparity of a research domain, where 'variety' denotes the number of disciplines associated with the domain, 'balance' is concerned with how evenly distributed the articles are across disciplines, and 'disparity' addresses how different these disciplines are. For further details, the reader is referred to Leydesdorff et al. (Leydesdorff et al., 2019).

Research question vi), i.e. the current key research topics in the safety and security research domains, is answered through analysis of keywords associated with the articles. Keywords are frequently relied on in scientometric research to illustrate the core topics of research activity (Li et al., 2020b). Keyword frequencies and co-occurrence analysis are also widely used to understand the evolution of research domains, their knowledge structures, and the analysis of hot topics (Lozano et al., 2019; Su and Lee, 2010). In the current work, author keywords and keywords co-occurrence networks were constructed by VOSviewer (van Eck and Waltman, 2010) and

Gephi (Bastian et al., 2009) to analyse the hot topics and knowledge structure of safety and security research. To analyse the keywords of safety and security research, the datasets [2019∩ (A, ~B) and 2019∩ (~A, B)] were used.

3. Results

In this section, the analysis results associated with the research questions outlined in Section 2.2 are provided. Research questions i) and ii) are addressed in Section 3.1, research questions iii) to v) in Section 3.2, and research question vi) in Section 3.3.

3.1 Publication outputs

3.1.1 Temporal evolution of the research domains

In this Section, an answer is sought to the first research question listed in Section 2.2, i.e. what are the temporal development trends of the safety and security research domains. Figure 1 shows in the top row the publication trends of the safety and security research domains. The bottom row shows the gap in the publication output of safety and security papers. The publication trends show that during the period 1900 to the 1960s, the safety and security research domains have a very slow growth. After the 1960s, the number of publications has grown rapidly, with an exponential trend during the period 1991 to 2019.

Both papers in the field of safety and security date back to 1900. The earliest papers on safety ([Anonymous], 1900; Earle, 1900b; Earle, 1900a), related to the topics of 'Emergency safety lighting' and 'Port Safety'. The earliest papers on security (Bach, 1900; Claude, 1900; von, 1900), focused on 'steam boiler security' (the origin language of the paper is German, and "Sicherheit" is translated as security in Web of Science), 'industrial alternative currents', and 'general social security'. This implies that in some instances, 'security' is used where the concept 'safety' should be applied, as in these cases.

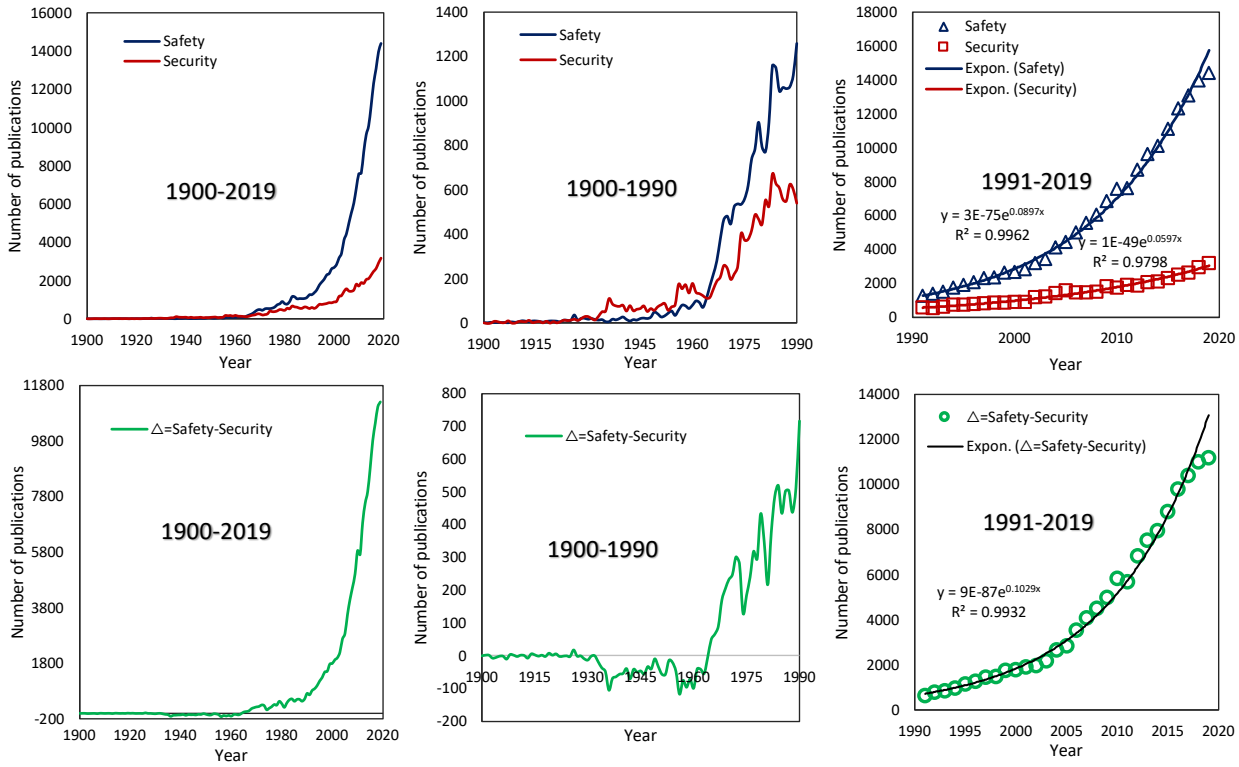

Figure 1. Publication trends of safety and security research, period 1900 to 2019, data retrieval process as in Section 2.1

Before 1930, the number of publications in the safety research domain is quite similar to the security research domain. From the 1930s onwards until 1964, the situation changed: during this period, the number of security-related publications surpassed the safety-related publications. Another trend reversal is identified from 1965. From that point onwards, the number of safety-related publications outpaced those related to security, a trend lasting until the present. The figure clearly shows that in recent years, safety-related research has attracted more attention than security in scientific communities.

3.1.2. Geographical distribution of the safety and security research domains

The geographic distribution of global safety and security research is shown in Figure 2 and Figure 3, providing an answer to the second research question of Section 3.2. The information about the geographical region is used as reported in Web of Science, which may lead to some biases as further discussed in Section 4. The top 20 of highly productive countries/regions in the respective research domains are listed in Table 2. These are ranked in terms of the total number of publications published, as is commonly done in scientometric analyses, see e.g. van Nunen et al. (2018a) and Merigó et al. (2019). In addition, information concerning the population size is added to the table and relative publication numbers by population size are reported. This provides further insights as to the relative contribution by capita to these scientific domains. For this, population data from 2019 as reported by UN (2019) is used. As the total number of populations are counted over more than 100 years and the population data only concerns one year, there is a potential for some bias in the comparison, but as a rather rough indication of the relative contribution to these scientific domains per capita, the analysis is considered appropriate.

In terms of total number of publications, the United States of America (USA) has published 74,418 papers in safety research, ranked first place in this research domain, followed by the United Kingdom (UK) (19,587), Germany (15,552), China (11,281) and Italy (10,439). The USA is, with 18289 papers, also the most productive country in security research, followed by UK (5356), China (3910), Canada (2463) and Germany (2252). Among the top 20 of highly productive countries/regions in absolute terms, there are 17 countries/regions which appear in both research domains (indicated with the symbol '■' in Table 2).

When further inspecting these top 20 productive countries/regions in terms of populations by capita, a rather different picture is obtained. In the safety research domain, Switzerland (656.7), Denmark (416.2), Belgium (397.3), the Netherlands (355.6), and Sweden (322.2) complete the top 5, whereas the USA (226.1) takes place 10, the UK (290.0) place 6, Germany (186.2) place 11, and Italy (172.4) place 12. China (7.9) drops to the 19th place in this re-ranked list. In the security research domain, Norway (92.4), the UK (79.3), Australia (78.2), Switzerland (76.1) and Canada (65.8) complete the top 5, whereas the USA (55.6) drops to place 7, China (2.7) to place 18, and Germany to place 10.

Overall, the results indicate that Russia, countries from the Middle East, South Asia, Africa, and South America are not very active in safety and security research, with the exceptions of India, South Africa, and Brazil. One possible explanation of this observation, or at least a possibly contributing factors to these findings, is that almost all publications in the WoS databases are written in English, whereas it is possible that other research publications are produced in locally or regionally important languages (and therefore not included in the WoS databases).

