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REVIEW PAPERS

Enhancing armored crew safety: a scientometric and scoping review of key trends, challenges, and innovations

Elias M. Radzi[a], *Zuraida* Hassan[b], *Mohd Azril* Ismail[c], *Khairul Hafezad* Abdullah[d], *Intan Suraya* N. Arzahan[e], *Aswalni* Ishak[f], *Ejiro* U. Osiobe[g], *Muhammad Hazim* A. Ghalib[h]

[a] University Utara Malaysia, UUM College of Business, School of Business Management, Occupational Safety and Health Management Program, Kedah, Malaysia, e-mail: eliasmdradzi9@gmail.com, **corresponding author**, ORCID iD: https://orcid.org/0009-0000-5580-2869

[b] University Utara Malaysia, UUM College of Business, School of Business Management, Kedah, Malaysia, e-mail: h.zuraida@uum.edu.my, ORCID iD: https://orcid.org/0000-0003-2636-7540

[c] University Utara Malaysia, UUM College of Business, School of Technologies Management and Logistics, Kedah, Malaysia, e-mail: azril@uum.edu.my, ORCID iD: https://orcid.org/0000-0003-0990-6653

[d] University Utara Malaysia, UUM College of Business, School of Business Management, Social Security Management Center of Excellence, Kedah, Malaysia, e-mail: ezadneo88@gmail.com, ORCID iD: https://orcid.org/0000-0003-3759-6541

[e] University Utara Malaysia, UUM College of Business, School of Business Management, Kedah, Malaysia, e-mail: intanarzahan@gmail.com ORCID iD: https://orcid.org/0000-0002-0966-057X

[f] University Utara Malaysia, UUM College of Business, School of Business Management, Occupational Safety and Health Management Program, Kedah, Malaysia, e-mail: sonydenko2001@gmail.com ORCID iD: https://orcid.org/0009-0009-5470-8008

[g] Westcliff University, College of Business, Economics Department, Irvine, CA, United States of America, e-mail: jiji.osiobe@bakeru.edu ORCID ID: https://orcid.org/0000-0002-1107-6620

[h] University Utara Malaysia, UUM College of Business, School of Business Management, Human Resource Management Program, Kedah, Malaysia, e-mail: mhazimagy@gmail.com ORCID iD: https://orcid.org/0009-0002-0942-4718

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Abstract:

Introduction/purpose: This study presents a comprehensive analysis of the existing literature on armored vehicle crew safety through an integrated scientometric and scoping methodology.

Methods: Data sourced from Scopus and Web of Science were employed to analyze a total of 197 documents following preprocessing and the removal of duplicates. Scientometric analysis was conducted utilizing ScientoPy and VOSviewer software to identify publication trends, keyword co-occurrence, and influential academic contributions. Furthermore, a scoping review based on the SPIDER framework was undertaken to synthesize critical insights related to whole-body vibration (WBV), vehicle design, and safety technologies.

Results: The findings indicate that the installation of bulletproof armor significantly reduces WBV exposure levels, with reductions ranging from 10% to 20%. These reductions are attributed to modifications in vehicle mass distribution and stiffness. Advanced materials, such as aluminum alloys, were identified as essential for enhancing blast resistance and vibration mitigation. The results emphasize the importance of structural modifications and adaptive technologies, including enhanced suspension systems, in managing WBV and improving overall crew safety.

Conclusion: This study establishes a robust foundation for future research, underscoring the necessity for optimized vehicle designs and integrated safety strategies to address the physiological and psychological stressors encountered by armored vehicle crews.

Key words: armored vehicle crew, whole-body vibration, scientometric analysis, scoping review, bulletproof armor.

Introduction

Armored vehicles are crucial in modern military operations, with various types serving specific functions. Tanks, for instance, are heavily armored and armed vehicles designed for frontline combat. They engage enemy forces with powerful weaponry while providing substantial protection for their crews, making them essential for penetrating enemy lines and delivering direct fire support (Radovanović et al, 2023). Armored Personnel Carriers (APCs) are built to transport infantry safely to the battlefield, offering protection against small arms fire and shrapnel. While they are less heavily armed than tanks, APCs play a vital role in ensuring the mobility and safety of troops in combat zones (Kokhan, 2023). Infantry

Fighting Vehicles (IFVs) are similar to APCs but feature heavier armament, allowing them to support infantry through direct fire and engage enemy forces more effectively. They strike a balance between firepower, protection, and mobility, making them versatile in various combat scenarios (Zelenyukh et al, 2020). The development and enhancement of these vehicles focus on improving protection, mobility, and operational efficiency. Modern advancements include optimizing design layouts, enhancing mine resistance, and utilizing high-strength materials to bolster protective capabilities (Zelenyukh et al, 2020). The effectiveness of armored vehicles in specific roles, such as technical reconnaissance, is assessed using specialized indicators, including the technical intelligence efficiency factor which helps evaluate their performance in diverse operational contexts (Kovtun et al, 2020; Jasman et al, 2018). The selection of military vehicles, including armored types, is guided by quality indicators that consider tactical and technical characteristics, ensuring they meet the demands of armed forces in challenging environments (Kokhan, 2023; Radzi et al, 2025). In summary, the strategic deployment and continuous enhancement of armored vehicles are essential for achieving military objectives and ensuring the safety and effectiveness of military operations.

Safety in armored vehicle operations is crucial due to unique and multifaceted risks faced by crews, especially in combat zones where these vehicles often become prime targets for attacks involving mines and improvised explosive devices (IEDs) (Kaidalov et al, 2023). The design of vehicle hulls, particularly double-V hulls (DVH), plays a key role in mitigating blast impacts by optimizing load transfer paths and reducing injury risks for occupants. Additionally, advancements in materials, such as aluminum alloys, improve resistance to mines and enhance energy absorption, thus increasing crew survivability (Cong et al, 2021; Bisyk et al, 2023). However, the confined interiors of armored vehicles can worsen injury severity—such as burns, extremity injuries, and exposure to depleted uranium—by complicating evacuation and medical treatment. Conditions like traumatic brain injuries and bone fractures require advanced medical intervention and effective evacuation systems (Li et al, 2023; Khorram-Manesh et al, 2021; Sheng & Solah, 2022). Moreover, psychological challenges stemming from high-stress combat environments, coupled with prolonged operations in cramped spaces and extreme temperatures, further undermine operational effectiveness. This highlights the necessity of addressing both physical and mental health concerns (Ameen et al, 2022). Together, these challenges emphasize the urgent need for integrated safety systems, innovative vehicle designs, and

comprehensive crew training to enhance operational effectiveness and resilience in armored vehicle missions.

