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Research Article

Innovations In Road Traffic Noise Mitigation Through Pavement Solutions: A Comprehensive Literature Review

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ARTICLEINFO **ABSTRACT**

This comprehensive literature review delves into recent advancements in the realm of road traffic noise mitigation, with a special emphasis on innovative pavement solutions. The two studies under scrutiny contribute novel insights to this critical field, addressing challenges associated with noise pollution and presenting sustainable approaches to alleviate its impact. The first study, conducted in Sao Paulo, Brazil by Aps, Bernucci, and Vittorino (2020), explores the implementation of a porous asphalt overlay on a Portland Cement Concrete (PCC) pavement in a residential area. The second study, by Zhu, Hu, Liao, Chen, Su, Wu, and Wang (2023), proposes a fast and efficient approach to optimize tire tread pattern shapes, aiming to minimize tire noise. These studies collectively showcase cutting-edge strategies and methodologies, reflecting the ongoing efforts to create more livable urban environments by mitigating the adverse effects of road traffic noise.

Keywords: Road traffic noise, porous asphalt overlay, pavement solutions, tire noise reduction, predictive modeling, optimization strategies.

Introduction:

The urban landscape, with its bustling streets and vehicular traffic, offers unparalleled connectivity and accessibility, yet it brings forth a persistent challenge — road traffic noise. As our cities expand and populations surge, the adverse effects of noise pollution become increasingly pronounced. The deleterious impact of incessant traffic noise on human health and the overall quality of urban life necessitates innovative solutions to mitigate its effects. This literature review delves into recent advancements, with a focal point on groundbreaking pavement solutions, offering promising strategies to address the intricate issue of road traffic noise.

a) Urbanization and the Growing Challenge of Noise Pollution:

The relentless march of urbanization has transformed cityscapes, creating vibrant hubs of economic and social activity. However, this rapid urban growth has also given rise to a cacophony of noise, predominantly emanating from the ever-expanding vehicular traffic network. The surge in noise levels poses a significant threat to public health, leading to heightened concerns about its far-reaching consequences. Recognizing the imperative need to curtail the adverse effects of road traffic noise, researchers and urban planners are actively exploring innovative solutions, with a particular focus on advancements in pavement technologies.

b) The Multi-Faceted Impact of Road Traffic Noise:

Road traffic noise, comprising a complex amalgamation of engine sounds, tire-road interaction noise, and other environmental factors, transcends mere auditory discomfort. Studies consistently highlight its adverse effects on human health, encompassing sleep disturbances, increased stress levels, and a range of cardiovascular issues. Beyond individual health, noise pollution infiltrates the social fabric, impacting community well-being and diminishing the overall livability of urban spaces. Hence, there is an urgent imperative to develop sustainable and effective strategies to mitigate road traffic noise, and recent research endeavors have been pivotal in this pursuit.

c) Pavement Solutions: A Paradigm Shift in Noise Mitigation:

In the quest for innovative noise mitigation strategies, pavements have emerged as a focal point of exploration. Traditionally viewed as infrastructural elements for vehicular movement, pavements are now being reconsidered as potential allies in the battle against noise pollution. A series of recent studies have shed light on groundbreaking approaches, ranging from the application of porous asphalt overlays to the optimization of tire tread patterns. These studies not only address the auditory challenges posed by road traffic noise but also align with broader sustainability goals by utilizing eco-friendly materials and techniques.

d) Research Focus and Organization:

This literature review scrutinizes a selection of recent studies that contribute significantly to the discourse on road traffic noise mitigation, concentrating specifically on innovative pavement solutions. Each study, conducted by diverse research teams across various geographical locations, introduces distinctive methodologies and strategies, collectively advancing our understanding of how pavements can serve as active participants in the broader goal of creating quieter and more sustainable urban environments.

e) Importance of Reviewing Recent Studies:

The choice of recent studies is intentional, reflecting the dynamism of ongoing research endeavors and the contemporary challenges posed by urbanization. The selected studies span diverse geographical contexts, incorporating findings from Brazil, Greece, China, and other regions, showcasing a global commitment to addressing the universal issue of road traffic noise. By examining these studies in a chronological order, we aim to delineate the evolving landscape of pavement-based noise mitigation strategies and discern patterns that can inform future research directions.

f) Scope and Structure of the Review:

This literature review unfolds with an exploration of innovative pavement solutions in chronological order, commencing with a study from 2009 that delves into the application of waste tire rubber in civil engineering projects. Subsequent sections navigate through studies investigating the acoustic performance of low-noise pavements, the utilization of environmentally friendly materials for sound absorption, and strategies for noise reduction in pavements. Each study is dissected to unravel the methodologies employed, key findings, and implications for road traffic noise mitigation. Furthermore, a critical analysis of research gaps and the future scope of study is undertaken, paving the way for a holistic understanding of the current state and potential trajectory of this evolving field.

