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Mapping the Crashworthiness Domains: Investigations Based on Scientometric Analysis

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Abstract - *This paper provides a scientometric analysis of research advances in the crashworthiness of vehicle analysis. Using the software of VosViewer and MATLAB, a scientometric analysis is carried out by reviewing 1047 papers with various perspectives from 1969 to 2023, providing an integrated knowledge mind map of crashworthiness. The findings suggest that the United States, Germany, China, India, the United Kingdom, Japan, and Italy have made the most significant contributions to the field of crashworthiness. Important institutions, publications, citations, and article keywords are also covered. The main goals of crashworthiness are to prevent energy transmission entry into the car's compartment during collision, to stop crushing and collapsing, and to use new geometrical designs, materials, and parameter choices to absorb impact energy through controlled mechanisms. Analysis found that the number of publications increased from one (0.10%) in 1969 to 52 (4.97%) in 2016 and observed good progress in scholarly literature, in particular, the study of crashworthiness analysis, which is rapidly growing. This analysis generates a thorough and integrated knowledge mind map that adds to the crashworthiness information network and enables researchers and software developers in the field of crashworthiness to gain useful insights about next research paths and advances.*

Key Words: Crashworthiness, Collision, Energy Absorption, *Scientometric analysis*

1.INTRODUCTION

Every year, 1.3 million people lose their lives in traffic accidents. The severity of a collision's effects and the likelihood that one will happen are strongly correlated with an increase in average speed. The risk of fatal accidents rises by 4%, and the risk of serious accidents rises by 3%, for every one percent increase in mean speed. Automobiles play a crucial role in reducing serious injuries and avoiding collisions. A number of UN regulations on vehicle safety have the potential to save a lot of lives if they are implemented in the manufacturing and production standards. (Road Traffic Injuries, WHO) Crashworthiness emphasises occupant safety to reduce the number of fatalities and serious injuries. The research on crashworthiness can achieve the World Health Organisation's (WHO) ambitious goal of preventing at least 50% of deaths and injuries from traffic accidents by 2030.

2. DATA AND METHODS

2.1 Source of Data

Scopus is the world's largest abstract and citation database of peer-reviewed literature, including scientific journals, books, and conference proceedings, covering research topics across all scientific and technical disciplines, ranging from medicine and social sciences to the arts and humanities. This study used the Scopus source database to find the data, and it contains a database of 1047 documents from 1969 to 2023. After screening, we obtained 1047 documents from 56 different countries, 1010 research institutions, 663 conferences, 349 journals, and 1036 authors.

Methods

The Scientometric study covered all research publications indexed in the Scopus database on crashworthiness. It accessed the contributions on "Crashworthiness", "Automotive", and other related areas to crashes. Using the following search query, the subject-related bibliographic data were retrieved from Scopus on March 30, 2023, without restriction on time span. TS=("automotive*" AND "crash*" AND "design*" OR "simulation*" OR "crashworthiness*" OR "materials*" OR "deformation*" OR "energy*" OR "absorption*") - Timespan: All years. The retrieved data were carefully examined, and 1,047 records were included in the analysis. The information downloaded was dissected for various parameters, like type of document, references, and usage; publication and citation growth year-wise; top source journals and keywords used most frequently; countries that work together; pattern of authorship and the most prolific authors; and the highest contribution of organisations. MS-Excel was used to analyse the data, and VOS viewer and MATLAB were used to create a visual representation of the keywords that were used together. This study included crashworthiness-related Scopus-indexed publications as of March 30, 2023. As a result, scholars ought to take the findings of this study into account in light of these limitations.

3.DATA ANALYSIS

Figure 1 shows the year-wise distribution of publications on crashworthiness from 1969 to 2023 using MATLAB. The total number of records in the dataset is 1,047. The number of

publications related to crashworthiness shows an upward trend from 1969 to 2016, with the highest number of records published in 2016 (52 records). After 2016, the number of records fluctuates, with a relatively small number of publications in some years. The most recent years, 2020, 2021, 2022, and 2023, show a moderate number of publications (ranging from 5 to 37 records). Based on this information, crashworthiness appears to be a thriving field of study with varying publication rates in recent years.