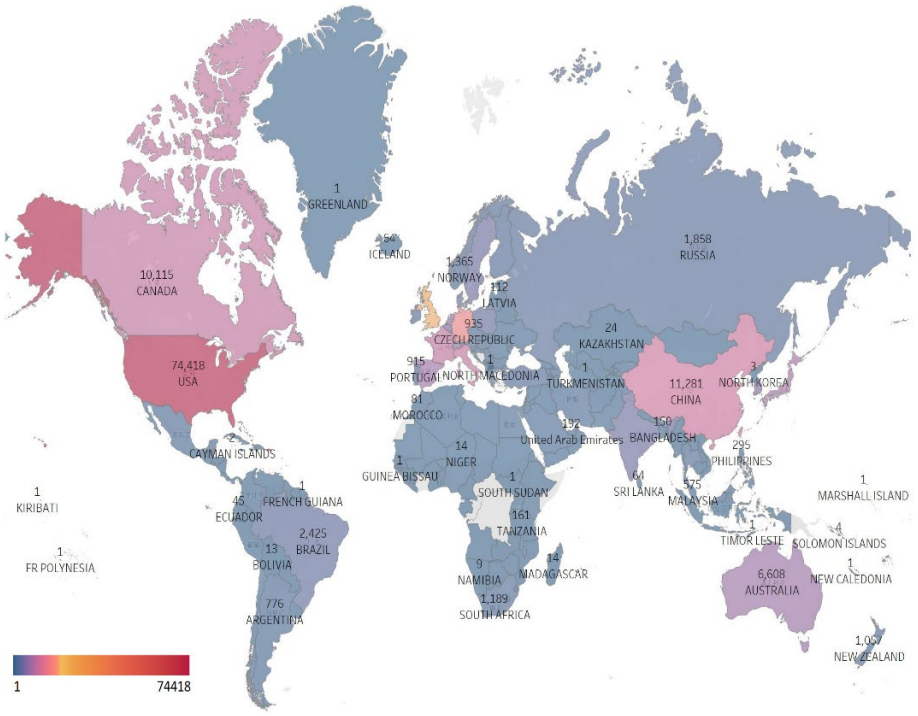

Figure 2. Geographic distribution of safety research, period 1900 to 2019, data retrieval process as explained in Section 2.1

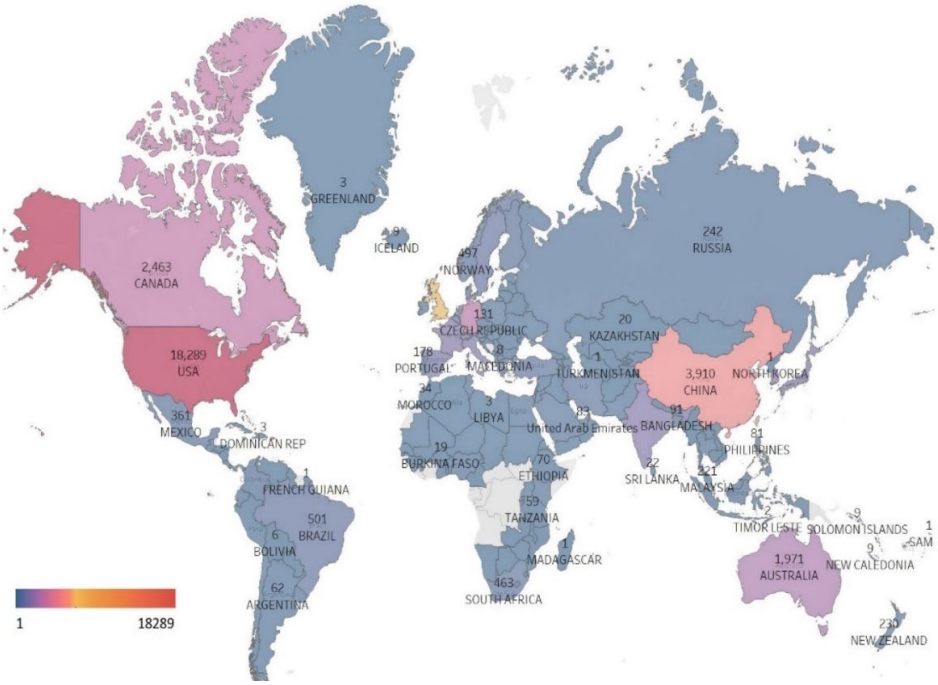

Figure 3. Geographic distribution of security research, period 1900 to 2019, data retrieval process as explained in Section 2.1

3.2 Core journals and position of journals and categories on global science map

3.2.1 Core journals of safety and security research

In this Section, an answer is sought to the third research question listed in Section 2.2, i.e. what are the core journals publishing on safety and security topics. Based on the datasets obtained from the Web of Science database according to Section 2.1, there are 10,057 journals which have published papers on safety, and 6,497 journals which contain publications on security. The results from Section 3.1.1 show that safety receives more attention as a research domain than the domain of security research, which is also reflected in the higher number of journals publishing on the topic.

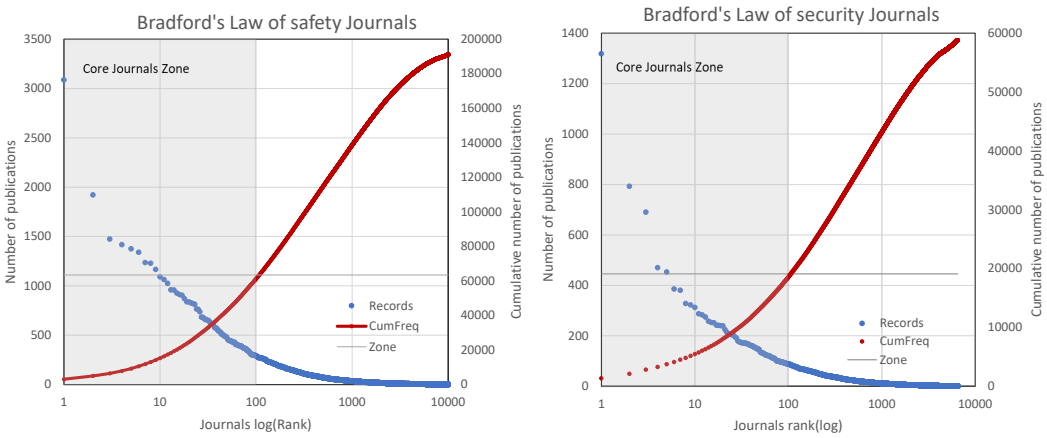

Figure 4. Identification of core journals of safety research (left) and security research (right), period 1900 to 2019, data retrieval process as in Section

The curves in Figure 4 show the journal's output distribution of safety and security research. The core zone of safety and security journals is identified based on Bradford's Law, as explained in Section 2.2. There are 107 out of 10,057 core safety journals and 106 out of 6,497 core security journals. This indicates that even though the number of publications in the domain of safety research is much higher than in the domain of security research, the number of core knowledge carriers of safety and security research is very similar. The figure shows that there are comparatively few key journals where safety and security are an important topic of research activity (marked with grey shaded background), whereas the concepts are also widely used in more peripheral research environments (marked with white background).

Highly productive journals on the topic of safety and security provide insights in which journals drive the research on these topics. Furthermore, through the journal names, a first indication can be obtained as to what topics, application domains, or knowledge areas are concerned with safety and security. A high-level comparison of the core journals in which safety and security research is published can also provide initial insights in to how well these domains are linked. The top 50 of most productive journals on the topic safety and security are listed in Table 3. Safety related research is mainly published in the Journal of Clinical Oncology (3086), Blood (1921), Annals of Oncology (1474), Abstracts of Papers of the American Chemical Society (1417) and Journal of the American College of Cardiology (1375). Security related papers are mainly published in Lecture notes in Computer Science (1318), International Affairs (793), Computer Security (690), Social Security Bulletin (470) and Business Lawyer (453).

As seen from the results in Table 3, there are several journals where research on both topics is published, creating areas where issues of common

interest and concern can be addressed. These journals are for instance Abstracts of Papers of The American Chemical Society (1417 safety papers, 126 security papers), Chemical Engineering News (660 safety, 242 security), and Aviation Week Space Technology (334 safety, 165 security). Finally, there are 617 articles with both 'safety' and 'security' in their titles.

The results of Table 3 however also indicate that the broad research domains of safety and security have different overall focuses. Safety research on a high level is mostly concerned with health and medical topics, where food safety, and safety in industrial and transportation contexts is comparatively less significant. However, security research focuses more on computer sciences, international affairs, and social sciences. Industrial applications appear to be a comparatively more significant research topic within security research than within safety research, although journals such as Safety Science, Accident Analysis and Prevention, and Reliability Engineering and System Safety, which appear in the top 50 journals in the broad safety domain, are considered among the core safety journals in industrial safety contexts (Li and Hale 2015, 2016).

3.2.2 Journals of safety and security research in global science map

This Section provides an answer to the fourth research question of Section 2.2, i.e. how the journals associated with the broad safety and security research domains are situated on the global journals map. The results of this analysis are displayed in Figure 5 and Figure 6. 5440 safety journals and 3290 security journals are matched and located in the layer of the journals map by Leydesdorff and his colleagues. From Figure 5, it is observed that safety-related journals are mainly located in medical, health, toxicological, clinical, psychological, physics, and materials related research domains. Ergonomics, certain mathematical domains, and policy-oriented research are included as well. From Figure 6, it is seen that security-related journals are mainly located in political and economic science, IT and communication systems, and to a lesser extent psychology, health, and mathematical sciences. Based on Figure 5 and Figure 6, safety research addresses a wider variety of topics and research domains compared to security science, as tentatively concluded earlier in Section 3.2.1 based on the identification of core journals.

