A review into studies related to the effect of the pavement surface condition on traffic safety: A scientometric analysis

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1. Introduction

With the development of transportation systems, traffic safety has become a widespread problem around the world, and with the increase in the number of vehicles, crashes have increased significantly. Any crash involving a collision between two cars or more or a car crash with others, such as pedestrians, walls, animals, or any objects on the road, will result in death, injury, or property damage (Garber & Hoel, 2009). According to the World Health Organization (World Health Organization, 2018), approximately 1.35 million people are killed annually in traffic accidents. A further 50 million people sustain non-fatal injuries, with many becoming disabled as a result. Traffic injuries cause great economic losses to individuals, their families, and entire countries. The statistics of the World Health Organization. Researchers have conducted many studies to reduce traffic crashes and preserve the safety of people and property.

Many factors affect accident rates, including the road, the driving environment, and the driver. Pavement condition is one of the main reasons that lead to an increase in crash rates. (Elghriany, 2015). (Zubaidi et al., 2022). In most U.S. states, injury severity is quantified based on the KABCO scale, which consists of five injury levels: (K) death, (A) incapacitating injury, (B) non-incapacitating injury, (C) potential injury, and (O) no injury. The fatal category receives special attention; if an injured individual dies within 30 days of the incident, the crash report is revised to reflect this occurrence (Tarko et al., 2010). Many researchers used a scientometric overview as a review of previous research, for example (Alnedawi et al., 2022; Caffo et al., 2020; Kim & Chen, 2015; Olawumi & Chan, 2018; Ospina-Mateus et al., 2019; Zou et al., 2020) (Das & Zubaidi, 2021; Hughes et al., 2015; Vigneshkumar & Salve, 2020).
2. Literature Review

Researchers have conducted many studies that show the relationship between crashes and pavement conditions. In a study conducted on some streets in Bauchi city in 2012, Bauchi-Jos, Bauchi-Yobe, and Bauchi-Gombe, the influence of pavement surface conditions on accident rates were investigated using road condition scores for these three roads. There are significant relationships between surface conditions and the severity of crashes (Mohamed et al., 2016). In Northern Virginia's Fairfax District, researchers investigated the effect of pavement defects on the rate of crashes. The purpose of this research is to investigate accidents and street features associated with each collision to determine the impact of those factors on the accident rate and, subsequently, to construct models for forecasting the accident rate on each section of the road. According to the findings, the surface state has a considerable effect on the crash rate (Mohagheghi et al., 2020). (Chistoforou et al., 2010; Hughes et al., 2015; Lozano et al., 2012; Obaid et al., 2022; Washington et al., 2020; Zubaidi et al., 2020), (Aldhalemi & Abidi, 2022; Leidman et al., 2016) (Darma et al., 2017). According to the researchers (Lee et al., 2015), bad pavement conditions reduce the severity of crashes for single-vehicle accident rates on low-speed highways and increase high-speed loads. When there are multiple collisions, the severity of the accidents increases when the pavement is in poor condition. Another study about cities with harsh climates, moisture, temperature, bad drainage, improper maintenance, and excessive traffic. In this section, we discuss some pavement defects that significantly impact accident rates and severity (Abdel-Aty et al., 2009; Cenek et al., 2014; Chandra et al., 2013; Lee et al., 2015; Pinatt et al., 2020; Solla et al., 2014; Takallo, 2010).

2.1. Pavement Defects

The state of the pavement can be negatively impacted by some factors affecting pavement failures, such as poor construction conditions, a harsh climate, moisture, temperature, bad drainage, improper maintenance, and excessive traffic. In this section, we discuss some pavement defects that significantly impact accident rates and severity (Abdel-Aty et al., 2009; Cenek et al., 2014; Chandra et al., 2013; Lee et al., 2015; Pinatt et al., 2020; Solla et al., 2014; Takallo, 2010).