In conclusion, the exploration of pavement solutions for road traffic noise mitigation represents a paradigm shift in urban planning and infrastructure development. The subsequent sections of this review delve into each study, providing a nuanced understanding of the methodologies employed, key findings, and the broader implications for sustainable urban development. Through this comprehensive examination, we aim to contribute to the ongoing dialogue on innovative strategies to create quieter, healthier, and more livable urban environments.

Literature Review:

Oikonomou and Mavridou (2009) tackled the global issue of millions of trash tires piling up every year. In order to address this growing problem, the study looked into a number of recycling strategies, such as using rubber composites, cement kiln fuel, burning waste to produce energy, and a variety of civil engineering uses, like building roads. The study notably brought to light encouraging findings from ongoing investigations concerning the addition of tire rubber to Portland cement concrete. This novel method shown improvements in characteristics including permeability and resistance to the penetration of chloride ions, indicating a possible way to mitigate the environmental impact of waste tires and enhance the functionality of building materials.

An assessment of traffic noise pollution in Larkana was carried out by Chandio (2010), and the results showed elevated levels linked to unplanned urban growth. The study emphasized how crucial sustainable land-use planning is and how essential it is to enhancing urban environments. In order to achieve sustainability, the study promoted the implementation of environmental laws, emphasizing the critical role that local governments play in controlling transportation and land use. Through examining the negative effects of unplanned urban growth on noise pollution, Chandio's study added significant value to the conversation on environmentally conscious urban planning and the critical role that local government plays in reducing environmental problems.

In order to tackle the problem of end-of-life (EOL) tires, Kehagia and Mavridou (2014) investigate the use of rubberized bituminous mixtures in the building of roads. The study reveals a significant 1 to 3 dB decrease in traffic noise, which has a good impact on the public, especially drivers. The outcomes highlight the need for this strategy to be used more widely and highlight the advantages it offers for the environment when incorporating EOL tires into road surfaces.

The importance of tire pavement noise was emphasized by Gandage (2016), especially when it comes to concrete pavements. PCC pavements have advantageous mechanical qualities, but they also tend to produce greater noise. Regular interventions are necessary to maintain the interface between tires and pavement, which is controlled by pavement texturing. Because of its high capacity for absorption, porous concrete has emerged as a viable method for noise reduction.

Liu and Huang (2016) emphasized how surface friction can effectively reduce noise through the use of porous asphalt pavements with large air void ratios. An acoustically beneficial and durable double-layer porous asphalt pavement type was created. For maximum noise reduction in each layer, certain thicknesses, aggregate sizes, and air void ratios were optimized.

Sonaviya (2017) carried out a critical evaluation of India's noise regulations and offered suggestions for bolstering efforts to reduce and manage noise pollution. The proposed amendments included updates to ambient noise regulations and legislative requirements, as well as the setting of noise limitations for construction activities and domestic appliances. The primary objective of these changes was to fully address noise pollution, highlighting the critical requirement of an all-encompassing strategy in addressing this environmental issue. The research has provided significant insights into the legislative framework pertaining to noise in India. It has also provided focused recommendations aimed at improving the effectiveness of noise control measures and advancing a more environmentally friendly method of managing noise.

Yi et al. (2018) conducted a thorough investigation into the elements that affect noise in densely graded asphalt mixtures, offering valuable insights for the development of noise control strategies. For passenger cars, the recommendations included bigger NMAS and rubber asphalt; for heavy trucks, the recommendations included smaller NMAS with SBS improvements. The implementation of rubber asphalt for successful noise reduction and traffic speed management were validated by field measurements.

Li (2018) described how the pavement and tire sectors have proactively responded to regulatory demands to reduce noise from tire-pavement interactions. Tire companies concentrated on improving tread designs and construction, and pavement associations tried to reduce noise by modifying the texture and rigidity of their surfaces. The study underlined the necessity of more investigation to fully comprehend tire-pavement interaction in order to develop a cohesive strategy for noise reduction.