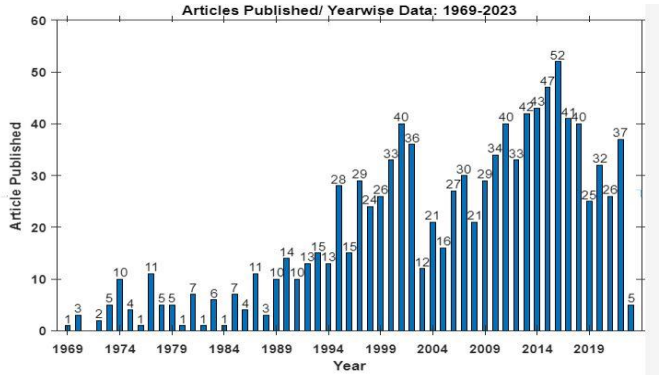


Fig. 1. Year wise distribution of publications from 1969 to 2023

3.1 Top 11 Countries with most significant contributions to the field of crashworthiness

According to Figure 2 and Table 1, the four active countries with the greatest number of publications are the United States of America, Germany, China, and India. Although the ACI is only 9.6 for the United States, which is the lowest among the top 11 countries with the highest number of publications, the number of publications by United States scholars ranks first globally. It is evident that the United States research recognition still has a long way to go. China has the highest ACI index among the top 4 countries with the highest publications. However, despite having the lowest number of publications, Australia, Turkey, Italy, and Iran have a high ACI, indicating that their research recognition levels are relatively high.

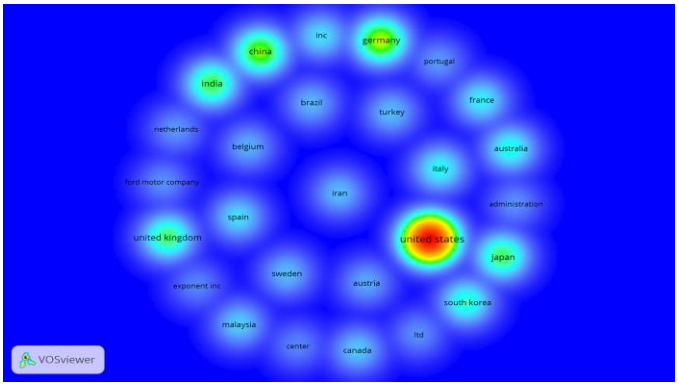


Fig 2. Crashworthiness Density Visualization with Co-Authorship Type Analysis and Country Unit Analysis

Table -1: Top Countries with ACI

S.No.	Country	No. of documents	TC	ACI
1	United States	469	4497	9.6
2	German	85	770	9.06
3	China	72	987	13.71
4	India	52	340	6.5
5	Japan	49	413	8.4
6	United Kingdom	46	533	11.6
7	Australia	28	665	23.75
8	Italy	25	514	20.56
9	Spain	18	261	14.5
10	Iran	12	239	19.92
11	Turkey	12	262	21.8

3.2 Distribution of publication types and Number of Records

The number of records related to crashworthiness for nine different types of publications is shown in Figure 3. Conference papers are the most common type of document, with 663 records accounting for 63.32%, followed by articles with 349 records (33.33%). Compared to an article, conference papers are 50% more expensive. The other 6 records are for reviews (16), book chapters (8), conference reviews (5), notes (3), books (2), and one short survey. Researchers, students, and professionals who are interested in crashworthiness and want to know what kinds of publications are available on the subject might find this information helpful.