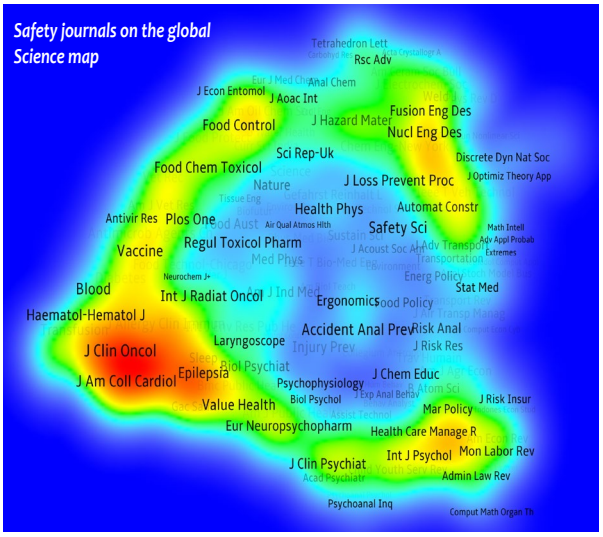

Figure 5. 5440 safety-related journals located in the global science map, period 1900 to 2019, data retrieval process as in Section 2.1

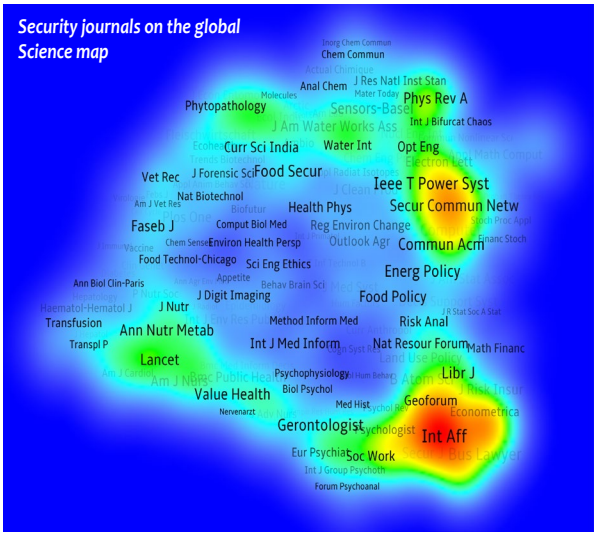

Figure 6. 3290 security-related journals located in the global science map, period 1900 to 2019, data retrieval process as in Section 2.1

Table 2. Highly productive (Top 20) countries/regions in safety and security research, period 1900 to 2019, data retrieval process as in Section 2.1

NO.	Countries/Regions	#SAFPUB	POP	#SAFPUB/POP	Countries/Regions	# SECPUB	POP	#SECPUB/POP
1	United States of America ■	74418	329.1	226.1	United States of America ■	18289	329.1	55.6
2	United Kingdom ■	19587	67.5	290.0	United Kingdom ■	5356	67.5	79.3
3	Germany ■	15552	83.5	186.2	China ■	3910	1433.8	2.7
4	China ■	11281	1433.8	7.9	Canada ■	2463	37.4	65.8
5	Italy ■	10439	60.6	172.4	Germany ■	2252	83.5	27.0
6	France ■	10199	65.1	156.6	Australia ■	1971	25.2	78.2
7	Canada ■	10115	37.4	270.4	South Korea ■	1317	51.2	25.7
8	Japan ■	7901	126.9	62.3	India ■	1172	1366.4	0.9
9	Spain ■	7162	46.7	153.2	France ■	1115	65.1	17.1
10	Australia ■	6608	25.2	262.2	Italy ■	1062	60.6	17.5
11	the Netherlands ■	6080	17.1	355.6	Japan ■	992	126.9	7.8
12	Switzerland ■	5642	8.6	656.7	Spain ■	859	46.7	18.4
13	South Korea ■	4958	51.2	96.8	Netherlands ■	836	17.1	48.9
14	Belgium ■	4584	11.5	397.3	Switzerland ■	654	8.6	76.1
15	Sweden ■	3234	10.0	322.2	Sweden ■	600	10.0	59.8
16	India ■	3148	1366.4	2.3	Taiwan	589	23.8	24.8
17	Poland	2507	37.9	66.2	Brazil ■	501	211.0	2.4
18	Brazil ■	2425	211.0	11.5	Belgium ■	500	11.5	43.3
19	Denmark	2402	5.8	416.2	Norway	497	5.4	92.4
20	Austria	2323	9.0	259.4	South Africa	463	58.6	7.9

Notes: #SAFPUB: Total number of publications on safety | #SECPUB: Total number of publications on security | POP: Population total in 2019 (million)
■: appears both in the top 20 ranking for safety and security in terms of absolute numbers | population data from (UN, 2019).

Table 3. Top 50 Journals in safety (left) and security (right) research, period 1900 to 2019, data retrieval process as in Section 2.1

Safety Journals	Records	% Tot	Security Journals	Records	% Tot
Journal of Clinical Oncology	3086	1.62	Lecture Notes in Computer Science	1318	2.30
Blood	1921	1.01	International Affairs	793	1.38
Annals of Oncology	1474	0.77	Computers Security	690	1.20
Abstracts of Papers of the American Chemical Society	1417	0.74	Social Security Bulletin	470	0.82
Journal of the American College of Cardiology	1375	0.72	Business Lawyer	453	0.79
Safety Science	1340	0.70	IEEE Security & Privacy	385	0.67
Vaccine	1236	0.65	IEEE Transactions on Power Systems	380	0.66
Annals of the Rheumatic Diseases	1228	0.65	Annals of the American Academy of Political and Social Science	328	0.57
Gastroenterology	1166	0.61	IEEE Access	322	0.56
Circulation	1090	0.57	Security Dialogue	312	0.55
Pharmacoepidemiology and Drug Safety	1062	0.56	Securities Regulation Law Journal	287	0.50
Accident Analysis and Prevention	1025	0.54	International Labour Review	283	0.49
Lancet	959	0.50	Security and Communication Networks	274	0.48
Neurology	957	0.50	Food Security	258	0.45
Hepatology	926	0.49	Political Science Quarterly	253	0.44
European Heart Journal	911	0.48	American Political Science Review	251	0.44
American Journal of Cardiology	904	0.48	Chemical Engineering News ■	242	0.42
Journal of the American Academy of Dermatology	869	0.46	Journal of Finance	241	0.42
Gastrointestinal Endoscopy	837	0.44	International Journal	240	0.42
Drug Safety	836	0.44	Foreign Affairs	239	0.42
Journal of Urology	826	0.43	Science	225	0.39
Investigative Ophthalmology & Visual Science	819	0.43	Journal of Peace Research	214	0.37
Diabetes	812	0.43	Communications of the Association for Computing Machinery	208	0.36
Transportation Research Record	765	0.40	Computer	207	0.36
Expert Opinion on Drug Safety	761	0.40	American Economic Review	204	0.36
Plos One	736	0.39	Energy Policy	201	0.35
Arthritis and Rheumatism	682	0.36	Library Journal	195	0.34
American Journal of Respiratory and Critical Care Medicine	680	0.36	Pacific Affairs	190	0.33

Safety Journals	Records	% Tot	Security Journals	Records	% Tot
British Medical Journal	663	0.35	Gerontologist	179	0.31
Chemical Engineering News ■	660	0.35	Europa Archiv	175	0.31
American Journal of Gastroenterology	649	0.34	IEICE Transactions on Fundamentals of Electronics Communications and Computer Sciences	174	0.30
Transactions of the American Nuclear Society	648	0.34	Journal of Strategic Studies	172	0.30
Haematologica	635	0.33	Millennium Journal of International Studies	172	0.30
Injury Prevention	615	0.32	Internasjonal Politikk	171	0.30
Journal of Allergy and Clinical Immunology	611	0.32	Kriminalistik	171	0.30
Journal of Hepatology	610	0.32	Internationale Politik	168	0.29
Arthritis Rheumatology	576	0.30	Osteuropa	168	0.29
Journal of the American Medical Association	572	0.30	Aviation Week & Space Technology	165	0.29
Nuclear Engineering and Design	568	0.30	Wireless Personal Communications	162	0.28
Clinical Pharmacology Therapeutics	548	0.29	Food Policy	161	0.28
Allergy	545	0.29	Australian Journal of International Affairs	160	0.28
Cancer Research	530	0.28	American Journal of International Law	159	0.28
Epilepsia	528	0.28	American Historical Review	154	0.27
Transfusion	508	0.27	Oil & Gas Journal	154	0.27
Value in Health	505	0.27	Department of State Bulletin	153	0.27
Nuclear Safety	495	0.26	Annals of Nutrition and Metabolism	148	0.26
Food Control	489	0.26	Bulletin of the Atomic Scientists	148	0.26
Reliability Engineering & System Safety	485	0.26	Sustainability	147	0.26
Diabetologia	483	0.25	Korean Journal of Defense Analysis	145	0.25
Multiple Sclerosis Journal	470	0.25	Yale Law Journal	136	0.24

Notes: % Tot: Percentage of the total number of publications in safety (190346) and security (57293) related research, total numbers as per Figure 1 | ■: journals appearing in both the top 50 journal list of journals publishing on safety and security research

3.2.3 Categories of scientific domains of safety and security research in global science map

This Section provides answers to both the fifth and sixth research questions identified in Section 2.2, i.e. what scientific categories are associated with safety and security research, and how these are distributed across the global science map. There are more than 200 Web of Science categories in both safety and security research. The top 50 of Web of Science categories of the safety and security research domains are shown in Table 4.

The categories covered by the safety and security research domains in light of their location on the science map by Leydesdorff et al. (Leydesdorff et al., 2013a) are shown in Figure 7 and Figure 8. In these figures, the size of the node labels is normalized by $\log_4(n+1)$, where n is the number of publications in a journal in the dataset (Leydesdorff et al., 2013b). From the figures, it is seen that for most categories, only a relatively small number of papers (the size of the nodes is small) are related to safety and security, i.e. safety and security research is strongly clustered in a relatively small number of scientific categories.