Effective safety protocols are essential for preventing injuries and fatalities among crews of armored or combat vehicles, directly impacting operational readiness and mission success. The development and implementation of advanced protection strategies for military equipment, such as armored combat vehicles, are crucial for safeguarding personnel against various threats (Gijsbertse et al, 2021; Jasman et al, 2018). Integrating individual armor protection into training methodologies enhances service members' survivability by adapting firing techniques and regulations to accommodate the additional protection, thereby improving their response speed and mobility in combat (Gijsbertse et al, 2021; Schram et al, 2019). Furthermore, the application of systematic safety management systems, such as the Injury and Illness Prevention Program (IIPP), which includes error reduction techniques, can significantly enhance the organization of safety committees and engagement in hazard analyses, fostering a safer operational environment (Koshy et al, 2019; Radzi et al, 2024b). The Hazard and Operability Study (HAZOPS) method is also vital for identifying and mitigating potential hazards, underscoring the importance of personal protective equipment (PPE) in minimizing the risk of accidents and occupational diseases (Noor Arzahan et al, 2022).

Additionally, the implementation of advanced accident detection and alert systems in vehicles can expedite emergency responses and provide critical location data, thereby reducing the time required to address incidents and enhancing crew safety (Alsayaydeh et al, 2023). Collectively, these safety measures not only protect the crew but also ensure that vehicles and personnel are consistently prepared for deployment, contributing to the overall success of military missions. By prioritizing safety, military operations can maintain high levels of readiness and effectiveness, ultimately leading to successful mission outcomes and the preservation of human life.

The increasing complexity of safety challenges in high-stress and hazardous environments calls for a structured evaluation of existing research to guide innovation and address knowledge gaps. Scientometric analysis has emerged as a powerful tool for systematically mapping research trends, identifying influential contributions, and assessing the application of statistical methodologies to advance the field (Donthu et al, 2021). Complementing this approach, scoping reviews provide a comprehensive method for exploring and synthesizing the current state of knowledge, offering a broader perspective on various methodologies and applications (Munn et al, 2018). In the safety domain, the use of statistical

tools and database analyses is crucial for predictive modeling of blast impacts (Nguyen et al, 2019), analyzing human factors under high-stress conditions (Xie & Guo, 2018), and optimizing protective system designs through database-driven methods (Karr et al, 2007). Techniques such as machine learning algorithms and bibliometric databases are widely utilized to enhance precision and effectiveness (Huo et al, 2024). Moreover, significant advancements in armored crew safety—including lightweight composite materials, ergonomic vehicle designs, and digital innovations like IoT-based monitoring and augmented reality training—highlight the potential for transformative progress (Wibneh et al, 2024). Despite these advancements, persistent gaps in material scalability, human-system integration, and the application of emerging technologies underscore the necessity of this review to establish a critical foundation for future research.

Method and analysis design

Scientometric analysis

Scientometric analysis is a widely used methodological framework for evaluating and interpreting large scientific data sets. This approach deepens our understanding of the development of specific academic fields (Donthu et al, 2021). The application of scientometric parameters to assess research quality has become increasingly prevalent. Researchers utilize scientometric analysis for various purposes, such as identifying emerging trends and evaluating journal performance (Struck et al, 2021). Additionally, it aids in investigating collaboration patterns, research components, and publication trends within specific research domains (Wachsmann et al, 2019; Abdullah, 2022b). Moreover, scientometric analysis elucidates the intellectual structure of particular areas of inquiry, as demonstrated in several published studies (Simao et al, 2021). This study applies scientometric analysis to examine research publication patterns related to armored vehicle crew safety in military environments. The objective is to identify countries actively publishing in this field and to analyze the themes and subthemes reflected in the authors' keywords.

Scoping analysis

The primary objective of scoping reviews is to identify and categorize the diverse types of evidence that exist within a particular field (Munn et al, 2018). This study aims to explore the critical elements associated with armored vehicle crew safety in military environments by synthesizing the existing literature in this domain. Through this scoping review, the objective is to identify knowledge gaps and emphasize areas necessitating

further investigation. To accomplish this, the five-step scoping review framework developed by Arksey & O'Malley (2005) is employed:

1) Establishing the research question,
2) Identifying relevant studies,
3) Selecting studies,
4) Data charting and
5) Reporting results.

Establishing research question

The SPIDER tool (Sample, Phenomenon of Interest, Design, Evaluation, Research Type) offers a systematic approach for synthesizing research findings, especially in complex fields like armored vehicle crew safety. By organizing data around essential components of study design and evaluation, this framework enables a thorough examination of trends, innovations, and gaps in the existing literature (Cooke et al, 2012). As a result, it enhances our understanding of both the advancements and the challenges related to improving crew protection.

Research question:

What are the key findings from previous studies on armored vehicle crew safety, analyzed through the SPIDER framework, concerning innovations, design approaches, and evaluation methodologies?

Identifying relevant studies

Database

Accessing scientific publications across journals, repositories, archives, and other collections necessitates the utilization of databases and search engines (Abdullah & Abd Aziz, 2020). For the purposes of this study, the Scopus and Web of Science (WoS) databases were selected to analyze scientometric and scoping indicators. These databases were chosen due to their emphasis on the impact of document citations in comparison to other databases (Vieira & Gomes, 2009). Furthermore, modifications were implemented to ensure the validity of the coverage analysis, encompassing enhancements in metadata accuracy, document category classification, and discipline assignment. Consequently, both Scopus and WoS prioritize these factors (Stahlschmidt & Stephen, 2022).

Search strategy

After identifying the relevant keywords, a search was conducted utilizing an encyclopedia to identify synonyms. Table 1 presents the search

criteria employed to compile lists of publications from the Scopus and WoS databases. This search was conducted in October 2024 and encompassed titles, abstracts, and keywords from both databases. It is important to note that no restrictions were applied to the retrieved data during this phase, including limitations related to date, publication type, or language.