Chu and Fwa (2018) investigated the complex interaction between porosity, sound absorption, and clogging. The results of the study showed that, even at comparable porosity levels, PC (Polymer-Modified Concrete) mixtures outperformed PA (Porous Asphalt) mixtures in terms of sound absorption. It was discovered that mixes of PA and PC were both prone to clogging; however, PC demonstrated superior sound absorption qualities, which persisted even when fully clogged at 100%. The investigation identified PA, PC, NC (Natural Coarse Aggregates), DG (Drainage Gravel), and PA as critical elements to be examined. Chu and Fwa provided insightful information about the dynamics of clogging, porosity, and sound absorption by analyzing these elements and their interactions. This allowed for a more detailed understanding of the performance differences between PC and PA mixtures in their study.

Kehagla and Mavridou (2020) focused on the usage of rubberized bituminous mixtures—a method for integrating end-of-life (EOL) tires into road construction—in their study. Experiments carried out in Greece revealed that adding 5% rubberized bitumen to regular asphalt reduced noise levels by an impressive 1-3 dB. The study vigorously promoted the general use of EOL tires in road pavements by highlighting the benefits to the environment and increased durability associated with this novel strategy. Kehagla and Mavridou's research shed light on the advantages of employing EOL tires in road building by concentrating on previous findings. This opened the door for future developments in environmentally friendly and noise-reducing infrastructure.

Studies were conducted by Teti et al. (2020) in an effort to determine the initial LCPX (Low Curing Point Binder) values for novel low-noise pavements. The study examined a prediction model three months after pavement installation, with an emphasis on the CPX (Curing Performance Index) scheme. The study's main finding was that, in order to anticipate tire/road noise, frequency-dependent techniques must be used. For this, a wide range of frequency bands were used in stepwise regression with forward selection. The study recommended that future research focus on the prediction of LCPX values for various tire types. The study also discussed the engineering difficulties posed by the problematic soil known as peat. The study, which tackled these issues in the past, shed light on the fundamental work needed to evaluate and forecast the performance of innovative low-noise pavements that take into account environmental and technological factors.

The safety, smoothness, and noise issues related to a PCC pavement in a Sao Paulo residential area are discussed by Aps et al. (2020). The researchers partially resolved these problems by using a porous asphalt overlay. The coating increased overall safety and skid resistance while also successfully reducing roadside noise. Further testing is expected to shed further light on this novel solution's long-term performance, surface quality, and noise reduction capabilities.

The acoustic environments of London during the COVID-19 shutdown in the spring of 2019 and 2020 were compared by Aletta et al. (2020). Results showed that sound levels were reduced by 5.4 dB, with variations in different urban situations. The analysis showed that in order to maintain gains, more actions were required, such as lowering traffic volumes. It emphasized how important it is for post-COVID planning plans to prioritize and uphold better urban acoustics.

The effects of pavement thickness, gradation type, asphalt binder type, and Kaolin (KS) content on Ultra Thin Layer (UTL) pavement were investigated by Li et al. (2020). Important discoveries indicated that pavement thickness was critical for durability and that 0.5% KS content produced the best results with limited consequences. Gradation and KS content had a major impact on noise reduction; because of its rich surface texture, UTL pavement outperformed Asphalt Concrete (AC).

The examination and utilization of noise barriers in the construction of highways was the main topic of study for Sun et al. (2021). The demand for efficient environmental control through noise barriers increased as highways developed quickly, along with the concomitant rise in noise pollution. The research highlighted a common goal among these barriers even if they used different materials and structures. In order to lessen the negative effects of noise pollution from highway building, emphasis was placed on the significance of strategic planning and sustainable decisions. By offering information on the many strategies and tools used to reduce noise pollution caused by highways, this study added to the body of literature already in existence.

A method for constructing low-noise pavement that takes traffic flow and vehicle speed into account was presented by Yuan et al. (2021). The study examined sound levels generated by various combinations of pavement at different speeds using the CPX method. The results showed that ECA-10 increased tire and road noise from heavy cars, and that double-layer porous pavement on both lanes reduced noise the best.

Over the previous ten years, Engel et al. (2021) have conducted extensive research on soundscapes, concentrating on psychoacoustic characteristics like as tone, sharpness, loudness, and fluctuation strength. Although the majority of research employed average values, a few also included percentiles to account for cognitive impacts. The study suggested implementing ISO standards for measuring psychoacoustic quantities and placed a strong emphasis on advice from psychoacoustic specialists.

Afrin et al. (2021) examined the growing environmental problem of tires that are abandoned in their study. The annual sales of tires are estimated to be around $3 billion. It highlighted the complex makeup of tires and how they can emit dangerous chemicals, attract pests, and cause fires, all of which can be hazardous to one's health and the environment. Various recycling approaches, including recovery, reuse, reduction, and recycling, were investigated to address these problems and increase economic value. The study highlighted the use of tires toward the end of their useful life in civil engineering applications, such as playground surfaces, road pavements, and landfill layers, showcasing them as viable materials for low-rise buildings around the world. The study explored the seismic and acoustic characteristics of tires nearing end of life and offered creative technical solutions. By using a mixed-methods approach and data from Tire Stewardship Australia and scientific literature, the study assessed the viability of using end-of-life tires to lessen the demand on raw materials, cut energy and water consumption, and minimize environmental impact.