In the category analyses of Figure 7 and Figure 8, DIV* diversity metrics are calculated to measure the interdisciplinary of the safety and security research domains, as outlined in Section 2.2. The results indicate that safety research has a higher diversity (DIV*=59.883) than security research (DIV*=44.509), but also that these domains are overall not highly diverse. Figure 7 and Figure 8 show a relatively high variety of scientific categories in which safety and security are addressed, but there is a significant imbalance in the relative importance of these categories, and the ones where significant research is performed are associated with sets of categories associated with relatively similar disciplines. Furthermore, while the results suggest that safety research is more interdisciplinary than security research, it is also apparent that the most significant categories are quite different between these research domains.

Table 4. Top 50 of WoS categories of safety (left) and security (right) research, period 1900 to 2019, data retrieval process as in Section 2.1

Safety research	Records	% Tot	Security research	Records	% Tot
Pharmacology pharmacy	16030	8.42	International relations	6938	12.11
Oncology	12394	6.51	Political science	6417	11.20
Public environmental occupational health	11229	5.90	Computer science information systems	5650	9.86
Medicine general internal	9925	5.21	Engineering electrical electronic	5189	9.06
Cardiac cardiovascular systems	9216	4.84	Economics	4981	8.69
Clinical neurology	8998	4.73	Law	4718	8.24
Surgery	8654	4.55	Telecommunications	3459	6.04
Gastroenterology hepatology	7704	4.05	Computer science theory & methods	3095	5.40
Immunology	7315	3.84	Computer science & software engineering	2772	4.84
Hematology	6881	3.62	Area studies	2037	3.56
Medicine research experimental	5475	2.88	Computer science hardware architecture	1918	3.35
Nuclear science technology	5277	2.77	Business finance	1896	3.31
Toxicology	5249	2.76	Sociology	1299	2.27
Food science technology	5136	2.70	Environmental sciences	1275	2.23
Rheumatology	4202	2.21	Public administration	1268	2.21

Safety research	Records	% Tot	Security research	Records	% Tot
Infectious diseases	4170	2.19	Public environmental occupational health	1218	2.13
Peripheral vascular disease	4161	2.19	Social issues	1214	2.12
Urology nephrology	4144	2.18	Environmental studies	1137	1.99
Endocrinology metabolism	4122	2.17	Multidisciplinary sciences	1095	1.91
Pediatrics	3985	2.09	Social sciences interdisciplinary	1079	1.88
Health care sciences services	3948	2.07	Information science library science	1058	1.85
Engineering chemical	3944	2.07	Criminology penology	966	1.69
Neurosciences	3902	2.05	Energy fuels	899	1.57
Respiratory system	3892	2.05	Computer science artificial intelligence	853	1.49
Radiology nuclear medicine medical imaging	3786	1.99	Management	837	1.46
Dermatology	3622	1.90	History	806	1.41
Engineering civil	3606	1.89	Food science technology	792	1.38
Psychiatry	3604	1.89	Business	743	1.30
Chemistry multidisciplinary	3419	1.80	Medicine general internal	703	1.23
Engineering industrial	3263	1.71	Industrial relations labor	699	1.22
Environmental sciences	3177	1.67	Nutrition dietetics	696	1.22
Transportation	2981	1.57	Computer science interdisciplinary applications	674	1.18
Obstetrics gynecology	2954	1.55	Engineering chemical	652	1.14
Critical care medicine	2718	1.43	Development studies	622	1.09
Transplantation	2690	1.41	Optics	596	1.04
Biotechnology applied microbiology	2632	1.38	Social work	573	1.00
Nursing	2632	1.38	Geography	544	0.95
Ophthalmology	2496	1.31	Operations research management science	542	0.95
Multidisciplinary sciences	2390	1.26	Chemistry multidisciplinary	523	0.91
Operations research management science	2368	1.24	Instruments instrumentation	497	0.87
Microbiology	2318	1.22	Engineering multidisciplinary	492	0.86
Health policy services	2313	1.22	Psychiatry	490	0.86
Ergonomics	2274	1.20	Health care sciences services	469	0.82
Engineering electrical electronic	2240	1.18	Water resources	461	0.81
Anesthesiology	2222	1.17	Green sustainable science technology	413	0.72
Allergy	2015	1.06	Psychology developmental	412	0.72
Social sciences interdisciplinary	1938	1.02	Mathematics applied	400	0.70
Veterinary sciences	1900	1.00	Psychology multidisciplinary	391	0.68
Transportation science technology	1899	1.00	Gerontology	367	0.64
Engineering multidisciplinary	1880	0.99	Agricultural economics policy	358	0.63

Notes: % Tot: Percentage of the total number of publications in safety (190346) and security (57293) related research, total numbers as per Figure 1

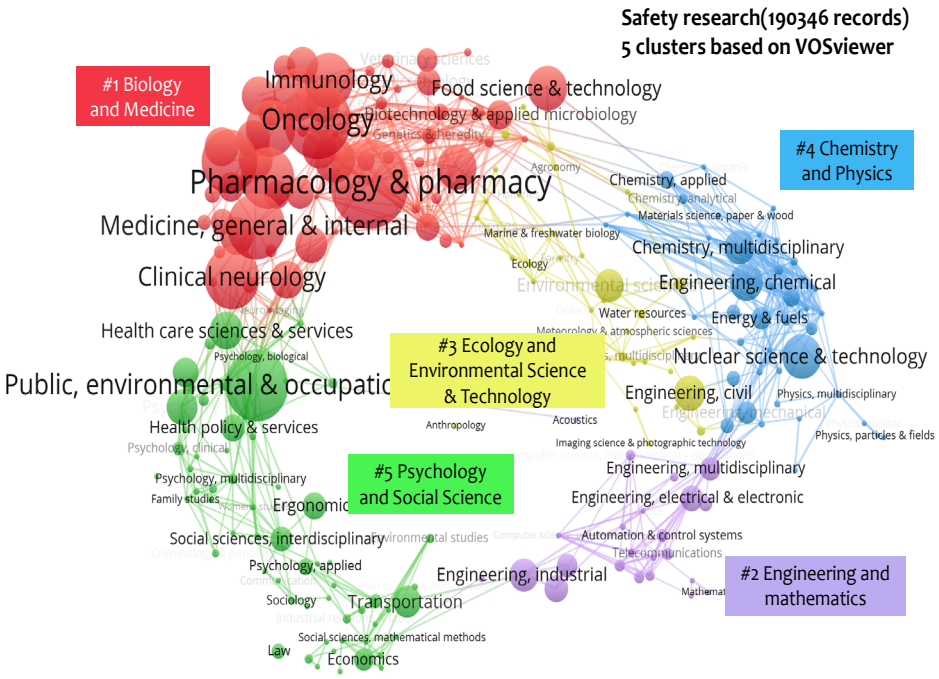

Figure 7. Categories overlay map of safety-related publications (DIV* diversity=59.883), period 1900 to 2019, data retrieval process as explained in Section 2.1

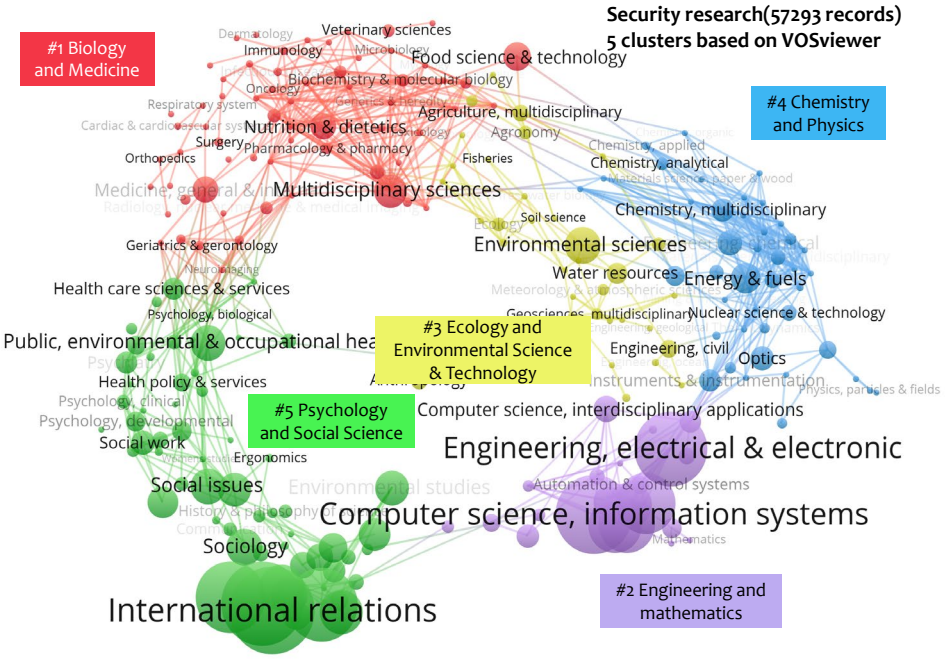

Figure 8. Categories overlay map of security-related publications (DIV* diversity=44.509), period 1900 to 2019, data retrieval process as explained in Section 2.1

For further interpreting Figure 7 and Figure 8, 5 clusters can be distinguished from the global Web of Science categories map (Rafols et al., 2010), including #1 'Biology and Medicine', #2 'Engineering and Mathematics', #3 'Ecology and Environmental Science & Technology', #4 'Chemistry and Physics', and #5 'Psychology and Social Sciences'.

