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# The Application of FAHP in Railway Infrastructure Maintenance: A Systematic Review

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## ABSTRACT

Rail transport is a critical backbone for regional mobility and economic development, and relies fundamentally on well-maintained infrastructure. The maintenance decision-making process for this infrastructure is complex, requiring the simultaneous evaluation of multiple technical and non-technical criteria under significant uncertainty. The Fuzzy Analytical Hierarchy Process (FAHP) has emerged as a prominent Multi-Criteria Decision Making (MCDM) method to address these challenges. While the application of FAHP in the broader transportation sector has been reviewed in various studies, a systematic review focusing specifically on its development and application for railway infrastructure maintenance is absent from the literature. This study conducts a Systematic Literature Review (SLR) following the PRISMA protocol to analyze the development of FAHP and its hybrid applications in railway infrastructure maintenance over a decade. The analysis, based on a systematic search of Scopus, Google Scholar, and MDPI databases, identifies and synthesizes the existing literature to define evolving research trends, methodological approaches, and future directions. The results reveal that FAHP and its hybrid variants (such as FAHP-TOPSIS, FAHP-GIS, and FAHP-FCE) have been applied to assess structural conditions, determine maintenance priorities, and manage geotechnical risks. This review confirms that FAHP effectively structures expert judgement and handles subjective data. However, a significant research gap persists in integrating these models with real-time data streams. This leads to the conclusion that future research must prioritize the development of real-time predictive FAHP models. These advanced systems should be designed to incorporate multi-stakeholder perspectives and leverage digital technologies such as the Internet of Things (IoT) and machine learning to enable a paradigm shift towards proactive and data-driven decision-making in railway infrastructure maintenance.

**Keywords:** fuzzy Analytical Hierarchy Process, railway infrastructure maintenance, MCDM, predictive maintenance.

## INTRODUCTION

Railways serve as a vital component in the transportation systems of many countries around the world [1]. Rail transport offers numerous advantages, including the ability to move goods and passengers quickly and efficiently across regions, as well as lower exhaust emissions compared to road-based transportation [2]. Research by Liden [3] suggests that maintaining optimal railway track performance requires routine maintenance. This can be done in stages by prioritizing maintenance. Scheduling for inspections and maintenance on railway tracks needs to be clearly defined to improve maintenance cost efficiency [4]. Delays in repairing railway components can lead to unsafe track conditions [5].

The decision-making process for railway infrastructure maintenance is a multi-criteria problem [6]. In this context, the Multi-Criteria Decision Making (MCDM) approach is widely applied in the transportation sector because it enables the systematic assessment of alternatives based on multiple criteria [7]. According to Justin & Ababa [8], one method frequently used to address these conditions is the Analytical Hierarchy Process (AHP). This multi-criteria decision-making method was developed by Saaty [9]. The Analytic Hierarchy Process (AHP) structures multi-criteria problems into a hierarchy, using pairwise comparisons to determine the importance weight of each criterion. According to Soetjipto [10], AHP has been extensively applied to establish priority criteria and determine the relative weights of factors in repair and rehabilitation contexts. This approach provides a systematic structure for decision-making, thereby facilitating the priority-setting process. However, the classical AHP method has several weaknesses. A primary issue is the potential for inconsistency in its non-reciprocal pairwise comparison matrices, which introduces uncertainty into the results. Furthermore, Kriswardhana [11] noted that using the classical AHP requires a detailed questionnaire with many pairwise comparisons, which places a considerable burden on evaluators. This burden makes the classical approach impractical for public surveys or studies with large sample sizes or non-expert respondents. To address these challenges, methodological adaptations are essential, such as employing simplified AHP, Fuzzy AHP, or integrating AHP with the Delphi method.

Research demonstrates that the Fuzzy Analytical Hierarchy Process (FAHP) not only better captures uncertainty in risk estimation for more realistic outcomes but also provides greater stability in its resulting weights when the comparison matrix undergoes minor changes [12], [13]. Fuzzy methods, particularly FAHP, are widely applied in decision-making for railway infrastructure maintenance. These approaches are frequently used to assess asset conditions [14], analyze rail damage [15], and establish maintenance priorities [5]. Research consistently shows that by better representing the uncertainty in expert assessments and field data, FAHP methods provide a more reliable and effective decision-making framework than classical AHP [16].