Table 1 – Search strategy for extracting data from the Web of Science and Scopus databases

Database	Search strategy	Records
Web of Science	Topic: ("armoured vehicle" OR "Armored vehicle" OR "Armored car" OR "combat vehicle" OR "fighting vehicle" OR "Armored Personnel Carrier" OR "Battle Tank" OR "main battle Tank" OR "Infantry Fighting Vehicle" OR "Armored Fighting Vehicle" OR "Armored troop carrier" OR "Protected mobility vehicle" OR "military combat vehicle") AND ("safety" OR "Security" OR "protection") AND ("soldier" OR "Driver" OR "crew" OR "operator" OR "gunner" OR "commander" OR "operators")	28
Scopus	Article Title, Abstract, Keywords: ("armoured vehicle" OR "Armored vehicle" OR "Armored car" OR "combat vehicle" OR "fighting vehicle" OR "Armored Personnel Carrier" OR "Battle Tank" OR "main battle Tank" OR "Infantry Fighting Vehicle" OR "Armored Fighting Vehicle" OR "Armored troop carrier" OR "Protected mobility vehicle" OR "military combat vehicle") AND ("safety" OR "Security" OR "protection") AND ("soldier" OR "Driver" OR "crew" OR "operator" OR "gunner" OR "commander" OR "operators")	222

Software

ScientoPy and VOSviewer are two widely utilized research tools within academic contexts. ScientoPy, a Python script, is specifically designed to extract valuable information from research articles, including primary subjects, authors, countries, and related documents. By employing keywords provided by authors, ScientoPy generates insights and aids in mitigating potential biases that may arise from independent investigations (Ruiz-Rosero et al, 2019). However, it is crucial to recognize that the analysis of studies based on author names may still introduce bias, particularly in instances of name similarities (Ruiz-Rosero et al, 2019).

VOSviewer, developed by Van Eck & Waltman (2010), is a software application that facilitates co-occurrence analyses of keywords, particularly in the context of armored vehicle crew safety challenges in military environments. It utilizes sophisticated mapping techniques to transform CSV data into visually informative diagrams or clusters (Abdullah, 2022a). These mapping strategies offer significant potential

benefits for researchers seeking to analyze specific data points, such as authors' keywords (Abd Aziz et al, 2021).

Selecting studies

Publications merge and removal of duplicates

The data from both databases were compiled and processed utilizing ScientoPy. During this stage, the data underwent standardization. This process involved substituting commas in the authors' names with semicolons, eliminating periods, commas, and distinctive formatting from the authors' names, and removing duplicate entries with identical titles and authors. Employing this methodology enhances the accuracy and reliability of the datasets. The results of the preprocessed data are presented in Diagram 1.

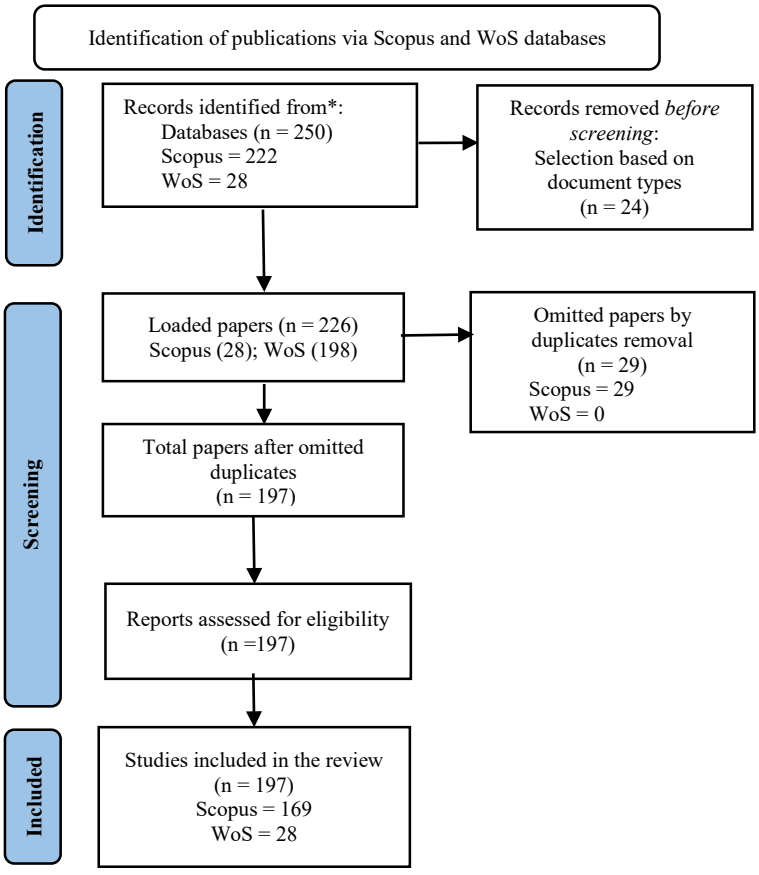

Diagram 1 – Flow diagram of the research of databases and registers

Figure 1 presents an overview of the preprocessing phase pertaining to research documents sourced from two databases: the Web of Science (WoS) and Scopus, within the framework of armored vehicle crew safety. The chart delineates the total number of documents processed and underscores the percentage of duplicate documents that were eliminated. Notably, no duplicates were removed from the WoS, indicating that all documents included were unique. In contrast, 15% of the documents from Scopus were classified as duplicates and subsequently discarded, leaving the remainder available for analysis. This preprocessing phase is essential for ensuring the accuracy and relevance of the data by removing redundant studies, thereby facilitating a more focused and efficient analysis of research trends and key findings related to crew safety. The elimination of duplicates refines the final dataset, thereby enhancing the quality of the subsequent scientometric and scoping review.

Diagram 1 offers additional insights by showing that the source dataset comprises 250 papers obtained from the WoS and Scopus databases. ScientoPy's automated categorization process eliminated 24 documents, which included books, letters, and errata, while classifying the remaining publications into various categories such as conference papers, articles, reviews, proceedings papers, and press articles. After the data reconciliation process, this study utilized a total of 197 entries from both databases: 28 papers from WoS and 169 from Scopus. Additionally, 29 duplicate entries from Scopus were removed.