The safety research is mainly located in the #1 'Biology and Medicine' cluster, showing that safety research not only an important, but also a highly active research focus in these areas. In this category, 'Pharmacology and pharmacy' (16030) and 'Oncology' (12394) are the primary research categories. While clearly a very important area of safety-related research, this cluster concerns highly specialized medical and biological knowledge. This is a quite distinct knowledge domain compared to the safety topics in focus in well-known core safety journals as identified by Li and Hale (Li and Hale, 2015; Li and Hale, 2016). Those include system modelling, organizational management of major hazards, road transport safety, safety culture and climate, and accident consequence analysis. The high-level analysis of the safety research domain also differs from or the topics covered in Safety Science, one of the flagship journals of the safety research domain, as found by Merigó et al. (Merigó et al., 2019), and listed as number 6 in the top 50 of journals publishing on safety research (Table 3). This is also evident from the fact that Safety Science is categorized in the research categories 'Operations Research & Management' and 'Engineering, Industrial' based on the Journals citation report (published by Clarivate Analytics), whereas other key safety journals relate to ergonomics, transportation, and engineering research areas (Li and Hale, 2015; Li and Hale, 2016). Hence, several important categories for safety-related research are located in the other categories than #1 'Biology and Medicine'. For example: 'Public environmental occupational health' (11229), 'Nuclear science & technology' (5277) and 'Engineering, chemical' (3944).

One possible explanation of the observation that safety related research is significantly more prevalent in areas related to medical sciences, medicine, and clinical research, than in for instance areas focusing on industrial safety, is that the overall rate and speed of scientific production in the medical sciences is higher than in industrially focused research areas (STM, 2018). It is widely accepted that safety research is derived from the actual needs of human beings and is regarded as one of the basic needs (Maslow, 1943). Hence, it can be argued that health-related safety, as covered in medical-related safety research, has a closer relationship with human needs than for instance industrial or transportation safety.

The papers related to security research are mainly located in the clusters #2 'Engineering and Mathematics' and #5 'Psychology and Social Science'. In the former, 'Computer science information systems' (5650), 'Engineering, electrical & electronic' (5189), 'Telecommunications' (3459), 'Computer science theory & methods' (3095), and 'Computer science software engineering' (2772), are important scientific categories. In the latter, 'International relations' (6938), 'Political science' (6417), 'Economics' (4981), 'Law' (4718), 'Area studies' (2037), 'Business finance' (1896) and 'Sociology' (1299) are highly productive areas and hence important scientific categories in security research.

These analyses clearly show that safety and security research differ significantly in the kinds of topics which are addressed, and the scientific categories which are primarily associated with these topics. As outlined in Section 1, the concepts of safety and security are sometimes difficult to distinguish. However, empirical evidence suggests that in fact the concepts are associated with significantly different knowledge domains and research activities. There are however several scientific categories where there is an important activity in both research domains. For instance, in Public, Environmental and Occupational Health (1129 safety papers, 1218 security) and Engineering Electrical Electronic (2240 safety, 5189 security).

3.3 Key research topics in safety and security research

In Section 3.2, high-level differences and similarities between the broad safety and security research domains are identified based on an investigation of the core journals publishing articles in these domains, and of the scientific categories with which these are associated. In this Section, an analysis focusing on keywords is presented to answer the final research question identified in Section 2.2. Keywords are chosen as these provide more detailed insights in the specific topics and themes associated with both domains. To obtain such insights, the dataset of papers with 'safety' or 'security' in the title and published in 2019, were downloaded as outlined in Section 2.1. In total, 14390 records in safety research and 3198 records in security research are obtained. The analysis focuses on the author keywords, which are indicative of the research topics addressed in the articles.

Raw keywords are first cleaned up and standardized to improve the consistency of the keywords, which is a necessary process in scientometric analyses (Li et al., 2020b). Subsequently, the top 300 most frequently occurring keywords from the safety and security research domains are extracted and analysed using VOSviewer. A choice of 300 keywords is made to provide a broad insight in the various main narrative themes in safety and security research. Finally, the keywords co-occurrence networks are visualized by Gephi. Figure 9 and Figure 10 show the keyword co-occurrence networks of hot topics of safety and security research. The top 20 of highly frequently used keywords are listed in Table 5. In Figure 9 and Figure 10, the least frequently occurring keywords have 5 and 4 occurrences, respectively.

In 2019, the broad domain of safety research focuses mainly on medicine and drug safety, and safety associated with different diseases and their treatments. In these lines of research, there is a strong focus on 'efficacy', as this is found to be the most frequently occurring keyword (apart from 'safety'). While safety related to medicine, drugs, medical conditions and treatments are clearly the dominant narrative themes in the broad safety research domain, there are other domains in which safety research is important. These include food safety, patient safety, occupational health and safety, and safety in various industrial contexts such as construction and transportation. In these latter subdomains, topics like risk assessment, safety management, resilience, human factors, risk perception and safety climate/safety culture are significant topics.

Key research themes in security research are broad societal themes such as food security, energy security, social security, and national security. These themes are linked to scientific categories such as 'international relations', 'political science', 'environmental sciences', 'public administration', and 'social issues' identified in Section 3.2.3. Food security is strongly linked to climate change, ecosystem services, agriculture, aquaculture, poverty, and sustainability, reflecting that food security strongly links to large-scale global risks and societal governance. Likewise, energy security links with renewable energy, water management, and sustainable development. Social security is linked with development and governance, whereas national security is linked with terrorism, geopolitics, intelligence, and cooperation.

Another major theme in security research is more related to scientific categories such as 'telecommunications', 'computer science theory & methods', and 'computer science & software engineering'. Important keywords in such technology-oriented security research include internet of things, information security, cyber security, physical layer security, which are connected to a wide range of terms from computer and information sciences, such as phishing, machine learning, cyber-attack, cloud computing, big data, blockchain, and network security.

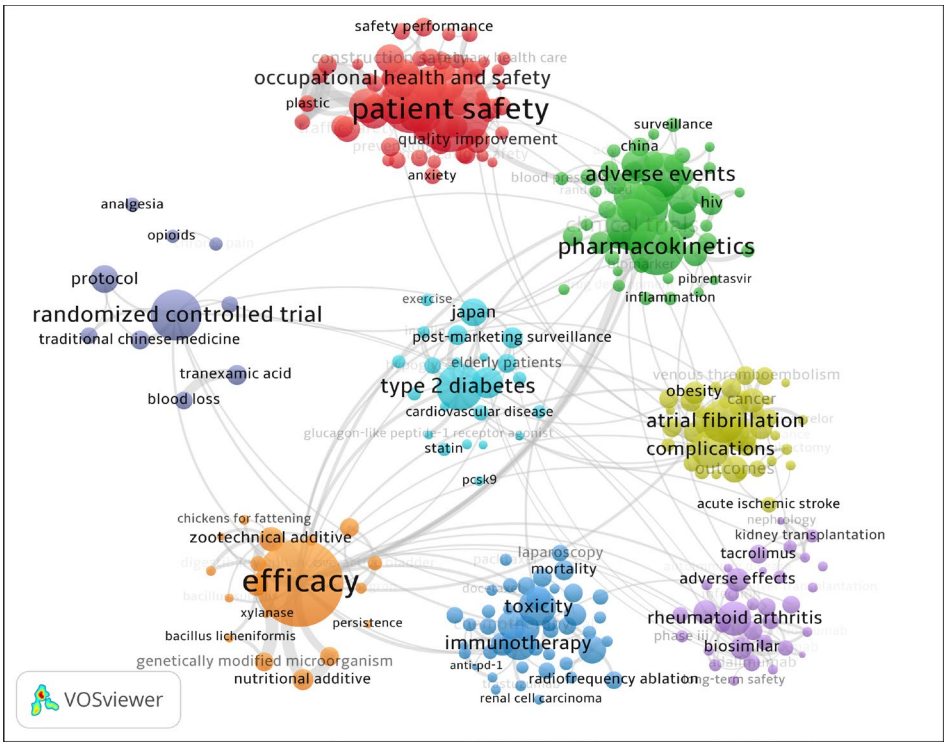

Figure 9. Key safety research topics in 2019: network with 300 most frequently used author keywords, data retrieval process as explained in Section 2.1