In recent years, several systematic reviews have examined the growing application of AHP and FAHP in transportation decision-making. For instance, Moslem [17] provided a comprehensive review of studies from 2003 to 2022, highlighting the extensive use of AHP in complex transportation planning, routing, and policy issues. In parallel research, Ruiz Bargueño [18] conducted a state-of-the-art review to identify AHP applications in urban mobility. More recently, Kriswardhana [11] combined bibliometric and systematic methods to trace the evolution of AHP and FAHP in transportation over the past two decades, identifying major methodological trends, thematic developments, and emerging directions in hybrid model design.

**Table 1**. Comparison of earlier reviews and current paper on AHP-FAHP implementation in transportation

| Author | Aim | Coverage / Method | Range / Database | Docs |
|---|---|---|---|---|
| Ruiz Bargueño [18] | Discovering how AHP has been applied to solve decision problems regarding urban mobility | Application areas; State-of-the-art review | 2020–2021; Scopus | 103 |
| Moslem [17] | Analyzing the contribution of AHP and FAHP to solve transportation problem | Application areas; Systematic Review (PRISMA) | 2003–2019; Scopus, WoS, Google Scholar | 58 |
| Kriswardhana [11] | Investigating how the AHP has beenused to support transportation-related decisions | Application areas, combination of methods; Bibliometric analysis and PRISMA | 2000–2022; Scopus, WoS | 112 |
| Current Paper | Examining FAHP applications in railway maintenance decision-making | Focused application; Systematic Review (PRISMA) | 2015–2025; Scopus, Google Scholar, MDPI | 6 |

Whereas previous reviews have addresed broader transportation contexts, this research fills a specific gap by systematically examining the development and application of FAHP in railway infrastructure maintenance decision-making. A detailed comparison is presented in Table 1.

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## RESEARCH METHODS

### Research Design

The SLR method is a systematic and transparent approach to collecting and presenting evidence relevant to a specific research topic, which involves the processes of collecting, evaluating, and synthesizing research results [19]. The procedure used for reporting SLR results in this study follows the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, developed by Page M [20], and the research stages proposed by Kitchenham [21], encompassing three essential phases: planning, which defines objectives and protocol development; conducting, which involves literature search, selection, and data extraction; and reporting, which synthesizes findings and presents them systematically. Together, these frameworks ensure methodological rigor, transparency, and consistency throughout the review process

This study follows a structured multi-stage research methodology. The process begins with the planning phase, dedicated to formulating the research problem, objectives, and a comprehensive search strategy. Next, the formulation stage focuses on defining specific research questions, establishing inclusion and exclusion criteria, and selecting the academic databases for the review. The implementation phase starts with a comprehensive search across three databases, Scopus, Google Scholar, and MDPI, a practice justified by the need to capture the broadest possible scope of relevant literature, as recommended for thorough systematic reviews [22]. The resulting articles are then screened for relevance based on their titles and abstracts, followed by a full-text eligibility assessment to confirm their direct relevance to FAHP applications in railway infrastructure. In the final reporting phase, data are systematically extracted from the qualified articles, and a thematic analysis of the findings is conducted. The entire process, from initial identification through screening and eligibility to final inclusion, is clearly documented in a PRISMA 2020 flowchart. The PRISMA flowchart provides a schematic overview of the systematic review's methodology, charting the progression from initial identification through screening and eligibility to the final inclusion of studies.

### Research questions

The research questions for this study are formulated to define the scope and guide the data synthesis toward the main objectives. The specific questions are:

RQ1: What are the key trends and developments in FAHP applications for railway infrastructure maintenance and evaluation?

RQ2: How are hybrid FAHP approaches being used to support decision-making in railway infrastructure maintenance?

RQ3: What is the future direction for FAHP development to improve decision-making systems in this domain?

To ensure the inclusion of relevant studies, a systematic literature search was conducted. The selection criteria prioritized peer-reviewed journal articles that explicitly address the use of FAHP in railway infrastructure maintenance or evaluation.