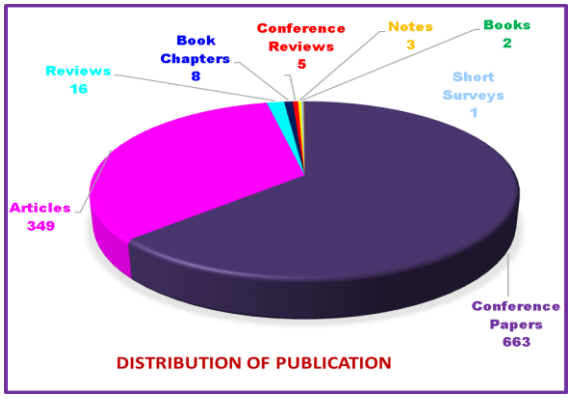


Fig 3. Distribution of publication types and Number of Records

3.3 Top Contribution

Retrieved publications were also analyzed by means of citation. Therefore, the feature "Top Cited Articles," shown in Table 2, was used to calculate the total citations of both authors and total citations per year. The first rank of the article belongs to Jacob, George C. TC 319, and the TC per year is 14.50. The average number of cited references per article varied in the general search over the last 20 years, between a maximum of 319 in 2002 and a minimum of 110 in 2017. The maximum TC per year shows 16.13 in 2008, for the article published by Liao and Xingtao, and 15.71 by Lea K. in 2017.

Top 11 cited articles are presented in the Table 2

Table- 2: Top cited articles

S.No	First Author	Year	Title	TC	TC/Y
1	Jacob, George C.	2002	Energy absorption in polymer composites for automotive crashworthiness	319	14.50
2	Liao, Xingtao	2008	Multi-objective optimization for crash safety design of vehicles using stepwise regression model	258	16.13
3	Kononen, Douglas W	2011	Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes	174	13.38
4	Bisagni, Chiara	2005	Progressive crushing of fiber-reinforced composite structural components of a Formula One racing car	163	8.58
6	Lee, K.	2005	Evaluation of automotive forward collision warning and collision avoidance algorithms	163	8.58
7	Mayer, R.R.	1996	Application of topological optimization techniques to structural crashworthiness	129	4.61
8	Duddeck, Fabian	2008	Multidisciplinary optimization of car bodies	118	7.38
9	Oliver, S	2007	Dual phase versus TRIP strip steels: Microstructural changes as a consequence of quasi-static and dynamic tensile testing	113	12.56
10	Goel, Manmohan Dass	2015	Deformation, energy absorption and crushing behavior of single-, double- and multi-wall foam filled square and circular tubes	113	6.65
11	Kisters T	2017	Dynamic impact tests on lithium-ion cells	110	15.71

3.4 Co-occurrence of Keywords

The keywords convey the major ideas of the article. As a result, a keyword analysis can be used to pinpoint the knowledge's expanding research horizons. Figure 2 depicts the top 41 keywords from the crashworthiness studies. "Crashworthiness" has the highest total link strength and number of occurrences, followed by "energy absorption," which is the type of crashworthiness that is developed and used the most. "Optimisation" and "Finite Element Methods", "Crash", "Crash Box," and "Safety" imply that design, research, and development processes must in large part fulfil safety and performance as the fundamental requirements of crashworthiness. In recent years, grooves,", "beads," and "holes" as "triggers" have gradually emerged as the prevalent energy absorption solution for crashworthiness; however, there are still numerous technical issues to be resolved. As shown in Fig. 2, VOSviewer was utilised to implement and collect a keyword co-occurrence analysis of the crashworthiness investigations. The hubs address the keywords, and the sizes of the nodes represent how frequently the associated keywords occur and how strongly two nodes are connected to one another. When it is thicker, there is a stronger relationship between the terms. In Fig. 2, there are four clusters in the co-occurrence network; the blue cluster has the biggest volume, followed by the pink and red clusters, and the yellow cluster has the smallest volume. The keyword with the highest notable recurrence in the blue group is "Crashworthiness" (127); other keywords with greater frequencies include "Energy Absorption" (42), "Optimisation," "Finite Element Techniques," "Crash," and "Crash Box." The term "crashworthiness" appears throughout

the entire collection. The general research focus areas include enhancing the crash box and vehicle mechanisms safety performance by fusing relevant literature and other cluster keywords.