2.1.1. Rutting

Rutting is a permanent deformation, which is a depression that occurs in the wheel path on the road surface. Pavement elevation may rise along the rut’s sides. The rut is often only visible after a downpour. When water fills a rut, the vehicle will pull into the rut paths, causing hydroplaning. (Huang, 2004). (Williams, 2003) indicated that several factors influence rutting, such as increased binder content, which increases rut depth. When the binder is used more than is required, aggregate particles lubricate and move. In addition, when layer thickness increases, so does rut depth; when the layer thickness is too thick, the aggregate has the potential to move. Also, rut depths decrease as the performance grade PG (binder grade) increases. Binders are polymer-modified to improve performance, which can result in less rutting susceptibility. Moreover, rut depth increases as void mineral aggregate (VMA) increases. (Kandhal & Mallick, 2001) found that mixes with stiff binders and large particles of aggregates are generally more rut-resistant than those with finer aggregates and higher binder contents. In a study by (Hicks et al., 2000) the authors classified rutting into three levels: If the depth of rutting is under 6 mm, it is considered minor severity. It's doubtful that there will be any hydroplaning issues or wet weather mishaps. When the depth of rutting is between (7 and 12 mm), the severity of the accident is moderate because rainy weather accidents and hydroplaning might result from an insufficient cross slope. When the depth of rutting is greater than (13 mm) high severity, which greatly increases the danger of wet weather accidents and hydroplaning. (Start et al., 2004) discovered that the accident rate increases as the rut depth exceed (7.6 mm) (0.3 in). Another study in Indiana used accident data for nine years to show the effect of pavement defects on traffic accidents. It was found that increasing the rutting depth in paving increases the crash rate by 94.27 percent while reducing the crash rate by 5.73 percent. (Anastassopoulos et al., 2012), (Al-Humeidawi, 2016).

2.1.2. Roughness

Roughness is defined as irregularities on the pavement surface; it refers to pavement ride quality and leads to an increase in the vibration of vehicles, which reduces vehicle speed. It causes harm to the vehicle's tire and raises the vehicle's operating costs. The International Roughness Index (IRI) produced from measured roadway segments can be used to measure the roughness of pavement (Huang, 2004). A study conducted to explore the relationship between the roughness of the road and traffic safety found that the parts of the road that have the highest accident rate have a higher rate of road roughness than the parts of the road that have the lowest accident rate (King, 2014). Other researchers found that when the roughness of the road is high, the crash rate will be higher (Alhasan et al., 2018). IRI values are different based on the roadway classification. Under common traffic speeds on dry roads, the new pavement may range from 1.5 m/km to 3.5 m/km and older pavement may range from 2.5 m/km to 6 m/km (Elghriany et al., 2016), (Yu & Lu, 2014), (Chandra, 2004), (Sjögren, 2004) (Arhin et al., 2015). The Federal Highway Administration (FHWA) proposes ride quality criteria of 170 in/mile (2.7 m/km). A study in Indiana State investigated the impact of the pavement surface condition on crash severity on a rural highway. The data was collected for 1524 road segments over three years. This study used a negative binomial model to analyze the data. It is noted that in poorer pavement conditions that have higher roughness, accidents will be more frequent due to the difficulty of controlling the vehicle by the drivers. The other part of the study indicates that under the same conditions, the increase in the roughness reduces the frequency of accidents because the drivers will be more careful when driving (Chen et al., 2017). A study at Ohio State investigated the influence of pavement roughness on accident rates. The results showed that pavement with a roughness index of 1.5 m/km has a low accident rate, while pavement with a roughness index of 2.25 m/km and greater has higher accident rates. The researchers also suggested that the study’s findings could be used as a reference to assist local and governmental transportation agencies with road maintenance operations (Elghriany et al., 2016). A one standard deviation increase in road roughness (IRI) can result in an 11% decrease in average speed and an increase in vehicle crashes large enough to move a safe road segment with no crashes in an average month to about 0.5 standard deviations above the sample period's average crash rate, resulting in a...
significant decrease in traffic safety (Anastasopoulos et al., 2012). Another study examined the effect of changes in roadway roughness on vehicle speed by using a linear regression model. The data was collected from the freeway network in California from 2000 to 2011. The results indicated that roadway roughness has a small influence on free-flow speed; a one-meter-per-kilometer change in IRI results in a 0.48-0.64-kilometer-per-hour change in average free-flow speed (Wang et al., 2014). (Al-Humeidawi et al., 2021) (Nguyen et al., 2020).

2.1.3. Skid resistance

Skid resistance refers to the friction force between the surface of the road and the tire of the vehicle. It is considered one of the most important characteristics of the road, the loss of which affects traffic safety. A study in Spain measured skid resistance with Sideway-force Coefficient Routine Investigation Machine (SCRIM) for a two-lane rural roadway. Crash data was collected for 1750 km to find the effect of road surface conditions on crash rate and to evaluate the impact of improved friction on pavement safety. The results showed that when skidding resistance values increased, both dry and wet pavement accident rates decreased. Pavement friction schemes had a significant decrease in wet pavement accident rates of 68% (Mayora & Piña, 2009). Another study in Virginia analyzed data from 1.6 km of road with wet accidents to examine the relationships between accident rate and skid resistance and found that when the skid numbers decrease, the wet accident rate increases (Kuttesch et al., 2014). (Tyfour, 2009).

A study in Iowa state examined the effect of pavement conditions on the risk of highway departure accidents. The information was collected between 2006 and 2016. According to the study, having a high skid resistance reduces the severity of an accident regardless of whether the road is dry or wet (Alhasan et al., 2018) (Hossain et al., 2018; Jitsangiam et al., 2019).