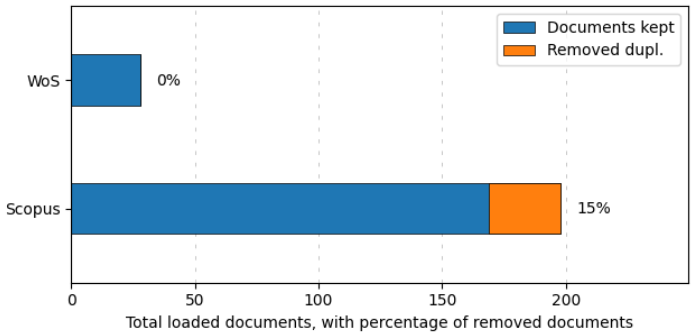

Figure 1 – Data combination and duplicates removal

Data charting

The publication growth graph exemplifies the evolution of publishing within the Scopus and WoS databases, offering significant insights into overarching publication trends. In order to attain a more comprehensive understanding of the articles selected in the preceding stage, we analyze the progression of the top 10 authors' keywords and investigate the co-occurrence of these keywords.

Reporting results

In alignment with the objectives of our study, we have prepared a succinct summary and report of our findings. We employed ScientoPy to analyze the growth of publications, identify countries actively engaged in research, and investigate relevant keywords. To assess the co-occurrence of authors' keywords, we utilized VOSviewer as a descriptive metric. It is noteworthy that a minimum of two keywords is required to generate co-occurrence results for authors' keywords using VOSviewer. Furthermore, we systematically reviewed and modified the thesaurus files to prevent duplication of authors' keywords, adhering to the recommendations of Abdullah (2022a).

The scoping review methodology aims to provide a comprehensive overview of the existing research within a specific field. A primary objective of conducting a scoping study is to identify gaps or deficiencies in the current literature. In this study, we sought to thoroughly examine and describe the current state of research on armored vehicle crew safety challenges in military environments, as well as to identify areas where the literature is lacking. To conduct this analysis, we utilized articles obtained from Scopus and WoS, which were preprocessed using ScientoPy. The specific inclusion criteria for this scoping review are detailed in Table 2.

1) Written in English,
2) Published since 2013,
3) Describe primary research, and
4) Use the keyword “whole-body vibration” in the authors’ keywords.

Results

Scientometric outcome

Publication growth

Figure 2 illustrates the temporal trends in publications related to armored vehicle crew safety, drawing on data from two prominent academic databases: Scopus and WoS, encompassing the years from 1996 to 2024, including some projected future data points. Notable findings indicate a substantial increase in publications around 2006 within Scopus, where over 25 documents were produced, representing a zenith of research activity during that period. Following this peak, the number of publications exhibited a gradual decline; however, a resurgence commenced around 2014, characterized by a consistent output of documents from 2015 to 2024. Conversely, WoS has consistently yielded

a lower volume of publications over the years, maintaining a stable rate of output with sporadic minor increases, particularly noted in 2008 and 2016. This trend implies that while Scopus has undergone phases of heightened research engagement, WoS has sustained a more subdued, yet stable, contribution to the literature concerning armored vehicle crew safety. The discrepancies in the publication volume between the two databases may reflect differing research emphases or coverage of the subject matter within these sources.

The increasing scholarly focus on the safety of armored vehicle crews reflects a broader recognition of the critical need to enhance survivability and operational safety for military personnel. This is evident in various research efforts aimed at addressing different aspects of military safety and health. For instance, the PREPARE study protocol underscores the importance of assessing and mitigating risks associated with musculoskeletal injuries among service members, which is crucial for maintaining operational readiness and ensuring safety in high-risk environments, such as those involving armored vehicles (Butowicz et al, 2022). Furthermore, the development of advanced protective clothing, including graphene-based intelligent personal protective equipment, highlights ongoing efforts to improve protection technologies against chemical threats relevant to armored vehicle crews who may encounter such hazards in combat situations (Giurgiu et al, 2023; Witte & Schwarz, 2023). In addition, research on the effects of load carriage on landing techniques provides insights into the physical demands placed on military personnel, including those operating armored vehicles, and the potential for injury, thereby informing safer operational practices (Witte & Schwarz, 2023). The implementation of mobile ultrasound vascular assessments in remote and conflict areas illustrates innovative approaches to healthcare delivery, ensuring that military personnel, including armored vehicle crews, have access to essential medical evaluations even in challenging environments (Jasman et al, 2018; Kaidalov et al, 2023; Radzi et al, 2025). Lastly, the long-term safety analysis of apremilast for conditions such as psoriasis and psoriatic arthritis, while not directly related to the safety of armored vehicle crews, exemplifies the broader commitment to ensuring the health and well-being of military personnel through safe and effective medical treatments (Prasanna et al, 2019). Collectively, these diverse research initiatives contribute to a comprehensive strategy aimed at enhancing the safety and effectiveness of armored vehicle crews, reflecting a growing recognition of the importance of this issue in military operations.

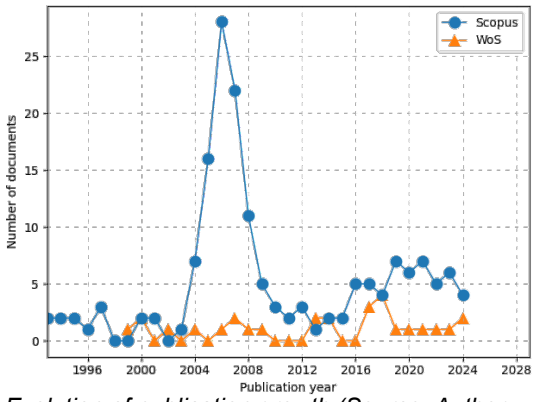

Figure 2 – Evolution of publication growth (Source: Author, using ScientoPy 2.1.3)

Most influential academic works

Figure 3 provides an overview of the most influential academic works on armored vehicle crew safety, highlighting institutional contributions based on the total number of documents published and the percentage of recent outputs (2022–2024). The Silesian Technical University in Poland stands out as the most influential institution, contributing the highest total number of publications, with 25% of its research outputs produced during the 2022–2024 period. In contrast, the China Agricultural University and the China North Vehicle Research Institute emerge as key contributors in the recent period, with 100% of their works published between 2022 and 2024, demonstrating their concentrated efforts and growing influence. While institutions from Germany, India, Malaysia, and Canada made significant earlier contributions, their lack of recent publications highlights a shift in research leadership, with Polish and Chinese institutions now driving the advancements in the field of armored vehicle crew safety.

