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Analysis of Pavement Condition Index Method for Maintenance and Rehabilitation Strategy for Airport Flexible Pavement: A Bibliometric Review

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ABSTRACT
This study presents a comprehensive bibliometric review aimed at examining the effectiveness and applicability of the pavement condition index (PCI) method, particularly in assessing airport pavement distress and guiding maintenance and rehabilitation (M&R) strategies. Through bibliometric analysis spanning the last two decades, we investigate the evolution of the PCI method in both road and airport pavement contexts, exploring patterns of keyword co-occurrence, co-authorship, geographical distribution, and publication trends. Our findings reveal significant advancements in the PCI model and associated M&R strategies, largely driven by technological innovations. However, limitations are identified in current bibliometric analysis tools, such as Harzing's Publish or Perish, particularly concerning handling large datasets. Practical implications highlight the importance of integrating bibliometric analysis tools with automated big data handling to enhance research efficiency and reliability. Future research should focus on improving methodological integration to streamline the visualization of scientific network techniques with minimal effort and time investment.
Keywords: Pavement Condition Index, Maintenance, Rehabilitation, Airport Pavement.

INTRODUCTION

Pavements are widely acknowledged as the pivotal and indispensable constituent of road structures in numerous countries around the world. The advancements in the automobile industry stimulate a parallel increase in motor vehicle ownership. Hence, high-quality pavements are needed to accommodate high traffic conditions (Liu, Su, Li, You, & Zhao, 2020). However, well-designed pavement structures do not always resemble the final practical product, as engineers are always presented with practical dilemmas. The performance of a pavement is characterized by the conditions of its surface and structure. The evaluation of pavement performance is often measured using a set of indicators, such as Present Serviceability Rating (PSR), Pavement Condition Index (PCI), and International Roughness Index (IRI) (Issa, Samaneh, & Ghanim, 2022).

These performance indicators are widely used to develop pavement rehabilitation strategies (Shah, Jain, Tiwari, & Jain, 2013).

Assessing road performance is crucial in determining the appropriate tools for measurement. The Pavement Surface Rating (PSR) is derived from road user opinions regarding pavement conditions, alongside measurements of selected distresses, and calculated through regression analysis to obtain the Present Serviceability Index (PSI) (Yoder & Witczak, 1975). The International Roughness Index (IRI) is expressed in slope units, measuring a vehicle's suspension motions caused by profile roughness, and is linearly proportional to roadway roughness (Park, Thomas, & Lee, 2007) Meanwhile, the Pavement Condition Index (PCI) serves as an assessment of the current state of the pavement, indicated by observed distresses on its surface. This evaluation reflects the surface's operational condition, including localized roughness and safety, and provides insights into the pavement's structural integrity (ASTM International, 2020). These index methods serve different purposes in pavement performance evaluation. However, Li developed an evaluation model based on PCI, IRI, and pavement friction coefficient (Li, 2011).

The research results show important parameters that shed an elementary understanding of some methods in pavement performance. PCI only measures the structural integrity of pavement but not its capacity, nor does it provide a direct measurement of roughness or skid resistance. Longitudinal/transverse distress of the PSR refers to roughness caused by pavement elevation differences while surface distress refers to the relationship of surface texture level to skid resistance (Pranjić, Deluka-Tibljaš, Cuculić, & Šurdonja, 2020). However, from the standpoint of airfield pavements, the structural capacity of the aircraft and passenger safety become the top priority. Nevertheless, the concept may be applied to the airport pavement under strict guidelines. This was proven when Inoue et al conducted a consciousness survey based on pilots' opinions and their relationship with distress data (Inoue, Kawamura, Hachiya, & Himeno, 2002) as well as by Kanazawa (Kanazawa, Su, Noguchi, Hachiya, & Nakano, 2010).

Several aviation agencies adopted the PCI methodology for pavement surface evaluation through guidelines demonstrated in ASTM Standard D 5430-20 (ASTM International, 2020) by ASTM International and FAA AC 150/5380-7B by the Federal Aviation Administration (FAA) (Federal Aviation Administration, 2014). The PCI values are determined by visually identifying the types of distress, magnitude, and quantities prevalent on the pavement surface (Miah, Oh, Chai, & Bell, 2020). Based on the ASTM Standard, PCI provides feedback on pavement performance to validate or enhance existing pavement design and maintenance processes. Visual inspection data can be used to evaluate the current pavement condition, predict future pavement performance, determine and prioritize pavement maintenance and rehabilitation (M&R) needs, estimate repair quantities, and evaluate the performance of different M&R techniques and materials (Karim, Rubasi, & Saleh, 2016). While there are several options for pavement performance evaluation, the PCI method is deemed appropriate for airfield pavement.