The study by Xie et al. (2022) concentrated on the sound absorption capacity of porous asphalt concrete (PAC). By using CT scanning technology, PAC samples were imaged in detail so that the voids in the material could be precisely identified. The acoustic properties of PAC were modeled using finite element software, and the study systematically connected void characteristics with the Sound Absorption Coefficient (SAC). Principal discoveries exposed discrete trends that illuminated the processes by which PAC reduces noise by virtue of its void properties. By providing insightful information about the relationship between void features and sound absorption in the material, this study made a substantial contribution to our understanding of the acoustic behavior of PAC.

Bozkurt and Karaka (2022) focused on the effective control of noise pollution in cities, with a particular focus on roads with asphalt pavement. According to the study, porous asphalt pavements are a reliable way to reduce noise levels. However, there is a need for optimization in a number of areas, including material selection, clogging avoidance, mixture proportions, and thickness concerns. The study emphasised how important it is to install drainage systems and carry out routine maintenance in order to avoid blockages and maintain the capacity of porous asphalt pavements to absorb sound. Bozkurt and Karaka's work, by exploring these important elements, offered useful ideas for the improvement and upkeep of porous asphalt pavements on roads, as well as insights into efficient strategies for noise reduction in urban environments.

Barros et al. (2023) investigated the use of SPL measurements to calculate acoustic and psychoacoustic indicators for road traffic noise. ΔL, N50, S50, R50, and FS50 were among the indicators that showed a correlation with larger and heavier cars. Machine learning achieved 71.5% accuracy in predicting vehicle classifications, offering an alternative to visually-based categorization. Multinomial logistic regression was used to identify indicator contributions.

Amjed et al. (2023) compared the road surfaces (PCC and HMA) on three highways in Baghdad in order to better understand traffic noise. Compared to HMA roads, PCC roads have traffic noise levels higher than Iraqi requirements. With an accuracy of 86.26%, the study's algorithm, which took into account variables including vehicle speed, was able to forecast noise levels.

Tekampe and Oeser (2023) aimed to create and evaluate a two-layer polymer-based road surface that reduces noise while maintaining mechanical and acoustic efficacy. Although less noise reduction was accomplished than with alternatives, the two-layer structure demonstrated strength and stability. The

stabilized two-layer solution demonstrated potential for lowering road traffic noise as it lowered noise by 3.1 dB(A) when compared to conventional pavements, despite tradeoffs in acoustic efficacy.
Zhu et al. (2023) suggest a comprehensive approach to reduce tire pattern impact noise. The paper presents a quick strategy that includes creating a predictive model, optimizing tread patterns with the basis vector method, and creating a multi-objective function with noise reduction as its goal. This method eliminates the need for a great deal of trial and error by streamlining the early design phases. The study acknowledges the difficult balancing act needed to achieve low noise levels without sacrificing other important tire design goals. Moreover, an examination of these approaches' applicability to electric cars is conducted, highlighting the need of accurate leading edge identification and optimization techniques in the context of EVs.
Jang (2023) explored a variety of environmentally friendly materials for sound absorption. The sound-absorbing qualities of a variety of green materials—such as coconut fiber, kenaf fiber, rice bran, rice husk, rice straw, Hanji (a traditional Korean paper), corn husk, peanut shell, sugar palm trunk, Yucca gloriosa fiber, fruit stones, wood barks, flax fiber, and nettle fiber. Compressing the raw material or processing it into fibrous materials or composites are two ways to create natural fibers. The thickness and density of the green material as well as the existence of an air back chamber are the main factors that affect sound absorption ability. Thick materials often perform better in absorbing sound in the low- to mid-frequency range. Furthermore, better sound absorption at the same thickness is correlated with higher densities. Improving the distance between the air back cavity and the sound-absorbing material improves the absorption of low frequencies. Therefore, these physical factors have a greater influence on sound absorption capabilities than do the particular materials utilized. Therefore, if their thickness, density, and air back cavity are appropriately managed, a variety of green materials, including fibers, granules, and porous materials, can be efficient sound absorbers.
Teti et al. (2023) evaluated low-noise drainage pavements in 2023 and looked at the effects of different aggregate sizes. The investigation highlighted the greater roughness seen in the 13 mm pavement and the noteworthy permeability of the 19 mm pavement. It indicated that there might be room for improvement by looking into finer aggregate sizes and putting good maintenance procedures in place to improve slide resistance and permeability. Understanding pavement performance in the context of building quieter road infrastructure has greatly benefited from the research. It did, however, also highlight the necessity of more research to examine the long-term impacts of these low-noise drainage pavements, especially in a variety of traffic scenarios.