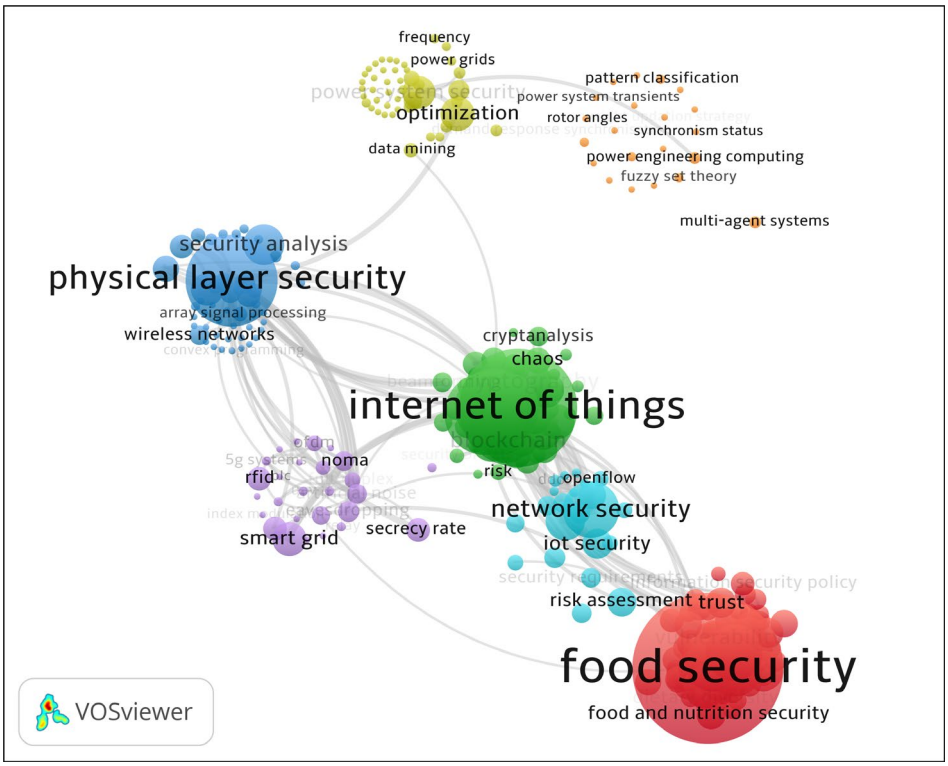

Figure 10. Key security research topics in 2019: network with 300 most frequently used author keywords, data retrieval process as explained in Section 2.1

Table 5. Top 20 of most frequently occurring keywords in safety (left) and security (right) research, data retrieval process as in Section 2.1, 'safety' and 'security' are excluded from these lists

Keywords in Safety research	Occurrences	Keywords in Security research	Occurrences
efficacy	290	food security	195
patient safety	261	internet of things	131
food safety	150	physical layer security	85
pharmacokinetics	135	cybersecurity	73
clinical trials	121	information security	64
randomized controlled trial	119	privacy	50
children	101	cloud computing	45
type 2 diabetes	100	china	39
adverse events	95	energy security	38
atrial fibrillation	88	network security	38
occupational health and safety	75	authentication	37
complications	71	climate change	35
risk assessment	71	blockchain	27
toxicity	70	cryptography	27
immunogenicity	64	encryption	26
immunotherapy	63	European union	25
rheumatoid arthritis	60	food insecurity	25
safety assessment	60	water security	25
safety climate	60	data security	24
safety culture/ safety management	58	gender	24

4. Discussion

4.1 Identifying common grounds for security and safety research

Comparing safety and security research, it is evident that on a global research level, safety is closer to the natural sciences, with a very strong link to medicine-related scientific disciplines. There are also notable scientific categories related to engineering, technology, and selected social sciences, with industrial engineering, chemical engineering, nuclear science and technology, civil engineering, and transportation among the most prominent. Security related research shows a different high-level profile, with a much more focused and narrower focus on social science issues related to international relations, political science, and law, and a strong focus on issues related to food security in relation to climate change and related global environmental phenomena.

In medically oriented safety science research, experiments (e.g. trials in the medical area) are an important way to obtain insights in understanding of the mechanisms of diseases, causes, and treatments, and related safety problems. However, as found in Section 3.2 and Section 3.3, safety also addresses various technological and social science areas of knowledge, in which topics such as personal and organizational behaviours, perceptions, human factors play an important role, in addition to often technology- and engineering-oriented themes related to different industrial application domains. The knowledge underlying to such work relates to natural sciences, chemistry, and physics on the one hand, as applied through engineering disciplines and often relying on mathematical modelling. On the other hand, industrial safety relies heavily on applied social science and psychological knowledge obtained through observations and qualitative research methods.

Compared to safety research, security has a relatively stronger focus on engineering sciences and mathematics, in which disciplines related to electronics, computer science, and information systems are very strongly represented. Focus topics in security research relate to information/cybersecurity or other new emerging IT technologies. As a prime example of this, prominently present in the keywords map of Figure 10, the internet of things is an emerging technology, which allows humans to remotely connect with objects anytime and anyplace, ideally using any network and service (Kamran et al., 2020). As a key technology to drive the so-called fourth industrial revolution (Industry 4.0), internet of things has become popular in recent years in various industrial domains. Increased interconnectivity through digital services can take us into a new world of connected intelligence and data analytics, leading to new services, higher efficiency and productivity, and disruptive changes to many industry sectors, including manufacturing (Brettel et al., 2014), logistics (Hofmann and Rüsch, 2017), and transport (Kans et al., 2016). Increased system safety is often raised especially by industry stakeholders as an important driver for increased autonomy for instance in the maritime industry (Goerlandt, 2020), whereas it has been argued that new safety paradigms relying on systems theories and resilience need to be developed to cope with the safety concerns which these new technologies and systems raise (Leveson, 2012; Dekker S, 2018). Furthermore, concerns have been raised about the implications of the technologies and processes related to Industry 4.0 on occupational health and safety (Badri et al., 2018). Furthermore, with many interconnected devices, remote operations relying on digital infrastructures and communication systems, hackers have opportunities to attack the integrity of systems (Liu and Zhang, 2020). Hence, there are many security-related challenges with the move towards increased digitalization, interconnectivity, and remote operation, in addition to the mentioned safety challenges.

Considering the results of Section 3.2.3 and Section 3.3, it is apparent that safety and security research has several areas where integration efforts and cross-domain fertilization of ideas can be academically fruitful and lead to new concepts, methods, and applications in especially industrial contexts. In particular, it can be argued that with the development of knowledge-intensive and large-scale systems, safety and security should be integrated in research agendas and in practical application contexts. This appears especially relevant for in complex socio-technical and cyber-physical systems, because for such systems safety and security represent two partially complimentary or conflicting conceptual domains, where security measures may conflict with safety goals and vice versa (Cusimano and Byers, 2010; Schnieder et al., 2010).

Hence, a cross-fertilization between these research domains, in terms of the underlying theories, methods, models, tools and techniques, can be considered critical to the continued safe and secure operation of existing systems, and especially for the increasingly interconnected socio-technical and cyber-physical systems of the future (Piètre-Cambacédès and Bouissou, 2013; Brostoff and Sasse, 2001; Bloomfield et al.). Several research contributions have focused specifically on such integration-oriented work (Young and Leveson, 2014; Young and Leveson, 2013; Kriaa et al., 2015; Eames and Moffett, 1999; Steiner and Liggesmeyer; Stoneburner, 2006; Reniers et al., 2020), further justifying this view.

However, as found in the analysis of Section 3.2.1 and Section 3.2.2, there currently are few journals where safety and security are important research themes, even though a focus on safety and security in industrial and technological domains is clearly apparent from the results of Section 3.2.3 and Section 3.3. As found in Section 3.2.1, this relatively small number of journals which publish articles on both safety and security furthermore has a strong disciplinary focuses, with especially journals targeting chemical and aerospace industries providing a platform to bridge these knowledge domains.

This lack of journals providing a platform for broad cross-fertilization of ideas, concepts, theories,

methods, and techniques between the safety and security domains focusing on socio-technical and cyber-physical systems across industry sectors, justifies the objective and scope of the Journal of Integrated Security and Safety Science (JISSS) to locate itself in this space. This journal addresses the broad spectrum of security areas, including e.g., terrorism, piracy, theft, and sabotage, and the broad spectrum of safety areas, including process safety, transportation safety, and occupational safety. Its focus is on empirical work, technology or method development, and management strategies concerning the integration of security and safety in the chemical and process industries, oil and gas, transportation systems, power plants, drinking water and water treatment systems, and other industrial and commercial facilities. Based on the domain-specific findings of Sections 3.2.3 and 3.3, it is justifiable that its topics can relate to safety and security behaviours and perceptions, safety and security culture, safety and security analysis models and methods for likelihood, vulnerability, and consequences, new and emerging technologies, and decision making approaches. It is hoped that this journal can invigorate cross-domain integration, leading to novel solutions for addressing the practical security and safety related challenges in industrial environments.

4.2 Study limitations and future work

As in any study, there are several limitations which may have an influence on the results. A first issue is the chosen article database. While Web of Science is generally regarded as one of the most comprehensive databases with the highest quality for scientometric analyses (Li et al. 2020), it is known that the coverage differs somewhat between different academic databases such as Web of Science, Scopus, ProQuest, and Google Scholar, with some variations between scientific disciplines (Gusenbauer, 2019). The choice of Web of Science hence may lead to some biases in the results, and it may be valuable to perform a similar analysis using another academic database in future research.

A second issue concerns the language of the article database. As mentioned already in Section 2.1, the restriction to English as the language in focus of the Web of Science database, this may lead to some biases and blind spots in the analysis, as authors in traditionally less English-language oriented countries may be reluctant to publish in English. This may furthermore lead to some biases in the results of the geographic distribution of safety and security related work as reported in Section 3.1.2. Another possible bias in the geographic distribution is that the origin of an article is taken as reported in the Web of Science database. Given the trends in researcher mobility and increased international collaboration (Wagner and Leydesdorff, 2005), it may be that the geographical location associated with the publications is not entirely representative of the location(s) where the research is executed.

A related issue concerns the issue of ambiguity in languages. As outlined in the introduction, several languages do not make a distinction between safety and security. Hence, it is possible that certain authors, when writing in English as a second language, use one term while actually addressing the other. This may to an unknown extent influence the results in Section 3.