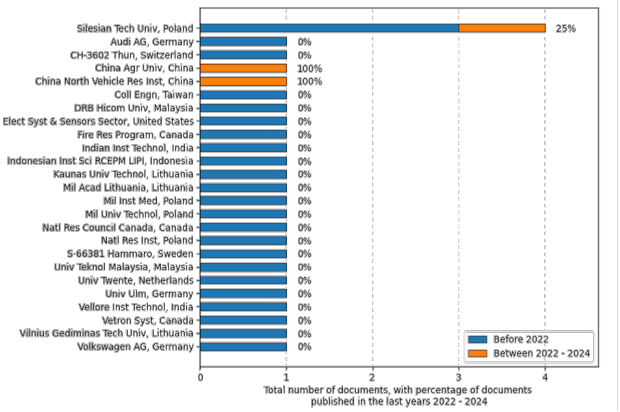

Figure 3 – Bar graph of institution trends

Authors' keywords

Figure 4 illustrates the distribution of authors' keywords pertinent to armored vehicle crew safety, comparing publications prior to 2022 with those published between 2022 and 2024. The keyword "armored vehicle" emerges as the most frequently utilized term, appearing in 75% of the related documents published during the latter period, which indicates a notable increase in scholarly focus on this subject. Additionally, the keywords such as "protection" and "whole-body vibration" demonstrate significant recent interest, accounting for 33% of the documents published between 2022 and 2024. This trend suggests that these domains are increasingly being investigated to enhance crew safety. In contrast, several other critical keywords, including "simulation," "uranium, depleted," "automated turret," "inhalation," "blast protection," "criterion of injuries," and "Madymo," have not been featured in recent publications (0% in 2022-2024), which may imply either a saturation of research in these areas or a pressing need for renewed inquiry. These findings underscore that while conventional safety aspects such as protection are attracting greater recent attention, other vital areas may necessitate further investigation to address the evolving challenges associated with armored vehicle crew safety.

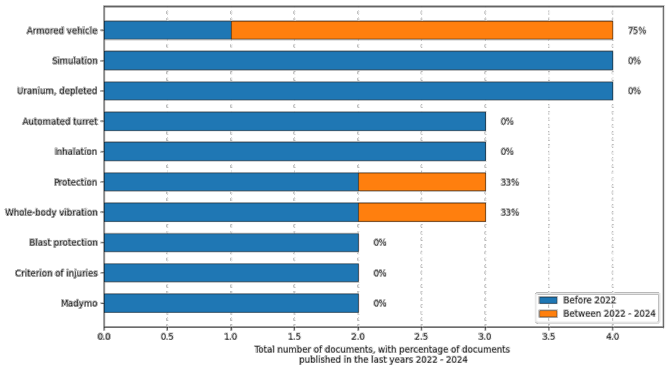

Figure 4 – Bar graph of the trend in research themes and emerging topics (Source: Author, using ScientoPy 2.1.3)

Figure 5 illustrates the overlay visualization generated by VOSviewer for armored vehicle crew safety, depicting the progression of research themes from 2017 to 2020. Initial research, represented by yellow and green nodes, concentrated on addressing critical threats and injury prevention, with terms such as "improvised explosive device," "criterion of injuries," "shock wave," and "blast protection." These keywords

underscore a significant emphasis on understanding and mitigating the impacts of explosive devices and associated injuries in earlier studies. As the timeline advances into 2018-2019 (blue and purple nodes), the focus transitions toward "protection" and "mobility," indicating an increased research interest in protective gear and ensuring crew mobility under armored conditions. More recently, in 2020 (red nodes), scholarly attention has expanded to encompass topics such as "suspension" and "vibration," reflecting a growing interest in vehicle dynamics and crew comfort. These latter keywords denote ongoing efforts to optimize vehicle design to minimize vibration and enhance safety and comfort for the crew. This timeline reveals an evolving research trajectory, transitioning from threat mitigation to improving overall vehicle and crew performance.

These findings indicate a clear evolution in the research focus on armored vehicle crew safety. Initially, efforts were primarily directed toward understanding and mitigating immediate threats such as improvised explosive devices and blast-related injuries. However, over time, the emphasis has shifted toward enhancing protective measures, improving crew mobility, and refining vehicle dynamics. The recent focus on suspension and vibration suggests that the field is now concerned not only with safeguarding the crew from external threats but also with optimizing vehicle design to improve comfort and reduce long-term health risks associated with vibrations and other mechanical stresses. This progression reflects a holistic approach to crew safety, integrating immediate protection with considerations for long-term well-being.

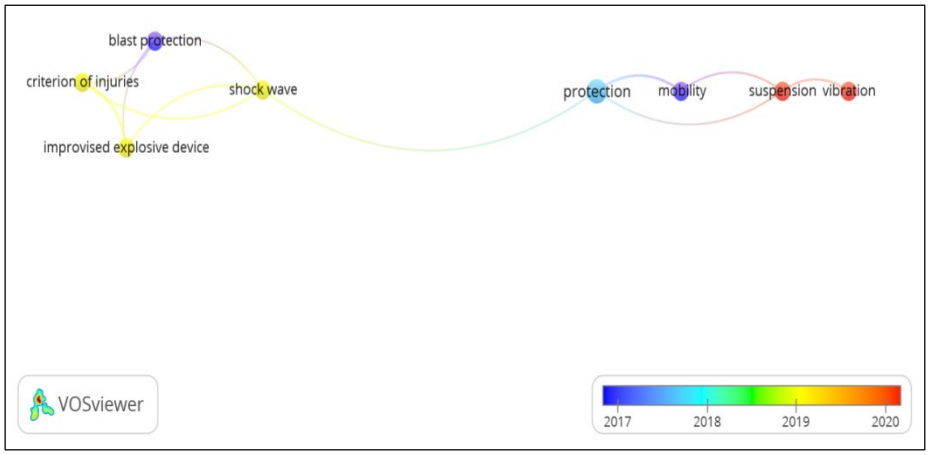

Figure 5 – Co-occurrence of authors' keywords

Scoping outcomes

This section provides a comprehensive examination of armored vehicle crew safety. Conducting this analysis represents a critical initial step in identifying knowledge gaps and guiding future research endeavors. Furthermore, it enhances the existing body of knowledge and establishes best practices within the field. To support this analysis, qualitative research questions were formulated, and the SPIDER tool was utilized as the search strategy. Table 2 presents a compilation of publications derived from the extended author keywords sourced from ScientoPy. Initially, the data in Table 2 were collected from a total of two documents. It is essential to note that this study focuses specifically on the scoping analysis of research articles; therefore, records that are not classified as research papers have been excluded at this stage.