### Data sources and search bases

The literature search is conducted systematically across two primary platforms. Publication metadata from Scopus and Google Scholar were gathered using the Publish or Perish (PoP) software, version 8. This tool efficiently collects key bibliographic details, including publication titles, authors, publication years, DOIs, and citation counts [22]. To complement these results and verify the availability of specific articles, supplementary searches are performed directly via the MDPI portal.

A systematic keyword search is designed using Boolean operators (AND, OR) to balance the precision and recall, following established methodological frameworks for scientific reviews [23], [24]. The primary search query is: ("Fuzzy Analytical Hierarchy Process" OR "FAHP") AND ("Railway Maintenance" OR "Track Maintenance" OR "Rail Infrastructure Maintenance"). This query is applied to publications from 2015 to 2025. The search strategy is structured to comprehensively map the landscape of FAHP applications by targeting three interconnected themes:

the direct implementation of FAHP for maintenance decisions, its use in asset condition and risk assessment, and the emerging trend of integrating FAHP with other MCDM techniques like TOPSIS, FCE, or BIM to enhance the objectivity of maintenance planning. A full summary of the search strategy is provided in Table 2.

**Table 2.** Formulation of keywords for searching FAHP and railway infrastructure maintenance

| No | Source(s) | Focus Area | Search Keywords | Publication Period | Number of Articles |
|---|---|---|---|---|---|
| 1 | Scopus, Google Scholar, MDPI | Rail maintenance | "Fuzzy Analytical Hierarchy Process" OR "FAHP" AND ("Railway Maintenance" OR "Track Maintenance" OR "Rail Infrastructure Maintenance") | 2015 - 2025 | 318 |
| 2 | | Condition, evaluation | "FAHP" AND ("Railway Risk" OR "Track Condition" OR "Railway Evaluation") | 2015 - 2025 | 152 |
| 3 | | Hybrid FAHP methods | ("Fuzzy AHP" AND (TOPSIS OR FCE OR GIS OR FSM OR GIS OR BIM)) AND ("Railway Maintenance") | 2015 - 2025 | 37 |
| | | | | | 507 |

Initial searches across Scopus, Google Scholar, and MDPI identify 507 articles. Preliminary findings indicate that the “rail maintenance” category is the most prevalent, with 203 articles from Google Scholar, 121 from Scopus, and 183 from MDPI.

**Inclusion and exclusion criteria**

Specific inclusion and exclusion criteria are established [25] to select literature that is both highly relevant to the topic and uses reliable research methods. These criteria, detailed in Table 2, are applied to filter articles based on their thematic suitability, scientific validity, and alignment with the research objectives. The use of these pre-defined criteria is essential to maintain objectivity and consistency throughout the screening process[20], [21]. The inclusion and exclusion criteria are described in Table 3.

**Table 3.** Inclusion and exclusion criteria

| Code | Criteria | Description |
|---|---|---|
| I1 | Publication Range: 2015–2025 | Reflects the latest developments in FAHP research over the past decade in the context of railway infrastructure. |
| I2 | Type of Publication: Peer-reviewed journal articles | Ensures scientific validity and quality. |
| I3 | Methodology: Applying Fuzzy AHP (FAHP) or its hybrid variants (e.g., FAHP–TOPSIS, FAHP–FCE, FAHP–GIS, FAHP–VIKOR) | Ensures the focus on the main research methodology involving fuzzy set theory and AHP. |
| I4 | Context: Maintenance, Condition Evaluation, Asset Prioritization, or Risk Management of Railway Infrastructure | Ensures the research domain aligns with the asset management and railway maintenance focus. |
| E1 | Data Duplication: Duplicate articles or identical data | Prevents data bias and result redundancy in the literature synthesis process. |
| E2 | Text Availability: Articles without full text or with restricted access | Prevents information gaps during data extraction. |
| E3 | Topic Relevance: Theoretical or non-railway domains (e.g., manufacturing, healthcare, maritime/road transport) | Maintains focus on practical applications within the railway asset context. |

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| Code | Criteria | Description |
|---|---|---|
| E4 | Non-Journal Publication Types: Theses, dissertations, technical reports, books, or preprints | Excludes literature not formally peer-reviewed. |