Another issue concerns the analysis of the temporal evolution of the research outputs, reported in Section 3.1.1. Apart from the linguistic issues which may influence these patterns as mentioned above, it is difficult to provide clear explanations for the observed trends. In particular, it is uncertain what subdomains of safety and security research (e.g. medical safety, food safety, industrial safety, social security, national security, food security, cyber security, etc.) have contributed to drive the overall trends over time. Given the very wide scope of safety and security related research as evident from Section 3.2.3 and Section 3.3, it is plausible that different subdomains have disproportionally contributed over time. This is a topic for future research.

Another important limitation which possibly leads to some biases and blind blind spots is the chosen

search strategy. To obtain a broad insight in the scientific domains, a search strategy using the terms 'safety' and 'security' has been adopted in Section 2.1. A first possible bias this introduces is that journals which focus on these concepts may in fact be underrepresented in the results based on the adopted title-based search strategy, as it is conceivable that authors publishing on core safety and security journals would not include these terms explicitly in the article title as it is clear from the context that those are in focus. Explicitly adding all articles from journals where 'safety' or 'security' appear in the journal name may alleviate this concern. Another possible challenge to the search strategy is that adding words related to 'safety' or 'security', such as 'hazard', 'risk', 'accident', 'threat', etc. may give a more comprehensive and wider image of the research domains. However, while such alternative search strategies may alleviate some limitations, the authors have consciously chosen the strategy as described in Section 2.1. For instance, adding all articles in journals which contain 'safety' in the journal can lead to another type of bias, as there may then be many articles related to safety-related terms such as risk and resilience, which however are conceptually different to 'safety', see e.g. (Meyer T and Reniers G, 2016). Moreover, from an analysis by Li and Hale (2015, 2016), it is known that many journals (even core journals) on safety science do not have the word 'safety' in their journal name, for instance Journal of Loss Prevention in the Process Industries, Accident Analysis and Prevention, and Ergonomics. Hence, simply adding journals with safety in the title would likely still need to (other) biases, with a significant drawback of a much more obfuscated rationale of inclusion or exclusion of certain sources. Likewise, adding search terms such as 'hazard', 'accident', 'risk', or 'resilience' would likely lead to a broader coverage of the safety domain, but will likely also lead to other biases. For instance, financial and economic risks are an important aspect of risk research, but are less directly a matter of safety. Other additional search terms will similarly lead to including literatures in the dataset which are only tangentially or even not at all related to safety. Considering also that there is no definite list of safety-related terms, which implies that there would likely still be gaps in the work which would be found to address 'safety', it is considered better to keep the search strategy simple and include only 'safety'. In this context, it is observed that in a recent edited volume entitled 'Handbook of Safety Principles' (Möller N., 2018), only 15 of the 30 contents-chapters (excluding introduction and preview) contain the word 'safety'. While justifying terminology and search terms for other safety principles may be possible based on the contents of such a book, the terms are often so broad (e.g. 'experience feedback', 'operating procedure', and 'human-machine system') that there would be very many non-relevant records included in the resulting dataset. Based on the above considerations, while acknowledging its possible biases and limitations, the authors find the adopted simple and clear search strategy defensible. In future research, the extent to which these choices in the search strategy and possible alternative ways to delineate these fields affect the findings, could be investigated.

Finally, as evident from the results in Section 3, safety and security are very broadly applied terms in many scientific research domains. While scientometric methods are useful to obtain high-level insights in the structure of these broad research domains to obtain high-level insights in the core journals, scientific categories, and focus research themes and topics, these analysis techniques do not easily lend themselves to a more detailed comparative analysis of the contents of the domains. More detailed insights into the main themes and focus topics of the subdomains of safety and security research could be obtained with scientometric analysis and visualization techniques, if a more narrowly defined dataset is selected for analysis. Considering the results of Section 3, which indicate that there are various large sub-domains within safety and security research associated with a variety of scientific categories (see for instance Figure 5 and Figure 6, and Figure 7 and Figure 8), it would be valuable to further investigate the similarities and differences between safety and security in more specific domains. This can be done either through selecting

more specific search terms in the data search process, or by restricting the search to cover only selected scientific categories or journals. Such comparative analyses of safety and security can also focus on different industries, for instance chemical and process safety and security, nuclear safety and security, maritime transportation safety and security, etc. Even then, scientometric analysis and visualization methods are mostly suited for detecting high-level patterns, trends, and clusters, and are not very well suited to obtain insights in the intricacies of the concepts, ideas, theories, methods, and approaches used in the different domains. When focusing on more specific comparisons between safety and security, it is therefore advisable to adopt other narrative review types in addition to scientometric analyses, such as those reported in (Grant and Booth, 2009). It is hoped that the current work can lead to such further comparative research.

5. Conclusion

In this article, high-level insights in the developments, similarities and differences of the safety and security research domains are obtained based on a large-scale and broad analysis of the literature available in Web of Science. These research domains have been analysed and compared, which gives unprecedented empirically grounded insights in the similarities and differences between those domains. Further insights are obtained concerning overall temporal development trends, the geographic distribution of active countries, the position of journals and scientific categories in the global science map, and recent key themes and focus topics in the research domains.

It can be concluded that both safety and security research have long histories in the scientific communities, where records in both domains date back to at least 1900. During the past half-century, safety research has seen more research activity than security, with the gap in overall research activity further widening every year. Only in the period 1930-1964, the security-related output outpaced the safety research. However, due to the chosen very broad search strategy, the results do not provide more detailed insights into which of the multiple subdomains of these broad scientific domains concerned with safety and security are the drivers behind the temporal evolutions. More detailed follow-up research in this direction may be fruitful. The geographic distribution of safety and security research shows that overall, the United States of America, the United Kingdom, Germany and China are highly productive countries in both research domains, in terms of the total number of articles published. When considered per capita, several western and northern European countries are the most productive in safety related research, whereas for security related research, highly productive countries are in northern and western Europe, in addition to Australia and Canada. While China is very productive in absolute numbers, when considered per capita its relative importance is considerably lower. In addition, Russia, and countries from South Asia, Africa, South America and the Middle East show comparatively very little research activity, with only a few exceptions.

From the global distribution of the journals and categories, it is evident that safety and security are very wide and multidisciplinary research fields. The diversity measure applied to the categories shows that safety research is more diverse than security research. Furthermore, whereas both research domains show research activity across many scientific categories, the relative importance between the categories is highly unbalanced for each concept, and different categories are associated with safety and security. The high-level analysis indicates that on the overall broad level safety research is more closely related to natural sciences and technology, whereas security is more related to social sciences and technology. Globally, safety-related research is primarily located in medical-related and clinical areas, even though flagship journals such as Safety Science focus on more socio-technical topics related to industrial safety. System safety and occupational health and safety represent a significant subset of the overall safety related research but is significantly smaller in scale compared to health- and medical-related research. Compared with safety, security research

is more embedded in social sciences, with disciplines such as international relations, political science and economics very significant contributors. Furthermore, security research has a very strong link to the computer, electric and electronical engineering research areas as well.

Based on a focused analysis of the research domains based on data from 2019, it is found that recent topics in safety research very strongly focuses on medical, medicine, and clinical research questions. Patient safety, food safety, and construction safety are also significant areas of recent safety research. Safety culture and safety climate are specific research topics in safety research and have been widely applied to patient and food safety problems, and to safety in industrial contexts. Compared to safety, current security research is mostly focused on food security and national security, with topics related information/cybersecurity very important research areas with industrial relevance. With the development of increasingly interconnected digital systems, new security problems emerge in practical application domains, warranting focused new research directions.

Based on the findings, it is concluded that there are significant opportunities for synergies between the safety and security domains in industrial contexts, especially in context of increasingly connected, complex socio-technical and cyber-physical systems. There are likely large gains to be made through increased empirical work, technology and method development, and definition of management strategies which explicitly link security and safety, given their complimentary but sometimes conflicting requirements. Given the observed dearth of journals which explicitly focus on such integration between security and safety across various industrial application domains, it is found that the Journal of Integrated Security and Safety Science provides a valuable platform to strengthen the link between these research domains and communities.

References

[Anonymous] (1900) Emergency safety lighting from the Ruhstrat brothers, Goettingen. Physikalische Zeitschrift 2: 26-28.

Akram R, Thaheem MJ, Nasir AR, et al. (2019) Exploring the role of building information modeling in construction safety through science mapping. Safety Science 120: 456-470.

Albrechtsen E (2003) Security vs safety. Norwegian University of Science.

Anwar MA, Rongting Z, Dong W, et al. (2018) Mapping the knowledge of national security in 21st century a bibliometric study. Cogent Social Sciences 4(1): 1542944.

Aven T (2014) What is safety science? Safety Science 67: 15-20.

Bach C (1900) Concerning the efficiency of the steam boiler security in Germany. Zeitschrift Des Vereines Deutscher Ingenieure 44: 811-813.

Badri A, Boudreau-Trudel B and Souissi A (2018) Occupational health and safety in the industry 4.0 era: A cause for major concern? Safety Science 109: 403-411.

Barnes JGP (2005) Safe and secure software: An invitation to Ada 2005. AdaCore, https://www.adacore.com/papers/safe-secure.

Bastian M, Heymann S and Jacomy M (2009) Gephi: an open source software for exploring and manipulating networks.