Conclusion:

The extensive literature review unveils a collaborative effort to tackle critical environmental and infrastructure challenges associated with waste tires, traffic noise, and advancements in pavement design. Oikonomou and Mavridou's (2009) exploration of global waste tire accumulation sets the stage for subsequent studies, emphasizing recycling strategies and diverse civil engineering applications to alleviate the environmental burden caused by discarded tires. Kehagla and Mavridou's (2014) investigation into rubberized bituminous mixtures showcases a pioneering approach, contributing not only to noise reduction but also to the sustainable integration of end-of-life tires in road construction.
Studies by Chandio (2010) and Sonaviya (2017) shed light on the pivotal role of sustainable urban planning and regulatory enforcement in mitigating traffic noise pollution. These findings underscore the significance of coordinated efforts between local authorities and policymakers to create noise-conscious urban environments.
Pavement-focused research, including works by Yi et al. (2018), Gandage (2016), Liu and Huang (2016), and others, delves into innovative solutions like rubberized mixtures and porous pavements. These strategies aim not only to enhance road durability but also to substantially reduce noise levels. The studies by Aletta et al. (2020) and Tekampe and Oeser (2023) integrate contemporary concerns such as the impact of the COVID-19 lockdown and the development of noise-reducing polymer-based road surfaces, reflecting a forward-looking approach to urban infrastructure challenges.
In conclusion, the reviewed literature provides a nuanced understanding of the intricate interplay between waste tire management, urban planning strategies, and cutting-edge pavement designs in addressing environmental sustainability and noise pollution challenges. The collaborative implementation of these innovative solutions holds promise for creating more resilient, eco-friendly, and noise-conscious urban landscapes. Future research should continue to explore and implement these solutions, fostering sustainable development and enhancing the quality of urban living.

Scope of Further Research:

The literature review highlights several areas where further research can be pursued to advance the understanding and implementation of noise-reducing and environmentally sustainable pavement solutions:

1. Long-Term Performance of Low-Noise Pavements:
Investigate the durability and effectiveness of low-noise pavements over extended periods and diverse traffic conditions. This includes monitoring the impact of weather, traffic load, and maintenance practices on noise reduction and pavement integrity.

2. Optimization of Rubberized Mixtures:
Explore different compositions and methods for integrating waste tire rubber into asphalt and concrete mixtures. Studies could focus on optimizing the blend ratios, aggregate sizes, and binder types to maximize noise reduction, durability, and environmental benefits.

3. Advanced Acoustic Modeling:
Develop and validate advanced computational models to predict the acoustic performance of various pavement types under different conditions. These models could incorporate factors such as vehicle speed, tire types, and environmental conditions to provide more accurate predictions.

4. Urban Planning and Policy Integration:
Assess the effectiveness of noise reduction policies and urban planning strategies in various cities. Comparative studies could evaluate the success of different regulatory approaches and identify best practices for integrating noise control into urban development plans.

5. Innovative Materials and Technologies:
Investigate new materials and technologies that could enhance the noise-reducing properties of pavements. This includes exploring the use of nanomaterials, bio-based additives, and other innovative substances that could improve pavement performance and sustainability.

6. Impact of Electric Vehicles:
Study the interaction between electric vehicles (EVs) and different pavement types. Given the unique noise profiles of EVs, research could focus on optimizing pavement designs to further reduce noise generated by these vehicles.

7. Clogging and Maintenance Strategies:
Examine the long-term effects of clogging on porous pavements and develop effective maintenance strategies to ensure sustained noise reduction and permeability. Research could include the development of self-cleaning pavements or advanced drainage systems.

8. Psychoacoustic Effects:
Explore the psychoacoustic effects of different pavement types on human perception of noise. This research could help in designing pavements that not only reduce measurable noise levels but also improve the subjective noise experience for urban residents.

9. Integration of Sustainable Practices:
Evaluate the environmental impact of various pavement materials and designs, focusing on lifecycle assessments and sustainability metrics. This includes assessing the carbon footprint, resource use, and overall environmental impact of different pavement solutions.
By addressing these areas, future research can build on the current knowledge base to develop more effective, sustainable, and comprehensive solutions for reducing traffic noise and managing waste materials in urban infrastructure.

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