**Article Selection Process**

The study selection process is conducted systematically, following the PRISMA 2020 guidelines, consisting of four key stages: identification, screening, eligibility, and inclusion. The entire screening process is conducted using Rayyan QCRI, which streamlined the evaluation and documented all inclusion/exclusion decisions. The sequential stages are detailed below:

1. Identification Stage

During the identification stage, an initial search across Scopus, Google Scholar, and MDPI portals using Publish and Perish (PoP) software identified 507 potentially relevant studies, with key metadata including titles, authors, publication years, DOIs, and citation counts being systematically extracted. All records are imported into Rayyan, where 46 duplicates are removed, leaving 461 distinct articles qualified for the screening phase.

2. Screening Stage

At the screening stage, the titles and abstracts of 461 articles are initially assessed on the Rayyan platform. The Inclusion (I) and Exclusion (E) criteria are applied to select articles specifically discussing FAHP applications in railway infrastructure maintenance and evaluation. This process identifies 32 relevant articles that advanced to the next evaluation stage.

3. Eligibility Assessment Level

During the eligibility stage, full-text assessments of the 32 remaining articles are conducted to evaluate methodological validity, data availability, and compliance with exclusion criteria. Rayyan software is used to manage this documented review process. Articles are excluded based on: (a) unavailability of full text, (b) purely theoretical content without specific application to railway infrastructure maintenance/evaluation, or (c) irrelevance to the railway domain.

4. Inclusion Stage

In the final inclusion stage, six articles met all quality and relevance standards, forming the core literature for analysis. These articles serve as primary sources for addressing the research questions. The complete selection procedure is visualized in Figure 1.

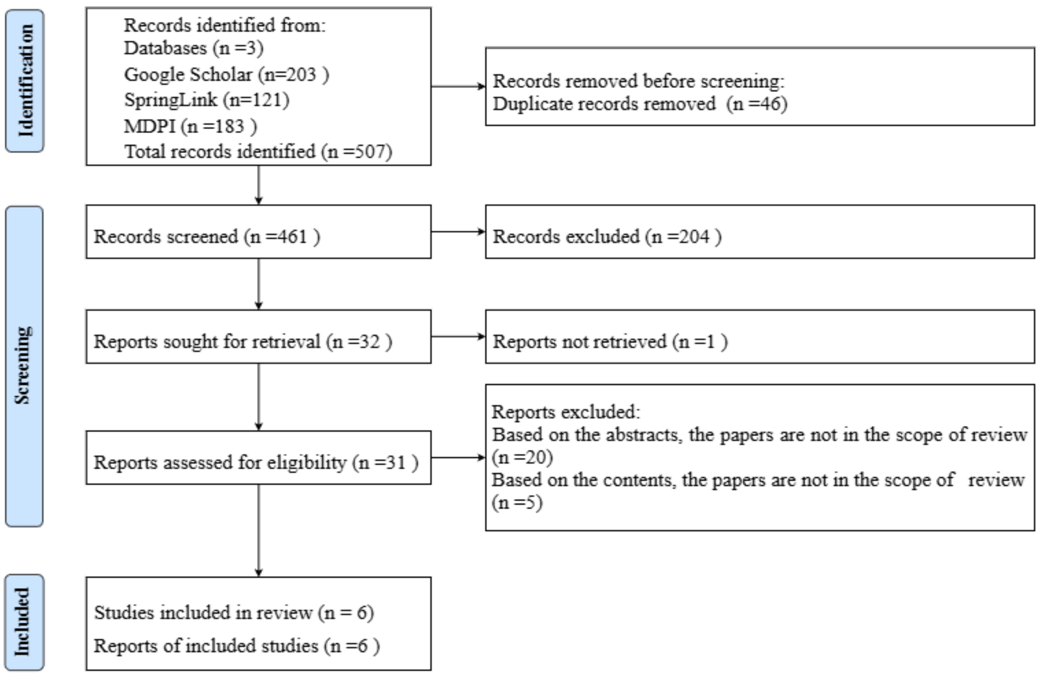


**Figure 1.** PRISMA flowchart of the article selection process in the FAHP systematic study on railway infrastructure

## RESULTS AND DISCUSSION

The following discussion maps the core findings from six key publications onto the framework of the Three Research Questions (RQs). This approach is taken to develop a comprehensive understanding of the FAHP application landscape in railway infrastructure maintenance.