Table 2 – List of inclusive publications

No	Sources	Sample	Phenomenon of interest	Design	Evaluation	Research type
1.	Alfaro Degan et al. (2017)	Compared whole-body vibration (WBV) exposure between a standard vehicle and an identical bulletproof armored vehicle, using the same driver for both to ensure consistent measurement conditions.	Focuses on how vehicle characteristics , especially bulletproof armor, influence WBV exposure in armored vehicle drivers and its potential impact on the risk of musculoskeletal injuries.	Measured WBV exposure in two phases: first in a standard vehicle, and then in the same vehicle model modified with bulletproof armor, both conducted on a curvilinear urban road under consistent conditions for reliable comparison	The installation of bulletproof armor altered the car's mass distribution and weight, leading to reduced WBV exposure, highlighting the significant impact of vehicle modifications on WBV levels according to ISO 2631-1(1997) standards	Quantitative

No	Sources	Sample	Phenomenon of interest	Design	Evaluation	Research type
2.	Alfaro Degan et al. (2016)	Involving 14 subjects driving urban vehicles, aimed to assess how vehicle armoring impacts whole-body vibration (WBV) exposure.	Investigates how the installation of bulletproof armor in armored vehicles impacts WBV exposure and the related health risks for professional drivers.	Utilized a case study approach with two sampling campaigns, comparing the performance of a standard vehicle and the same model modified with armor plating under controlled conditions for accurate comparison.	Indicates that vehicle characteristics, particularly the installation of bulletproof armor, significantly impact whole-body vibration (WBV) exposure, reducing the WBV dose by 10% to 20% depending on the driver's individual characteristic.	Quantitative

Discussion

The analysis of the keywords conducted in this study reveals a significant relationship between key methodologies—such as notational analysis, multivariate analysis, and kinetics—and their roles in evaluating and improving the safety of armored vehicle crews. Notational analysis, in particular, was identified as a crucial tool for systematically tracking and assessing crew actions, responses, and operational patterns. This approach facilitates the identification of performance gaps and opportunities to enhance safety in combat conditions. Additionally, this study examined the role of user state evaluations, underscoring the importance of understanding crew members' mental states and their interactions with human-machine interfaces. This comprehension is essential for developing tailored design solutions that support decision-making in high-stress environments (Witte & Schwarz, 2023). Furthermore, our analysis of factors influencing combat survivability—such as vehicle speed, acceleration, and detection distance—highlights the significance of accurate mobility predictions and logical operator actions in maintaining operational effectiveness and crew safety (Ostashevskiy & Piatkov, 2019).

The research provides evidence that advanced numerical simulations are vital for assessing the effects of explosive impacts and injury mechanisms, thereby contributing to the development of robust protection systems for armored vehicles.

The findings further demonstrate that the adverse effects of suspension and vibration on crew members are multifaceted, affecting both physiological and psychological aspects that compromise overall safety performance. Our analysis identifies whole-body vibration (WBV) as a significant risk factor for musculoskeletal pain, particularly low back pain (LBP), which is exacerbated by prolonged sitting and constrained postures during vehicle operation (Alfaro Degan et al, 2016; Bisyk et al, 2023). Moreover, cognitive performance significantly declines under vibration exposure, especially when compounded by occupational stressors typical in combat scenarios, such as elevated heart rate and respiratory frequency (Ismail et al, 2024; Aida et al, 2023). These findings underscore the necessity for strategies to mitigate both physical and psychological stressors, including enhanced ergonomic designs and technologies to reduce vibration exposure. This research identifies these areas as critical for improving safety outcomes and operational efficiency for armored vehicle crews.

Future directions emerging from this study emphasize the importance of integrating autonomous systems, hybrid vehicle designs, and advanced materials to bolster vehicle survivability and crew protection. The results suggest that incorporating technologies such as hybrid powertrains, blast-resistant materials, and IoT-based monitoring systems can provide more effective protective measures while enhancing vehicle performance (Piancastelli et al, 2023). Concurrently, our analysis stresses the necessity for standardized international safety protocols and collaborative efforts among stakeholders—including vehicle manufacturers, technology developers, and military organizations—to address the evolving challenges of military operations (Giurgiu et al, 2023; Hassan et al, 2020). Ultimately, this study underscores the critical need for comprehensive research into the long-term health impacts of WBV and blast exposure to inform future advancements in armored vehicle crew safety (Prasanna et al, 2019).

Based on a scoping analysis that examines the effects of bulletproof armor installation on WBV exposure among armored vehicle drivers, this study investigates how vehicle modifications impact vibration levels and associated health risks. The results indicate that the installation of bulletproof armor, primarily intended to enhance protection, can significantly reduce WBV exposure by 10% to 20%, depending on driver-

specific characteristics. This reduction is largely attributable to changes in vehicle mass and stiffness dynamics, as evidenced by our findings and supported by Alfaro Degan et al. (2017). The analysis reveals that the increased weight from armor installation lowers frequency-weighted root mean square (RMS) acceleration values, thereby attenuating WBV across various frequency spectra. Furthermore, advanced vehicle designs, such as anti-mine shields composed of aluminum alloy components, modify energy absorption and vibration response, leading to decreased WBV levels by influencing resonant frequencies (Bisyk et al, 2023). These findings underscore the significance of vehicle structure and weight distribution resulting from armor installation in mitigating WBV exposure and enhancing safety for armored vehicle drivers.