3. Data collection

Web of Science (WoS) is a platform consisting of many research databases described in previous literature and designed to support scientific and academic research. It provides access to many databases that refer to research sources for specialized research. Users can now conduct in-depth searches in specialized subfields of scientific and academic research. It has more than 148 million documents, including books, journals, and proceedings that date back to the turn of the 20th century. WOS was used to search for studies and research on accidents and traffic safety that relate to pavement conditions, and the keywords were used in the search (i.e., pavement vehicle crashes). Documents for the years 1990-2022 were retrieved from WOS using applicable research criteria and after filtering unrelated research publications, WOS shows some figures that illustrate the relationship between citations and publication numbers (Figure 1), where (4.183 transportation is above 180), followed by (7.3 asphalt with 20 citations). (Figure 2) shows the relationship between citations and publication types for the related studies. It includes transportation with 140 citations, followed by civil engineering with approximately 90 citations. Many researchers have used a Web of Science (WoS) site, and the VOSviewer program, especially in the field of traffic accidents (Mongeon & Paul-Hus, 2016; Pranckutė, 2021; Soosaraei et al., 2018). Many studies have discussed the risk of accidents and made a scientometric overview (He et al., 2022; J. Li et al., 2014; W. H. Li et al., 2022; Zou et al., 2018).

4. Analytical method

Bibliometrics is the research and analysis of the format components of texts, papers, articles, and data. It is widely used and approved in many different disciplines, particularly for quantitative assessments by researchers, institutions, and publications based on academic outputs. Many application programs have been developed to carry out the bibliometric method, including BibExcel, Vos Viewer, Pajek, Gephi, CiteSpace, and Histcite. In this study, VOSviewer was used to create bibliometric and visual maps.

![Figure 1. Relationship between citation and publication number](image-url)
VOSviewer is a software application that enables you to construct maps using network data and then visualize and explore those maps. There are three types of visualizations in VOSviewer network visualizations, overlay visualizations, and density visualizations. (Eck & Waltman, 2022). Several researchers presented a scientometric Overview of several important studies using the VOSviewer program such as (Das & Al-Zubaidi, 2021) and (Alnedawi et al., 2022). Many researchers have used the VOS viewer program to create charts and graphics that show the most prominent researchers, journals, and countries interested in the topic of research, accidents, and the work of A scientometric overview (Gautam, 2021; Kolesnykova et al., 2019; Musa et al., 2021; Xue et al., 2021).

4.1. Top contributions

Table 1 shows the 10 contributions by authors, countries, and institutes. In terms of total link strength, the top three authors are Abdel-aty, Mohamed, with 35 publications, Yan Xuedong, with 24 publications, and Li, Zongzhi, with 20 publications. A highly contributing country with 64 publications is the United States (USA), followed by China with 34 publications, and Canada with 14 publications. The top three terms of the total link strength for universities are Purdue University with 28 publications, Penn State University with 16 publications, and Changan University with 14 publications (Anastasopoulos & Manning, 2009; Bhat, 2003; Chen et al., 2019; Dey et al., 2021; Flintsch et al., 2012; Garrido et al., 2014; Hermans et al., 2009; W. Li et al., 2019; Y. Li & Huang, 2014; Shah et al., 2018; Zhang et al., 2020).

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Note: F= Frequency, U= University

4.1.1. Co-authorship Measures

Figure 3 shows a map of the most prominent authors discussing accidents due to the condition of the pavement and the joint research and cooperation among them. The elements are represented and classified by circles of different sizes and colors, and the elements are connected by lines representing the relationships between the elements. The thicker lines represent the strongest communication between the elements, as the space between the items, shows their degree of connectedness. The overall strength of co-authorship connections with other writers is computed. The writers with the most overall link strength are chosen. As a result, there are 67 items and 11 cluster networks, and the circles are colored based on the clusters. The larger the node, the more influential the author is. Among the
most important writers are Abdel-aty Mohamed, Yan. Xuedong; Anastasopoulos, Panagiotis ch.; Mannering, Fred; Ahmed. Mohamed m.; and Sarwar, MD Tawfiq. Abdel-Aty, Mohamed conducted many types of research on traffic safety. Some of his research with other researchers shows that road resurfacing projects reduce collision frequency (Park et al., 2017). Another study on ride quality (roughness) found that higher IRI led to the deteriorated pavement as a result of more accidents (Lee et al., 2020). Researchers Baoshan Huang and Xuedong Yan have been involved in many research projects. One of their studies illustrated that there is a significant relationship between pavement conditions and the type and severity of accident frequencies (Chan et al., 2009). Whenever researchers are within one group or close to the other group, this indicates the degree of cooperation and participation between researchers.