### Literature Selection Results

The selected literature reveals a rapidly growing trend in the application of Fuzzy AHP (FAHP) for railway infrastructure maintenance and evaluation from 2015 to 2025. The method has been widely adopted for critical tasks such as infrastructure condition assessment, maintenance prioritization, and risk management. The core studies forming the basis of this analysis are detailed in Table 4.

The analysis of the six selected studies reveals that FAHP applications in railway infrastructure span a diverse range of contexts, from emergency operational evaluations to physical asset assessments (rails, culverts, bridges) and geological risk management. A key finding is that all studies employed hybrid methodologies by integrating FAHP with complementary techniques such as WOWA, TOPSIS, GIS, and TPOP, demonstrating that combined approaches represent the prevailing trend for addressing complex railway maintenance challenges. The regional distribution of the research is diverse, covering Asia (China, Thailand, Sri Lanka), Europe (Poland), and Africa (Egypt).

**Table 4**. Results of FAHP Journal Selection in Railway Infrastructure Maintenance

| No | Authors & Year | Article Title | Research Location/Context | Research Object | Method |
|---|---|---|---|---|---|
| 1 | Zhao et al., 2016[26] | Applying Hybrid Decision-Making Method Based on Fuzzy AHP-WOWA Operator for Emergency Alternative Evaluation of Unattended Train Operation Metro System | Metro System, China | Unattended Train Operation System | Fuzzy AHP–WOWA |
| 2 | Fabianowski & Jakiel, 2018 [15] | Application of the Aggregated Calculation Algorithm EA FAHP and Fuzzy TOPSIS Methods in the Evaluation of Railway Culverts Serviceability | Railway Network, Poland | Railway Culverts | EA–FAHP, Fuzzy TOPSIS |
| 3 | Phanyakit & Satiennam, 2019 [5] | Fuzzy Multi-Attribute Decision Making for the Selection of a Suitable Railway Track Maintenance Plan: A Case Study in Thailand | Railway Line, Thailand | Railway Track | Fuzzy AHP, TOPSIS |
| 4 | Zheng et al., 2021 [27] | Risk Assessment of Geohazards along Cheng-Kun Railway using Fuzzy AHP Incorporated into GIS | Cheng-Kun Railway, China | Railway Line | Fuzzy AHP, GIS |
| 5 | El-Khateeb et al., 2021 [14] | A Hybrid Multi Criteria Decision Making Model for Defect-Based Condition Assessment of Railway Infrastructure | Railway Infrastructure, Egypt | Railway Infrastructure (General) | Hybrid FAHP–MCDM |
| 6 | Nakkawita & Pushpakumara, 2024 [28] | Development of a Rating Model for Assessing the Condition of Steel Railway Bridges | Railway Bridges, Sri Lanka | Steel Bridges | Fuzzy Scoring / Condition Rating |

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### Research Distribution

The publication timeline reveals that FAHP integration in railway infrastructure maintenance emerged as early as 2016, with initial research concentrating on developing fuzzy-based decision models for risk assessment and maintenance prioritization. A substantial increase in research activity occurred in 2021, marking a methodological shift toward hybrid approaches [5] and Fuzzy Multi-Criteria Decision-Making (FMCDM) frameworks [14]).

Publications from 2016 to 2024 reflect the sustained yet specialized development of this research domain. While the topic maintains relevance, as evidenced by a 2024 publication on railway asset management, it has not yet achieved mainstream prominence. The field experienced a peak in 2021 with two publications, followed by a two-year hiatus before the most recent contribution.

The spatial distribution of research countries shows a concentration in Asia and select European nations, particularly China, Thailand, and Poland. This distribution correlates with countries actively modernizing rail systems and prioritizing maintenance efficiency. Asia's significant role reflects the region's strategic prioritization of adaptive decision-making and advanced asset assessment for railway systems.