Additionally, this research highlights the necessity of optimizing vehicle design and implementing structural modifications to manage WBV. It demonstrates that careful adjustments to vehicle stiffness and mass properties can effectively reduce vibration amplitudes, similar to the results observed in vibration suppression technologies utilized in other transportation sectors (Aida et al, 2023). For instance, the baseline sensitivity method, which optimizes structural noise and vibration through strategic mass attachments, aligns with our findings that appropriate armor placement and material selection can minimize WBV levels across critical frequency peaks (Hong & Yoshimura, 2024). While not the primary focus of this study, it acknowledges advanced seat technologies and adaptive suspension systems as complementary solutions for further reducing vibration exposure. Overall, these findings suggest that the combined effects of bulletproof armor installation and structural modifications present a significant opportunity to mitigate WBV risks, thereby enhancing both driver safety and operational comfort. This study contributes to a deeper understanding of the engineering implications of armor installation, paving the way for future advancements in armored vehicle design and WBV management.

Armored vehicle crew safety is intricately linked to Sustainable Development Goal 3 (SDG 3), which emphasizes the need to mitigate the physiological and psychological impacts associated with operating in high-stress environments. Acute stress reactions (ASRs) are prevalent among military personnel, with 17.2% of soldiers reporting such experiences during combat, underscoring the necessity for effective prevention and management strategies to ensure the safety and well-being of the crew (Nordstrand et al, 2024; Radzi et al, 2024a).

The PREPARE study highlights the importance of addressing non-battle-related musculoskeletal injuries (MSKIs), which represent

significant medical issues affecting service member readiness. By identifying the physical and psychosocial factors that contribute to MSKI risks, the study seeks to enhance rehabilitation and risk mitigation strategies, thereby supporting the health and safety of military personnel (Butowicz et al, 2022; Radzi, 2024). Proactive psychological programs, as examined in the systematic analysis, demonstrate modest effectiveness in reducing posttraumatic stress injuries (PTSIs) and promoting psychological wellness through resilience and stress management strategies, which are critical for maintaining the mental health of individuals exposed to potentially traumatic events (Di Nota et al, 2021; Radzi et al, 2024a). The PRISMO study further underscores the long-term mental health impacts of military deployment, identifying biological and psychological factors that contribute to stress-related conditions, thereby informing strategies to support mental health post-deployment (Van Der Wal et al, 2020). Moreover, resilience has been shown to serve as a protective factor against psychiatric and physical health issues in combat-exposed veterans, suggesting that fostering resilience can mitigate the adverse effects of combat exposure, ultimately enhancing overall well-being (Di Nota et al, 2021; Radzi, 2024). Collectively, these studies highlight the multifaceted approach required to improve armored vehicle crew safety by addressing both physical and psychological health in alignment with the objectives of SDG 3.

Conclusion

The analysis presented in this study demonstrates that the installation of bulletproof armor in armored vehicles significantly influences WBV exposure levels, offering critical insights into the interaction between vehicle modifications and vibration mitigation. The results indicate that the addition of armor leads to a reduction in WBV exposure by approximately 10% to 20%, with variations attributed to vehicle mass distribution and specific driver characteristics. This reduction is primarily a consequence of alterations in the vehicle's stiffness and mass properties, which effectively decrease RMS acceleration values within critical frequency ranges, in accordance with ISO 2631-1 standards for vibration exposure.

Furthermore, the findings underscore the necessity for optimized vehicle designs that incorporate advanced structural modifications to manage WBV effectively. The study emphasizes the importance of integrating vibration-suppression technologies, such as enhanced suspension systems and structural improvements, to further mitigate WBV exposure. By addressing both protective and ergonomic dimensions of vehicle design, this research establishes a framework for enhancing the

safety and comfort of armored vehicle crews. These conclusions highlight that vehicle modifications aimed at improving survivability must also account for their impact on long-term crew health and operational efficiency.

Limitation of the current study

The inclusion of the publication list represents a significant limitation of this study. Although the analysis of scientometrics and scoping is founded on the Scopus and Web of Science (WoS) databases, future researchers could enhance the findings by also integrating data from Google Scholar, PubMed, and the Education Resources Information Center (ERIC).

Contribution to the body of knowledge and practices

This research contributes to the existing body of knowledge by systematically applying scientometric and scoping methods to evaluate publication trends, key research themes, and knowledge gaps related to armored vehicle crew safety. Through these methodologies, the study identified critical areas necessitating further exploration, such as the effects of WBV on crew health and the role of vehicle modifications in mitigating vibration exposure. The scientometric analysis elucidated publication growth patterns and the contributions of the leading institutions, thereby providing a clearer understanding of global research activity in this domain. Concurrently, the scoping review categorized evidence pertaining to technological advancements, including vehicle design modifications and material innovations, thereby emphasizing their potential impact on reducing WBV and enhancing blast protection. Collectively, these methodological approaches establish a robust foundation for advancing research priorities, guiding future inquiries, and informing the development of targeted safety strategies for military personnel operating armored vehicles.

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Mejora de la seguridad de la tripulación blindada: una revisión cienciométrica y de alcance de tendencias, desafíos e innovaciones clave

Elias M. Radzi[ac], **autor de correspondencia**, *Zuraida* Hassan[ac], *Mohd Azril* Ismail[ad], *Khairul Hafezad* Abdullah[ac], *Intan Suraya* N. Arzahan[ac], *Aswalni* Ishak[ac], *Ejiro* U. Osiobe[b], *Muhammad Hazim* A. Ghalib[ac]

[a] Universiti Utara Malaysia, Facultad de Negocios UUM, Kedah, Malasia

[b] Universidad de Westcliff, Facultad de Negocios, Departamento de Economía, Irvine, CA, Estados Unidos de América

[c] Escuela de Gestión Empresarial

[d] Escuela de Gestión de Tecnologías y Logística

CAMPO: ciencias militares, ingeniería mecánica
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Resumen:

Introducción/objetivo: Este estudio presenta un análisis integral de la bibliografía existente sobre la seguridad de la tripulación de vehículos blindados a través de una metodología cienciométrica y de alcance integrada.

Métodos: Se utilizaron datos procedentes de Scopus y Web of Science para analizar un total de 197 documentos tras el preprocesamiento y la eliminación de duplicados. El análisis cienciométrico se realizó utilizando el software ScientPy y VOSviewer para identificar tendencias de publicación, coexistencia de palabras clave y contribuciones académicas influyentes. Además, se llevó a cabo una revisión de alcance basada en la estructura SPIDER para sintetizar conocimientos críticos relacionados con la vibración de todo el cuerpo (WBV), el diseño de vehículos y las tecnologías de seguridad.