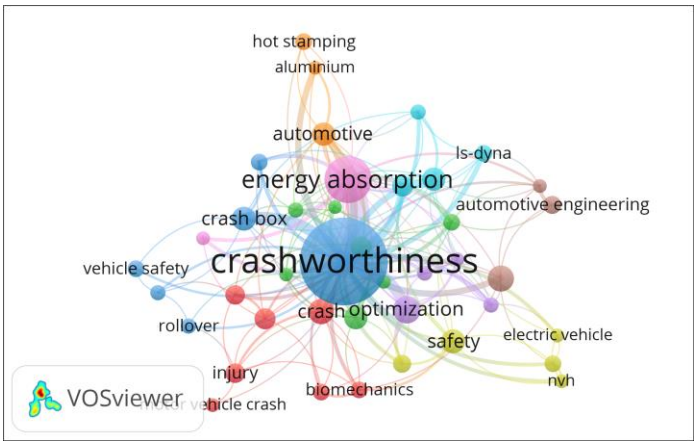


Fig. 4 Network Co-occurrence Visualization with Type of Analysis and Author's Keyword Unit Analysis

3.5 Most relevant sources

The number of papers on crashworthiness that were published by various sources is shown in Table 3. SAE Technical Paper ranked first in the list of publications, with 413 major journals published. Followed by Accident Analysis and Prevention, which published 35 (3.34%) papers, the American Society of Mechanical Engineers, Applied Mechanics Division (AMD), and the International Journal of Crashworthiness, which published 27 (2.57%) papers. The number of publications published by the first- and second-ranked journals was vastly different. It demonstrated how prominent and high-quality the research is in the SAE Technical Paper.

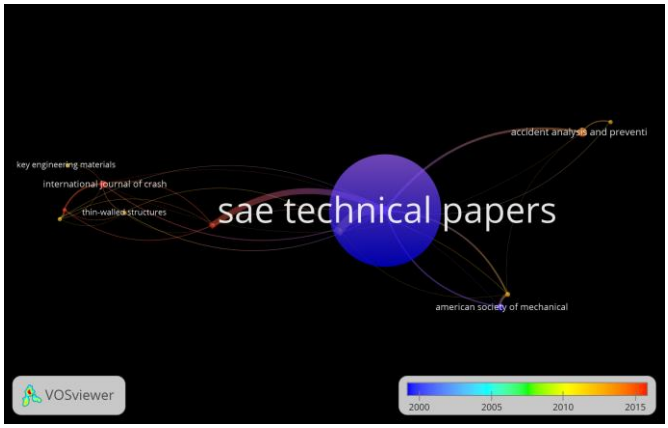


Fig-5 Overlay Visualization of Bibliographic Type of Analysis with Source Unit Analysis

Table-3 The major journals that published Crashworthiness research from 1969 to 2023

Sources	Articles	%
SAE TECHNICAL PAPERS	413	39.44
ACCIDENT ANALYSIS AND PREVENTION	35	3.34
AMERICAN SOCIETY OF MECHANICAL ENGINEERS, APPLIED MECHANICS DIVISION, AMD	27	2.57
INTERNATIONAL JOURNAL OF CRASHWORTHINESS	27	2.57
ASME INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION, PROCEEDINGS (IMECE)	19	1.81
THIN-WALLED STRUCTURES	16	1.52
COMPOSITE STRUCTURES	14	1.33
KEY ENGINEERING MATERIALS	12	1.14
VDI BERICHTE	12	1.14
SAE INTERNATIONAL JOURNAL OF MATERIALS AND MANUFACTURING	11	1.05

3.6 Funding sponsor for crashworthiness publication

The funders of crashworthiness publications are listed in this table. The ability of a vehicle or its components to safeguard occupants in the event of a crash is referred to as crashworthiness. The sponsors are listed in the table in order of how many documents they have funded in this area. The data cover a wide range of nations and regions, with 15 related publications funded by the National Natural Science Foundation of China, the largest sponsor. The US Department of Energy is the second-biggest supporter, subsidising nine distributions. A wide range of sponsors, including governments, research councils, universities, and businesses from all over the world, are depicted in the table.