Bloomfield R, Netkachova K and Stroud R Security-informed safety: if it's not secure, it's not safe. Springer, 17-32.

Bradford SC (1934) Sources of information on specific subjects. Engineering 137: 85-86.

Bradford SC (1948) Documentation. London: Crosby Lockwood.

Brettel M, Friederichsen N, Keller MA, et al. (2014) How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 8: 37-44.

Brostoff S and Sasse MA (2001) Safe and sound: a safety-critical approach to security. In: Proceedings of the 2001 workshop on New security paradigms, Cloudcroft, New Mexico, pp.41–50. Association for Computing Machinery.

Burns A, McDermid J and Dobson J (1992) On the meaning of safety and security. The Computer Journal 35(1): 3-15.

Carley S, Porter AL, Rafols I, et al. (2017) Visualization of disciplinary profiles: Enhanced science overlay maps. Journal of Data and Information Science 2(3): 68-111.

Claude G (1900) The elimination of harmonics of industrial alternative currents through the use of condensors and the interest of this elimination from the point of view of security for human life. Comptes Rendus Hebdomadaires Des Seances De L Academie Des Sciences 131: 613-615.

Cusimano J and Byers E (2010) safety and security: two sides of the same coin. Retrieved April 19: 2016.

Dekker S (2018) Drift into failure: From hunting broken components to understanding complex systems. CRC Press.

Eames DP and Moffett J (1999) The Integration of Safety and Security Requirements. In: Pasquini A, Felici M and Kanoun K (eds) Computer Safety, Reliability and Security. Berlin, Heidelberg: Springer Berlin Heidelberg, 468-480.

Earle BH (1900a) Report from Nome-Inspection of Port Safety, Solomon, Topkok, and Bluff City-Illness among the natives. Public Health Reports 15(40): 2433-+.

Earle BH (1900b) Sanitary report from Nome, Alaska-Smallpox at Port Safety. Public Health Reports 15(39): 2371-2371.

Ellis LA, Churruca K, Clay-Williams R, et al. (2019) Patterns of resilience: A scoping review and bibliometric analysis of resilient health care. Safety Science 118: 241-257.

Foulquier L (2013) Sûreté–sécurité: Il est possible maintenant de sortir des confusions. Environnement, Risques & Santé 12(4): 360-362.

Goerlandt F (2020) Maritime Autonomous Surface Ships from a risk governance perspective: Interpretation and implications. Safety Science 128: 104758.

Grant MJ and Booth A (2009) A typology of reviews: an analysis of 14 review types and associated methodologies. Health Information and Libraries Journal 26(2): 91-108.

Gusenbauer M (2019) Google Scholar to overshadow them all? Comparing the sizes of 12 academic search engines and bibliographic databases. Scientometrics 118(1): 177-214.

Hofmann E and Rüsch M (2017) Industry 4.0 and the current status as well as future prospects on logistics. Computers in Industry 89: 23-34.

Idsø ES and Jakobsen ØM (2000) Objekt- og informasjonssikkerhet: metode for risiko- og sårbarhetsanalyse[Object- and information security: methodology for risk and vulnerability]. Trondheim: Norges teknisk-naturvitenskapelige universitet, Institutt for produksjons- og kvalitetsteknikk.

Jalali M, Razak S, Gordon W, et al. Health Care and Cybersecurity: A Bibliometric Analysis of the Literature. Journal of Medical Internet Research 21(4): e12644.

Kamran M, Khan HU, Nisar W, et al. (2020) Blockchain and Internet of Things: A bibliometric study. Computers & Electrical Engineering 81: 106525.

Kans M, Galar D and Thaduri A (2016) Maintenance 4.0 in Railway Transportation Industry. the 10th World Congress on Engineering Asset Management (WCEAM 2015). 317–331.

Kriaa S, Pietre-Cambacedes L, Bouissou M, et al. (2015) A survey of approaches combining safety and security for industrial control systems. Reliability Engineering & System Safety 139: 156-178.

Leveson NG (2012) Engineering a Safer World: Systems Thinking Applied to Safety. The MIT Press.

Leydesdorff L, Carley S and Rafols I (2013a) Global maps of science based on the new Web-of-Science categories. Scientometrics 94(2): 589-593.

Leydesdorff L and Rafols I (2009) A global map of science based on the ISI subject categories. Journal of the American Society for Information Science and Technology 60(2): 348-362.

Leydesdorff L, Rafols I and Chen C (2013b) Interactive Overlays of Journals and the Measurement of Interdisciplinarity on the basis of Aggregated Journal-Journal Citations. Journal of the Association for Information Science and Technology 64(12): 2573-2586.

Leydesdorff L, Wagner CS and Bornmann L (2019) Diversity measurement: Steps towards the measurement of interdisciplinarity? Journal of Informetrics 13(3): 904-905.

Li J, Goerlandt F and Reniers G (2020a) Mapping process safety: A retrospective scientometric analysis of three process safety related journals (1999–2018). Journal Of Loss Prevention In the Process Industries 65: 104141.

Li J, Goerlandt F. and G. R (2020b) An overview of scientometric mapping for the Safety Science community: Methods, tools, and processes. Safety Science, submitted.

Li J and Hale A (2015) Identification of, and knowledge communication among core safety science journals. Safety Science 74: 70-78.

Li J and Hale A (2016) Output distributions and topic maps of safety related journals. Safety Science 82: 236-244.

Liu Y and Zhang S (2020) Information security and storage of Internet of Things based on block chains. Future Generation Computer Systems 106: 296-303.

Lozano S, Calzada-Infante L, Adenso-Díaz B, et al. (2019) Complex network analysis of keywords co-occurrence in the recent efficiency analysis literature. Scientometrics 120(2): 609-629.

Maslow AH (1943) A theory of human motivation. Psychological review 50(4): 370.

Merigó JM, Miranda J, Modak NM, et al. (2019) Forty years of Safety Science: A bibliometric overview. Safety Science 115: 66-88.

Meyer T and Reniers G (2016) Engineering Risk Management. De Gruyter Graduate, Berlin.

Möller N. HSO, Holmberg J.-E., Rollenhagen C. (Eds.) (2018) Handbook of Safety Principle. Hoboken, NJ, USA: John Wiley and Sons.

Okoroiwu HU, López-Muñoz F and Povedano-Montero FJ (2018) Bibliometric analysis of global Lassa fever research (1970–2017): a 47 – year study. BMC Infectious Diseases 18(1): 639.

Parkinson P (2011) Safety, security and multicore. Advances in Systems Safety. Springer, pp.215-232.

Piètre-Cambacédès L and Bouissou M (2013) Cross-fertilization between safety and security engineering. Reliability Engineering & System Safety 110: 110-126.

Rafols I, Porter AL and Leydesdorff L (2010) Science overlay maps: A new tool for research policy and library management. Journal of the American Society for Information Science and Technology 61(9): 1871-1887.

Reniers G, Landucci G and Khakzad N (2020) What safety models and principles can be adapted and used in security science? Journal Of Loss Prevention In the Process Industries 64: 104068.

Rousseau R (2019) On the Leydesdorff-Wagner-Bornmann Proposal for Diversity Management. Journal of Informetrics 13(3): 906-907.

Schnieder L, Schnieder E and Stein C (2010) Safety and security; two sides of the same coin: properties and relations? characteristics to refine? structure of terminology and its perception.

Steiner M and Liggesmeyer P Combination of Safety and Security Analysis - Finding Security Problems That Threaten the Safety of a System. SAFECOMP 2013, International Conference on Computer Safety, Reliability and Security. Workshops and Tutorials : CARS, SASSUR, DECS, ASCOMS. Toulouse, France: Technische Universität Kaiserslautern, 233-240.

STM (2018) The STM report: An overview of scientific and scholarly publishing.

Stoneburner G (2006) Toward a Unified Security-Safety Model. Computer 39(8): 96-97.

Su H-N and Lee P-C (2010) Mapping knowledge structure by keyword co-occurrence: a first look at journal papers in Technology Foresight. Scientometrics 85(1): 65-79.

UN (2019) World population prospects, the 2019 revision. Reportno. Report Number|, Date. Place Published|: Institution|.

van Eck NJ and Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84(2): 523-538.

van Nunen K, Li J, Reniers G, et al. (2018a) Bibliometric analysis of safety culture research. Safety Science 108: 248-258.

van Nunen K, Sas M, Reniers G, et al. (2018b) An integrative conceptual framework for physical security culture in organisations. Journal of Integrated Security Science 2(1): 25-32.

von Z (1900) Regional hospital of chronic patients as a branch of the general social security. Deutsche Medizinische Wochenschrift 26: 507-508.

Wagner CS and Leydesdorff L (2005) Network structure, self-organization, and the growth of international collaboration in science. Research policy 34(10): 1608-1618.

Young W and Leveson N (2013) Systems thinking for safety and security. Proceedings of the 29th Annual Computer Security Applications Conference. 1-8.

Young W and Leveson NG (2014) An integrated approach to safety and security based on systems theory. Communications of the Acm 57(2): 31-35.

Acknowledgements

This study was supported by the National Natural Science Foundation of China (No. 51874042, NO. 51904185) and the Canada Research Chairs Program, through a grant by the Natural Sciences and Engineering Research Council (NSERC). This support is gratefully acknowledged. The authors are furthermore indebted to two anonymous reviewers whose comments have been instrumental for making improvements to an earlier version of this work