### Trends in FAHP and Hybrid Decision Models

Analysis of the selected publications indicates a clear trend in railway infrastructure maintenance: the integration of hybrid methods to enhance decision-making objectivity and accuracy. Within these frameworks, FAHP serves as the main tool for determining the weights of subjective criteria, and other methods such as TOPSIS, GIS, or Fuzzy Comprehensive Evaluation (FCE) are integrated to enhance the assessment and prioritization of alternatives.

**Table 5.** Summary of Research Focus and Contributions

| No | Author(s) & Year | Research Focus | Main Contribution |
|---|---|---|---|
| 1 | Zhao et al. (2016) | Emergency alternative evaluation for unattended train operation (UTO) metro systems | Developed a FAHP–WOWA-based decision-making framework for emergency response in transportation systems, enhancing decision reliability through subjective and objective weighting. |
| 2 | Fabianowski & Jakiel (2018) | Evaluation of railway culvert serviceability | Integrated FAHP and Fuzzy TOPSIS to assess culvert serviceability based on technical criteria and field conditions, providing a systematic approach for inspecting small railway infrastructures. |
| 3 | Phanyakit & Satiennam (2019) | Selection of optimal railway track maintenance plans | Proposed a decision-making model to select the optimal maintenance plan based on rail condition parameters, cost efficiency, and operational risk. |
| 4 | Zheng et al. (2021) | Geohazard risk assessment along the Cheng–Kun Railway | Combined FAHP with Geographic Information System (GIS) to map geotechnical risks along railway lines, enabling spatial evaluation using fuzzy-based data. |
| 5 | El-Khateeb et al. (2021) | Defect-based condition assessment of railway infrastructure | Developed a hybrid FAHP–FCE model to determine damage levels and maintenance priorities based on visual inspection data. |
| 6 | Nakkawita & Pushpakumara (2024) | Condition assessment of steel railway bridges | Proposed a FAHP-based evaluation model to determine the condition rating of steel bridges, supporting predictive maintenance planning. |

According to the synthesis results presented in Table 5, it reveals a clear evolution in research focus from the application of a single FAHP to a hybrid multi-criteria approach. Initial research focused on using FAHP to evaluate strategic choices and the technical conditions of infrastructure elements [15], [26]. Advances in methodology emerged from integrating FAHP with TOPSIS and GIS to capture on-site conditions and spatial risk factors [5], [27]. A significant progress is the extension of FAHP into defect-based analyses and specific evaluations, such as steel bridge assessments [14], [28], demonstrating a substantial advancement in the method's analytical complexity and depth across diverse railway systems.

Overall, the research not only confirms FAHP's vital role in railway decision-making but also traces a conceptual evolution from technical evaluations to risk-based support systems. This progression marks a significant shift toward predictive infrastructure management aligned with modern asset management principles. Despite these advancements, significant research gaps persist, particularly concerning real-time data integration, dynamic weighting based on actual track conditions, and the application of FAHP within digital smart maintenance systems. These areas present critical opportunities for future research to enhance the adaptability of decision-support frameworks in line with ongoing digital transformation and evolving asset management policies.

**Future Directions of Hybrid FAHP**

Previous research has confirmed the benefits of FAHP in supporting railway maintenance planning. However, the literature review indicates the presence of several research gaps that require deeper examination:

**(i) Limited Real-Time and Dynamic Data Integration.** A primary limitation lies in the reliance on static data from periodic surveys or observations [5], [26], which fails to capture the dynamic nature of infrastructure degradation. Future research should explore the integration of FAHP with automated monitoring systems and the Internet of Things (IoT) to enable adaptive, real-time weighting based on actual asset conditions.

**(ii) A Narrowly Defined Scope of Analysis.** Existing studies often focus on isolated components, such as specific culverts or bridge sections. However, a railway is an interconnected network of assets, including rails, bearings, ballast, drainage, and other supporting structures [29]. A systems-level approach that considers these interdependencies is needed for comprehensive asset management.

**(iii) Underutilized Spatial and Environmental Risk Assessment.** While initial integrations with GIS show promise [27], the application remains limited. There is significant potential to leverage FAHP-GIS hybrid models with spatial risk analysis (e.g., for landslides, floods) or hydrometeorological data to proactively assess external threats and fortify infrastructure resilience against natural disasters.

**(iv) Lack of Multi-Stakeholder Weighting.** A participatory decision-making approach that involves railway operators, regulators, and end-users can generate more representative data that better reflects actual on-site needs.