Further discussion is done in the literature section as to why PCI is the preferred method with the support of existing literature. Bibliometric analysis can be used to narrow down research themes and visualize trends in research papers throughout a limited timeline (Inamdar, et al., 2021); (Koo, 2021); (Rejeb, Abdollahi, Rejeb, & Treiblmaier, 2022); (Jiménez-García, Ruiz-Chico, Peña-Sánchez, & López-Sánchez, 2020); (Haque, Islam, Hasan, & Akanda, 2019). Bibliometric analysis is a technique that makes it possible to provide a macroscopic overview of large amounts of academic literature (van Nunen, Li, Reniers, & Ponnet, 2018). It can be used to identify and quantify cooperation relationships, co-citation similarities, main research topics, and research trends in a research domain (Yang, Reniers, Chen, & Goerlandt, 2019). Currently, an M&R bibliometric review of road (Chen & Zheng, 2021) and pavement distress analysis of airport have existed (Noori & Sarkar, 2023), however, to the best of the author's knowledge, no bibliometric review of the PCI method for airfield pavement evaluation, currently exists.

RESEARCH METHODS

This study adopts a bibliometric analysis of academic publications to uncover PCI-related research on pavement followed by analysis using the science mapping tools. An organized comprehensive guideline for the techniques available in the bibliometric analysis is present (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021). Bibliometric analysis can be used to collect quantitative values, breaking down the existing literature in the different indexed reference sources (Alaminos, Guillén-Pujadas, Vizuete-Luciano, & Merigó, 2024). Quantitative values refer to science mapping techniques in step two. It is wise to provide step-by-step sub-methods providing linear insights in the methodology section. Step one –elaborate the aims and scope of the study, which should be such that the adapted topic warrants a bibliometric analysis discussed in the previous section. Additionally, this method is useful in formulating insightful proposals for further studies parallel to the writer's academic prospect (Catugno, Manta, Perdichizzi, & Stefanelli, 2024). In this case, this review is a preparatory step towards case study research. Step two – deploying a bibliometric technique referred to as science mapping, encompassing eight subsidiary techniques: citation analysis; co-citation analysis; bibliographic coupling; co-word analysis; co-authorship analysis; network metrics; clustering; and visualization (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021). Step three – analyze results from the science mapping technique later in the results and discussions section.

Data source. Publications for the literature review are retrieved from Crossref, a non-profit digital organization with open-source capabilities for scholarly research. A keyword search was performed under the notion of the selected literature topic using a scholarly database search software called Publish or Perish developed by Anne-Wil Harzing (Harzing, 2007). Applying Harzing's Publish or Perish for database research provides several advantages, such as being open-source, free to use, and providing automatic citation metrics (publications and citation years;

number of publications, citation ratio, h-g indexes, etc.). First, choose the desired publication database, e.g., Crossref, to retrieve articles. Then, in the Crossref search section, users are presented with several datasets to fill in. However, due to the nature of this bibliometric review, input the keywords related to the topic in the keywords section. The number of keywords depends on how specific the search is. More keywords put into the search engine could give specific results, but the number of publications retrieved that are related to the chosen topic would be fewer. In this case, three to four keywords are preferred in the context of the PCI method for pavement evaluation.

Figure. 1 shows the systematic step-by-step of data identification and filtration. Publications released after 1999 until the search date (26 November 2023) were considered. A total of 1000 publications were extracted from Harzing's Publish and Perish. Duplication removal, followed by title and abstract screening, was conducted, leaving 568 publications in journal articles, proceedings articles, and books or book chapters.

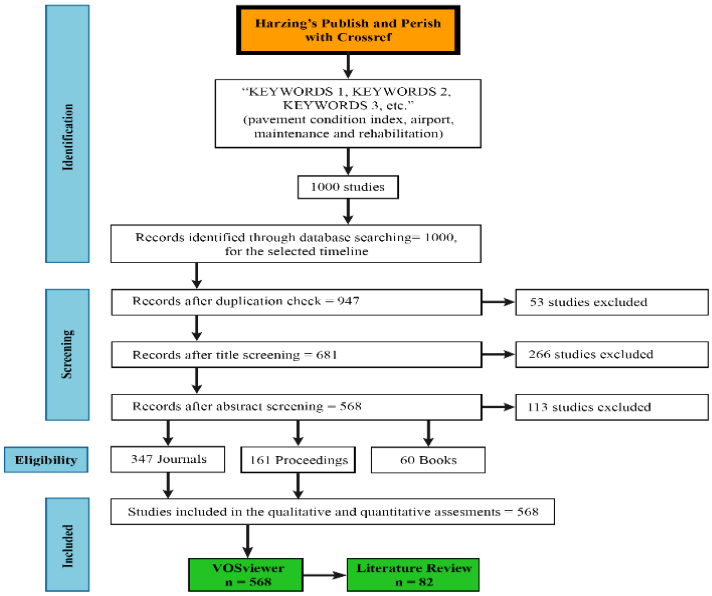

Figure 1. Systematic Diagram of Data Identification and Filtration

Identifying and screening are recognized as the more time-consuming phases when conducting a bibliometric study. This crucial step is essential for constructing a corrected and accurate database, which will be used as the science network mapping database in the VOS viewer software. After the screening phase, locally save the corrected database as an RIS file. However, this RIS file can only be used to visualize science maps of term co-occurrence and co-authorship. Other parameters, such as year trendline, number of publications on countries, journal names, and type, are analyzed manually with Microsoft Excel.

