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Fuzzy-AHP Based Decision Support System for the Selection of Optimal Maintenance Strategy for Meter Gauge Railway Infrastructure: A Review

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ABSTRACT

There are many uncertainties and complexities associated with maintaining Meter Gauge Railway (MGR) infrastructure, which calls for a methodical approach to decision-making. The development and application of a fuzzy-AHP-based decision support system (DSS) to select the optimal maintenance strategy for the MGR are presented in this study. The review covers research from 2013 to 2023 and focusses on the use of Multi-Criteria Decision Making (MCDM) and Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) techniques in railway infrastructure maintenance. To manage the inherent uncertainties and subjective judgements involved in maintenance decision-making, the Fuzzy-AHP methodology combines fuzzy logic with the Analytic Hierarchy Process (AHP). By assessing and prioritising maintenance strategies, this Fuzzy-Based DSS seeks to improve the MGR infrastructure's reliability, dependability, safety, and efficiency. The analysis reveals that while Fuzzy-AHP has been widely adopted for decision support in infrastructure maintenance, there remains a significant research gap in applying these systems to Meter Gauge Railways, particularly in developing regions. The review underscores the need for more targeted studies and suggests potential avenues for future research, including the exploration of hybrid DSS models and the application of advanced computational techniques. The findings offer insightful information to officials and railway operators about the efficacy of the Fuzzy-AHP-Based DSS in enhancing maintenance performance and optimising resource allocation.

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INTRODUCTION

Transportation networks heavily rely on the infrastructure of Meter Gauge Railways (MGR), especially in areas where narrow-gauge railways are more common. Maintaining this infrastructure effectively is essential to ensuring railway operations are safe, dependable, and efficient. Preventive, predictive, and corrective maintenance techniques are commonly employed to reduce the likelihood of infrastructure breakdowns and to maximise operating efficiency (Kilani et al., 2019)

Choosing the best or optimal maintenance strategy for MGR infrastructure involves

several factors and uncertainties, making it a difficult decision to make. Conventional decision-making techniques frequently fail to consider the subjectivity and ambiguity that are intrinsic to maintenance planning. As a result, sophisticated decision support systems (DSS) have been used, which use fuzzy logic and multi-criteria decision-making (MCDM) approaches to improve decision-making (Zadeh, 1965; Saaty, 1980).

The Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) is one of these methods that has drawn a lot of interest because of its methodical handling of both qualitative and quantitative criteria. Fuzzy-AHP is especially useful for selecting maintenance strategies because it incorporates fuzzy logic into the standard AHP to better reflect the imprecision and uncertainty in expert judgements or assessments (Kahraman et al., 2003). Railway maintenance managers have a strong tool to assess and rank different maintenance techniques when Fuzzy-AHP is integrated into a DSS framework.

Despite the potential benefits, there is a need for a comprehensive review of the existing literature to understand the current state of research on Fuzzy-AHP-based DSS for MGR maintenance. This review aims to synthesize the findings from previous studies, identify research gaps, and propose directions for future research (Belhadi et al., 2018; Moslem et al., 2019). By doing so, it seeks to provide valuable insights for both researchers and practitioners in the field of railway maintenance.

LITERATURE REVIEW

Maintenance Challenges in Meter Gauge Railways (MGR)

Addressing a variety of organisational, technological, and environmental issues is part of maintaining railway infrastructure. The deterioration of rolling stock, signalling systems, tracks, and other crucial components are among the technical difficulties that must be overcome regularly to preserve operational effectiveness (Kilani et al., 2019). The reliability and safety of railway operations are contingent upon the coordination of maintenance activities, resource allocation, and adherence to safety requirements. These organizational problems are central to this endeavour (Kihonge et al., 2020).

Railway infrastructure is subject to several environmental problems, such as weather, geography, and other external variables. Extreme weather occurrences, like floods and landslides, can result in considerable damage to railway tracks and infrastructure. Therefore, it is imperative to respond promptly and effectively with maintenance interventions (Makoba et al., 2021). In addition, many MGR assets are aging, which adds complexity to asset deterioration, dependability, and performance. To ensure ongoing operating efficiency, careful planning and resource allocation are necessary (Smith et al., 2020).

Decision Support Systems in Railway Maintenance

In the field of railway maintenance, decision support systems (DSS) are being used more and more to improve decision-making procedures and maximise maintenance plans. To facilitate complicated decision-making tasks, DSS integrates several data sources, analytical models, and user interfaces (Bekheet et al., 2020). DSS can aid in the prioritisation of maintenance tasks, the effective use of resource allocation, and the enhancement of the overall functionality of railway infrastructure.