Resultados: Los hallazgos indican que la instalación de armaduras antibalas reduce significativamente los niveles de exposición al WBV, con reducciones que oscilan entre el 10% y el 20%. Estas reducciones se atribuyen a modificaciones en la distribución de masa y la rigidez del vehículo. Se identificaron materiales avanzados, como las aleaciones de aluminio, como esenciales para mejorar la resistencia a las explosiones y mitigar las vibraciones. Los resultados enfatizan la importancia de las modificaciones estructurales y las tecnologías adaptativas, incluidos los sistemas de suspensión mejorados, para gestionar el WBV y mejorar la seguridad general de la tripulación.

Conclusión: Este estudio establece una base sólida para futuras investigaciones, subrayando la necesidad de diseños de vehículos optimizados y estrategias de seguridad integradas para abordar los factores estresantes fisiológicos y psicológicos que enfrentan las tripulaciones de vehículos blindados.

Palabras claves: tripulación de vehículos blindados, vibración de cuerpo entero, análisis cienciométrico, revisión de alcance, blindaje antibalas.

Повышение безопасности экипажей бронированных машин: наукометрический и аналитический обзор ключевых тенденций, проблем и инноваций

Элиас М. Раджи[ав], **корреспондент**, *Зураида* Хасан[ав], *Мохд Азрил* Исмаил[аг], *Хайрул Хафизад* Абдулах[ав], *Интан Сурая* Н. Арзахан[ав], *Асвални* Ишак[ав], *Еджиро* У. Осиобе[б], *Мухаммед Хазим* А. Галиб[ав]

[а] Университет Утара, Малайзия, Колледж бизнеса UUM, г. Кедах, Малайзия

[б] Вестклиффский университет, Колледж бизнеса, экономический факультет, г. Ирвин, Калифорния, Соединенные Штаты Америки

[в] Школа бизнеса и менеджмента

[г] Школа технологий менеджмента и логистики

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ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данном исследовании представлен всесторонний анализ существующей литературы по безопасности экипажа бронированной машины с применением интегрированной наукометрической и аналитической методологии.

Методы: Данные, полученные из Scopus и Web of Science, были использованы для анализа 197 документов после предварительной обработки и удаления дубликатов. Наукометрический анализ был проведен с помощью программного обеспечения Scientopia и VOSviewer для определения тенденций публикаций, совпадения ключевых слов и значимых научных вкладов. Помимо того, был проведен аналитический обзор, основанный на концепции SPIDER, с целью обобщения критических данных, касающихся вибрации всего

тела (WBV), проектирования транспортного средства и технологий обеспечения безопасности.

Результаты: Результаты исследования показали, что установка пуленепробиваемой брони значительно снижает уровень воздействия WBV, причем снижение составляет от 10% до 20%. Это снижение объясняется изменениями в распределении массы и жесткости транспортного средства. Современные материалы, такие как алюминиевые сплавы, являются необходимым фактором в повышении ударопрочности и снижения вибрации. Результаты подчеркивают значимость конструктивных изменений и адаптивных технологий, включая усовершенствованные системы подвески для управления ударопрочностью и повышения общей безопасности экипажа.

Вывод: Данная статья закладывает прочный фундамент для будущих исследований, подчеркивая необходимость оптимизации проектирования транспортных средств и внедрения стратегий по обеспечению безопасности для устранения физиологических и психологических стрессоров, с которыми сталкиваются экипажи бронированных машин.

Ключевые слова: экипаж бронированной транспортно-боевой машины, вибрация всего тела, наукометрический анализ, обзорный анализ, пуленепробиваемая броня.

Побољшање безбедности посаде оклопних возила: сциентометријска анализа и преглед заступљености кључних трендова, изазова и иновација

Елиас М. Раџи[ав], **аутор за преписку**, *Зураида* Хасан[ав], *Мохд Азрил* Исмаил[аг], *Хајрул Хафизад* Абдулах[ав], *Интан Сураја* Н. Арзахан[ав], *Асвални* Ишак[ав], *Еџиро* У. Осиобе[б], *Мухамед Хазим* А. Галиб[ав]

[а] Универзитет Утара Малезија, Колеџ бизниса УУМ, Кедах, Малезија

[б] Универзитет Вестклиф, Пословни колеџ, Одсек екеономије, Ервајн, Калифорнија, Сједињене Америчке Државе

[в] Школа за пословни менаџмент

[г] Школа технологије менаџмента и логистике

ОБЛАСТ: војне науке, машинство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Овај рад представља свеобухватну анализу постојеће литературе о безбедности посаде оклопних возила путем обједињавања сциентометрије и методологије заступљености.

Методе: Подаци из Scopus-а и Web of Science коришћени су у анализи укупно 197 докумената након претходне обраде и уклањања дупликата. У сциентометријској анализи коришћен је алат ScientoPy и софтвер VOSviewer за идентификовање трендова при објављивању, кључних речи, као и утицајних академских доприноса. Литература је анализирана по заступљености у окружењу SPIDER како би се синтетизовала најважнија знања из области вибрација целог тела (WBV), пројектовања возила и безбедносних технологија.

Резултати: Налази истраживања показују да инсталирање панцирног оклопа у знатној мери (од 10% до 20%) смањује изложеност целог тела вибрацијама. Ово смањење приписује се модификацијама у распореду масе и крутости возила. Напредни материјали, као што су алуминијумске легуре, идентификовани су као суштински важни за повећавање отпорности на удар и смањење вибрација. Резултати истичу важност структурних модификација и адаптивних технологија, укључујући побољшане системе вешања у решавању проблема вибрација целог тела, као и у повећању безбедности посаде у целини.

Закључак: Ова студија поставља чврсте основе за будућа истраживања, истичући потребу за оптимизованим пројектовањем возила, као и за интегрисаним безбедносним стратегијама ради решавања физиолошких и психолошких стресора којима су изложене посаде оклопних возила.

Кључне речи: посада оклопног возила, вибрација целог тела, сциентометријска анализа, преглед заступљености, панцирни оклоп.

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