RESULTS AND DISCUSSION

Trend Analysis. Fig. 2 shows a histogram that visualizes the number of publications (n = 568) per year of articles from journal proceedings and books throughout the limited period. Since the early period, there has been a constant exponential increase in publications until 2018. This means there was a steady talk regarding pavement distress and M&R. There was a massive increase in publications in 2016. This sudden jump can be explained by understanding mass publications. After 2018, the trend has shown a remarkable exponential rise in the context of developing pavement condition index and M&R treatments for the next five years. This incorporates well with the constant growth of technology, especially artificial neural networks, as its merits can be implemented onto pavement evaluation much later and with many following from behind.

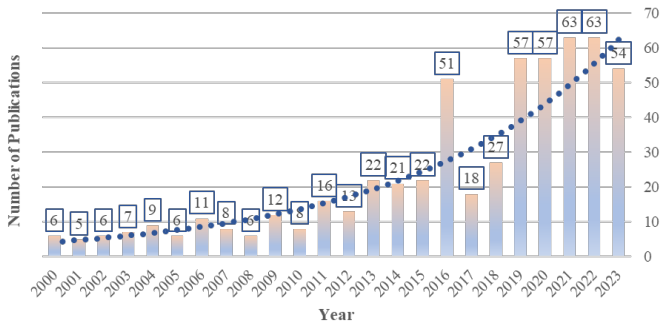

Figure 2. Number of Publications within the Limited Timeline

The reason why the authors included a review on road pavement can be explained in Figure 5. The number of publications based on countries is developed using the primary author's affiliation country region (e.g., University of the Sunshine Coast = Australia). Even though the keywords used for the database retrieval are as follows: airport, maintenance and rehabilitation, and pavement condition index, the application still retrieved road pavement-related publications. Moreover, publications in the context of airports are fewer than on road pavement. PCI for road and airport management are correlated, as the method of airport PCI is developed from the application of PCI on road distress evaluation. However, there is still a need to separate both terms, thus the purpose of Figure 5. With the widely used FAA and ASTM standards for airport design, it is no surprise that the USA stands far above all for its airport-related publications. As developing countries, Indonesia and India are more interested in road pavement publications. The road network is an essential commodity for sustainable and economic growth development. China and Japan show high initiatives in publishing their airport-related publications. Overall, the number of publications could be more balanced.

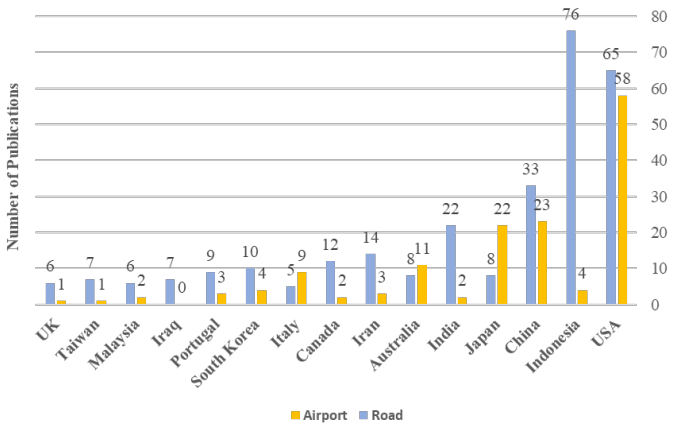

Figure 3. Number of Publications from Countries

As shown in Tab. III, "International Journal of Pavement Engineering" has the most publications entries with 53 publications, followed by "Proceedings of the Eighth International Conference on Maintenance and Rehabilitation of Pavements" with 31 entries. Journal entries dominate the top 5 publications. These titles only accept state-of-the-art, sophisticated articles, which are the dreams of many academic students and are considered one of the highest academic achievements. That said, both proceedings and journals are equally influential in academic prospects.