4.1.2. Institutes map

Figure 4 shows the joint organizations resulting in a total of 66 items in 12 cluster networks. It can be noticed that the university of central Florida, Virginia technology, Pennslyvania State University, Changan University,
and Texas A&M University Syst have the highest contribution to work related to crashes related to pavement conditions (Baskara et al., 2016; Chan et al., 2010; Christensen et al., 2006; Dhuahad, 2015; Han et al., 2011; Isradi et al., 2020; Jrew et al., 2015; Kuttesch et al., 2004; Mayora & Piña, 2009; Mkwata & Chong, 2022; Mohammed et al., 2016; Siriphun et al., 2019; Tsubota et al., 2018).

4.1.3. Country map

The network map shows the countries that publish the most research related to accidents, resulting in 30 items (12 clusters) where the United States is followed by China and Canada. These countries have presented a lot of research that contributes to the development of transportation systems to reduce their danger and link the relationship between the condition of pavement and traffic accidents.

4.1.4. Co-occurrence Measures

Figure 6 illustrates the joint author keywords, resulting in a total of 786 items in 45 cluster networks. Many nodes appear, each with its color and size, representing the impact of keywords and the degree to which they are used in the search engine, where we notice many keywords that can be used to find the most prominent research that links the relationship between pavement conditions, traffic safety, and the severity and frequency of accidents. The yellow color in Figure 7 shows the density visualization map of the co-occurrences. Road safety, pavement condition, pavement friction, highway safety, traffic safety, and injury severity are some of the high-density and closely related keywords. Each of these keywords helps the researcher find many types of published research. The large nodes show the most used keywords, and the line represents the degree of proximity between these words, as many keywords share one search. Many types of research have focused on the condition of pavement and its relationship to traffic safety. (Al-Masaeid, 1997), (Y. Li & Huang, 2014b), (Elhadidy et al., 2021), (Buddhavarapu et al., 2013), (Hicks et al., 2000), (Abdulwahab et al., 2021; Oyewola & Dada, 2022; Schrank, 2007; Stewart et al., 2016; Takallou, 2010b; Washington et al., 2020). (Asad, 2017; Awad & Parry, 2018; Bock et al., 2021; Hou et al., 2020; Hussein et al., 2021; Ivan et al., 2012; Y. Li et al., 2013)
5. Conclusion

The condition of the pavement and its deterioration is one of the main factors that increase the risk of accidents, as several studies have been presented that show the impact of pavement defects such as rutting, roughness, and skid resistance on traffic safety. The VOS program was used to meet the most important researchers who published about pavement defects and their relationship to accidents, and the degree of cooperation among them, including Abdel-aty, Mohamed; Yan, Xuedong; Anastasopoulos, Panagiotis Ch; Mannerling, Fred; Ahmed, Mohamed M.; and Sarwar, MD Tawfiq. It also identified the most prominent countries interested in this topic of research, which is more influential than other countries in the dissemination of research, which is the United States, China, and Canada. Active collaborating universities on the subject of traffic safety and its relationship to accidents are the University of Central Florida, Virginia technology system, Pennsylvania State University, Changan University, and Texas A&M University System. Therefore, this research provides a map to guide researchers and the basics of research related to the relationship between pavement conditions and vehicle crashes.

6. Recommendation

Given the importance of pavement condition, which is considered one of the main contribution factors, especially after studies have proven its impact on traffic safety, it is recommended conducting extensive and comprehensive studies on the pavement in Iraq. Furthermore, studying all other factors contributing to pavement failure, especially since there are not enough local studies on this subject and there is no evidence of the possibility of applying the results of previous studies in Iraq because Iraq has a unique economic, and social environment that may not be applicable to the results of previous studies. Also, Iraq's infrastructure and access to resources may be different than in other countries where the studies were conducted, making it difficult to apply the same results. In addition, the data used in previous studies may not be applicable or available in Iraq, making it difficult to draw meaningful conclusions from them.

For that, when conducting research about pavement condition related traffic safety, it is important to consider the following:

1. Identify the types of pavement conditions that may have an impact on traffic safety. This includes factors such as surface texture, surface roughness, and potholes.
2. Collect data on the pavement conditions in different areas and analyze it to determine if there is a correlation between pavement condition and traffic safety.
3. Develop a survey to collect information from drivers about their experiences with different types of pavement conditions and how they affect their driving behavior.
4. Analyze the survey results to identify any patterns or trends in how different types of pavement conditions affect driver behavior and traffic safety.
5. Use the data collected from the survey and analysis to develop recommendations for improving pavement conditions to improve traffic safety.

Finally, it is crucial that periodic maintenance be performed and that the pavement condition be continuously evaluated to control pavement defects and treat them before the pavement condition deteriorates and fails.

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