The integration of Fuzzy AHP with artificial intelligence (AI) technologies, such as machine learning, provides a promising direction for improving railway maintenance frameworks. This combination supports the development of predictive and automated decision-support systems that integrate historical data with real-time condition monitoring. From this potential, several key topics for future exploration can be outlined, including: (1) the integration of FAHP with IoT-based monitoring systems, (2) the development of holistic models integrating the entire railway network, (3) the application of FAHP-GIS for spatial risk and disaster analysis, (4) the implementation of participatory FAHP incorporating multi-stakeholder perspectives, and (5) the creation of AI-driven FAHP hybrid models for adaptive, predictive maintenance systems.

Based on the systematic literature screening and synthesis, the findings corresponding to the research questions (RQ1–RQ3) are summarized as follows:

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**RQ1:** The FAHP method has proven to be an effective decision-support tool for railway infrastructure maintenance and evaluation, particularly in handling multi-criteria problems involving both technical and non-technical factors. However, the review reveals that current applications remain predominantly reliant on static data and assessments of isolated components—such as individual tracks, culverts, or bridges—rather than adopting an integrated, system-wide perspective.

**RQ2:** Hybrid FAHP-based methodologies, including integrations such as FAHP–TOPSIS, FAHP–FCE, and FAHP–GIS, have demonstrated enhanced decision-making accuracy by incorporating spatial, environmental, and performance-based factors into maintenance evaluations. However, these applications remain context-specific and have yet to incorporate real-time data monitoring or multi-stakeholder input—critical dimensions for comprehensive and context-aware decision support.

**RQ3:** The evolution of FAHP is positioned toward the development of intelligent, adaptive decision-support systems. Current findings indicate significant potential for integrating FAHP with emerging technologies such as IoT and AI. While existing research is concentrated in developed nations such as China and South Korea, the systematic review underscores FAHP's applicability in developing countries, where data scarcity and complex environmental conditions amplify the need for uncertainty-informed, adaptive maintenance frameworks.

## CONCLUSION

This systematic literature review has traced the evolution of Fuzzy AHP (FAHP) and its hybrid applications in railway infrastructure maintenance and evaluation from 2015 to 2025. The analysis yields several key conclusions, which can be categorized into temporal-spatial trends, methodological developments, and practical implications. Research in this domain shows a steady, though still limited, pattern of growth, with publications covering the period between 2016 and 2024. Most studies have been conducted in Asia and Europe, indicating that the topic remains emerging yet holds considerable potential for global expansion. The review's findings highlight two principal aspects. First, in terms of methodology, the integration of FAHP methods like TOPSIS and GIS created hybrid approaches that effectively handle data uncertainty, thereby enhancing assessment accuracy and prioritization objectivity. Second, thematically, previous studies have focused on structural condition evaluation, geotechnical risk assessment, and maintenance strategy selection. However, these achievements are tempered by two major limitations. Most research remains case-study-based, limiting the wider validity of its conclusions. Furthermore, the developed FAHP models lack integration with real-time digital monitoring systems. From an academic perspective, FAHP provides a systematic and adaptable framework for decision-making in data-scarce and uncertain infrastructure contexts. In practical terms, the method offers a strategic tool for developing more efficient, risk-adaptive decision support systems in railway asset management, paving the way for more resilient and data-informed maintenance practices. This systematic literature review is subject to several limitations. The scope was restricted to English-language publications from 2015 to 2025, potentially excluding relevant studies outside these parameters. Furthermore, the reliance on three major international databases may have omitted significant contributions from regional or non-indexed sources. The review also focused specifically on FAHP's methodological applications without conducting quantitative performance comparisons with alternative Multi-Criteria Decision-Making (MCDM) techniques. Therefore, future studies must advance the integration of FAHP with real-time technologies such as the Internet of Things (IoT) and machine learning to create adaptive models that significantly improve the decision-making accuracy in railway infrastructure maintenance. In addition, a necessary direction for future work is the development of predictive maintenance frameworks. These frameworks would integrate historical and spatial data to forecast damage risks and maintenance requirements proactively, thereby preventing functional failures.

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