Table 1. Top journal and proceedings entries

Title	No. of Publications	Type
International Journal of Pavement Engineering	53	Journal
Proceedings of the Eighth International Conference on Maintenance and Rehabilitation of Pavements	31	Proceedings
International Journal of Pavement Research and Technology	25	Journal
JOURNAL OF PAVEMENT ENGINEERING, JSCE	15	Journal
Transportation Research Record: Journal of the Transportation Research Board	15	Journal
Road Materials and Pavement Design	10	Journal
Airfield and Highway Pavement	9	Proceedings
Airfield and Highway Pavement 2013	9	Proceedings
Lecture Notes in Civil Engineering	9	Proceedings
Advanced Materials Research	5	Journal
Construction and Building Materials	5	Journal
IOP Conference Series: Materials Science and Engineering	5	Proceedings
Pavement Materials, Structures, and Performance	4	Proceedings
Structure and Infrastructure Engineering	4	Journal

The Second International Conference on Maintenance and Rehabilitation of Constructed Infrastructure Facilities (MAIREINFRA2)	4	Proceedings

American universities dominated in terms of the number of publications. This correlates well with Fig 5. Even though Amirkabir University of Technology (Iran) has the highest number of publications, the theme of the published works is mostly about road pavements.

Table 2. Most Productive universities

University Name	Total Publications
Amirkabir University of Technology (Iran)	11
University of Texas (USA)	11
University of the Sunshine Coast (Australia)	9
Chang'an University (China)	8
Purdue University (USA)	8
National Institute of Technology Patna (India)	7
University of Illinois (USA)	7
Changsha University of Science and Technology (China)	6
Tongji University (China)	6
Griffith University (Australia)	5
Iowa State University (USA)	5
Universitas Sebelas Maret (Indonesia)	5
University of Tennessee (USA)	5
Vienna University of Technology (Austria)	5

Co-authorship analysis. With the visualization tool in VOSviewer, co-authorships can be visualized in a science map. This science mapping technique helps us understand the correlation between these authors in their publications throughout the year. The year based on color legend also provides insights into when these authors published their works.

Keywords co-occurrence analysis. A RIS file can also be a suitable source to visualize the keywords' co-occurrence science networks map. After thoroughly scanning and skimming the literature review, the following keywords represent the critical keywords that built up the whole literature. However, these filtered keywords assume that the author's final objective is within the promised academic focus: to build a foundation on airport pavement and PCI case study. The following science map is scaled up and normalized with the Lin/Log modularity method to enhance the visualization map. The size of the bubble labels manifests the number of occurrences of the word/phrase. At the same time, the line depicts the strength of the link between each word/phrase.

The pavement condition index has the most significant occurrence and a notable link strength with model, prediction, and development. This analysis relates to the objective of this bibliometric review, which is to show the development of the prediction model of the pavement condition index within the timeline. "Model" is deeply affiliated with "cost", "pavement maintenance", and "case study". A PCI prediction model is built with numerous case studies and different pavement maintenance to create a database. The implementation of M&R treatments sticks with cost. Hence, the development will provide an improvement and a more cost-effective M&R based on the distress database. When there is a database, software applications are bound to be used. In pavement management systems, software such as PAVEAIR, HD-4, FAIRFIELD, PAVER, etc., is a standard pavement maintenance and rehabilitation networking tool.

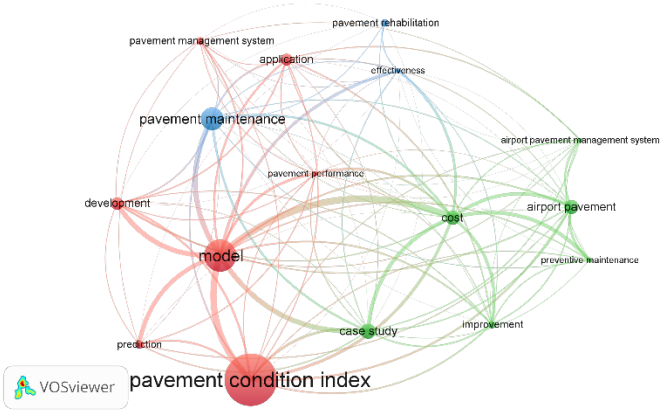

Figure 4. Keywords Co-occurrence Science Network Map

CONCLUSION

This research investigates the current status and future trends of the Pavement Condition Index (PCI) method in airport pavement through bibliometric analysis. Analyzing 568 publications concludes that PCI is a key tool for evaluating pavement distress in roads and airports, with Airport Pavement Management Systems (APMS) playing a crucial role. However, APMS's reliance on extensive databases poses challenges, limiting its applicability and accuracy, particularly across different regions and climates. Despite the growing interest in pavement-related research, particularly from American universities, international journals remain predominant, underscoring the importance of quality over quantity. While bibliometric techniques offer valuable insights, limitations in data handling and analysis methods are acknowledged, suggesting the need for improved methodologies to enhance efficiency and reliability in future studies.

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