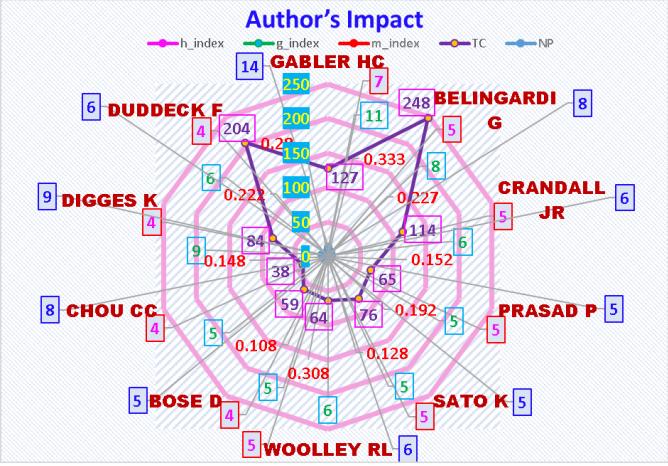
Table- 4: Funding sponsor for crashworthiness publication

S.No.	Funding sponsor	Documents
1	National Natural Science Foundation of China	15
2	U.S. Department of Energy	9
3	National Highway Traffic Safety Administration	5
4	Engineering and Physical Sciences Research Council	4
5	National Science Foundation	4
6	Fundamental Research Funds for the Central Universities	3

7	Generalitat de Catalunya	3
8	National Research Foundation of Korea	3
9	Natural Sciences and Engineering Research Council of Canada	3
10	State Key Laboratory of Automotive Safety and Energy	3

3.7 Author's impact

Table 7 displays the author's crashworthiness h-index, g-index, m-index, TC, NP, and PY values from 1985 to 2011. Gabler HC topped the list with the highest h-index (7), g-index (11), and NP (14) values, despite having the fewest citations (127). The next five authors to achieve the same h-index value were Belingardi G., Gradall JR, Prasad P., Sato K., and Wooley RL. It is essential to note that Duddeck F. has a TC 204 with an NP of 6, whereas Belingardi G. has a TC 248 with an NP of 8; this demonstrates the high quality of their research article. With fewer publications, the authors Belingardi G. (0.333) and Bose D. (0.308) had the highest m-index. In 1997, Dugges J. obtained NP 9 with a lower TC (84) but a g-index of 9.



Challenges

Due to the large population and shifting distribution of transportation use, crashworthiness faces numerous research gaps, including in vehicle fuel efficiency, safety, and consumer demands. Challenges with crashworthiness are discussed in this section.

C1: Vehicle that is safer in a crash: There has not been a consistent rise in the number of research articles that have been published. The vehicle design, materials, and parameters of new and improved vehicles ought to be the focus of additional research.

C2: Improve the level of research recognition: An article that is simple to read will greatly benefit from having a well-organised, high-quality paper on a hot topic or new research problem that includes all of the essential components necessary to convey the study's findings. Authors of research articles should promote their work within their networks, inform their colleagues and students, and encourage them to read the journal and cite it. This will improve the level of recognition for citations.

C3: Journals ought to be expanded in the field of crashworthiness.

C4: Researchers need to know how popular and influential their publications are in the scholarly community through citations.

C5: Choosing relevant keywords will improve search engine rankings.

C6: It sheds light on the most prevalent means by which researchers in the crashworthiness field share their findings.

C7. Tangible opportunities for researchers: Researchers should speak up to learn about new ideas, policies, and funding opportunities. Funding organisations should pave the way for a change in practises and policies that will make it easier for everyone, particularly young researchers and students, to access funding opportunities across international borders.

C8—Hot Streak Phenomena: A challenging task at the beginning of a researcher's success could not only provide a better understanding of how influence grows, but it could also guide and prepare high-impact researchers.

4. CONCLUSIONS

Crashworthiness is currently undergoing rapid growth in a variety of vehicle safety disciplines, including engineering and transportation. The world's top research topic is the United States, with substantial positions being held by Germany, China, and India. Globalisation may contribute to the ongoing challenge of crashworthiness progress among manufacturers and researchers. The primary research areas in the field of vehicle safety during the past 30 years have been collision avoidance systems, pre-crash systems, and active safety. With the use of simulation technologies, the study of crashworthiness recognition under various circumstances is growing and will continue in the future. According to the predictions made in this paper, the study of crashworthiness will gradually increase through crash simulation procedures using multiple software packages, a technique that will continue to grow in interdisciplinary fields. It is crucial to establish as a conclusion that crashworthiness is a multidisciplinary field of study with important implications for vehicle safety. Each year, research in this area increases; however, it fluctuates more than in other fields. The current information might provide accommodating data to the researchers who are entrusted with further developing exploration and execution in Vehicle Safety.

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