Predictive maintenance, condition-based maintenance, and risk-based maintenance methods are some of the DSS techniques that have been put out in the literature (Zhao et al., 2021; Zhang et al., 2021). To minimise downtime and maintenance costs, predictive maintenance makes use of data

analytic techniques to forecast when maintenance should be performed based on the state of railway assets (Li et al., 2020). Risk-based maintenance assigns a higher priority to maintenance tasks in accordance with the degree of risk connected with asset failures, whereas condition-based maintenance monitors equipment conditions in real-time to ascertain repair needs (Wu et al., 2019).

Fuzzy Logic and AHP in Maintenance Decision Making

The Analytic Hierarchy Process (AHP) and fuzzy logic are two popular approaches for maintenance decision-making. Fuzzy logic is appropriate for handling subjective judgements and partial information because it permits the inclusion of ambiguity and imprecision in decision-making processes (Zhao et al., 2021). In contrast, AHP is a methodical approach that combines psychology and mathematics to organise and analyse intricate decisions (Saaty, 1980). To find the optimal option, it entails breaking down a decision problem into a hierarchy of smaller problems, comparing them pairwise, and combining the findings.

Fuzzy-AHP, which combines fuzzy logic and AHP, improves DSS's ability to manage the inherent uncertainties in maintenance decision-making (Zhang et al., 2021). The advantages of both approaches are combined in fuzzy-AHP, which offers a strong framework for ranking maintenance plans in complicated and unpredictable contexts.

METHODOLOGY

Search Strategy

The literature review was conducted using a systematic approach to identify, evaluate, and synthesise existing research on the application of Fuzzy-AHP-based Decision Support Systems (DSS) to select optimal maintenance strategies for MGR infrastructure.

The search strategy involved querying multiple academic databases, including Google Scholar, IEEE Xplore, Scopus, and Science Direct, to ensure comprehensive coverage of relevant literature. Keywords used in the search included "Fuzzy-AHP," "Decision Support System," "Maintenance Strategy," "Meter Gauge Railway," and "Railway Infrastructure Maintenance." The search was limited to peer-reviewed journal articles, conference papers, and relevant technical reports published between 2013 and 2023.

Social Network Analysis

In this study, the citation-based network analysis was conducted using VOS Viewer 1.6.20. Two typical networks were formed and analysed. The networks established are the co-author network and the keyword co-occurrence network. A co-author network was established to analyse the scientific research collaboration. A keyword co-occurrence network was established to identify keywords and themes that appear in papers and to establish a correlation between a particular research topic or research direction related to the Fuzzy-AHP-based Decision Support System (DSS) for the selection of optimal maintenance strategy for MGR infrastructure.

All paper selection is illustrated by using PRISMA technique (Pamba and Taifa, 2024; Athuman et al., 2024), which depicts the article screening process and the literature search process. Excel was used to provide trends of research publications, journals used in publications related to Fuzzy-AHP-based Decision Support Systems (DSS) for the selection of optimal maintenance strategy for MGR infrastructure, and the academic databases utilised.

Inclusion and Exclusion Criteria

Specific inclusion and exclusion criteria were established to ensure the relevance and quality of the reviewed studies.

Inclusion criteria were studies that focused on the application of Fuzzy-AHP in maintenance strategy selection, studies that discussed DSS in the context of railway infrastructure, and studies published in English. Exclusion criteria included studies that did not apply Fuzzy-AHP, studies that did not focus on MGR or railway infrastructure, and non-peer-reviewed articles, editorials, and opinion pieces

Data Extraction and Synthesis

Data extraction was carried out systematically to ensure consistency and accuracy. A data extraction form was developed to record essential information from each study, including author(s), year of publication, study objectives, methodology, key findings, and conclusions. The extracted data were then organised into themes based on the research question (What are the most relevant literature on maintenance strategies for MGR infrastructure?). Thematic synthesis was employed to identify patterns and relationships within the data, facilitating a comprehensive understanding of the current state of research on Fuzzy-AHP-based DSS for MGR maintenance strategy selection (Thomas & Harden, 2008).

Data Collection

This systematic literature review's data gathering procedure was organized to guarantee that only relevant and high-Caliber research were included. The following actions were taken, choosing a Database: Major academic databases such as Google Scholar, IEEE Xplore, Scopus, and ScienceDirect were used to search the literature. These datasets were selected because they span a wide range of research on fuzzy-AHP applications, decision support systems, and railway infrastructure maintenance.

Method of Search: To find pertinent research, keywords like "Fuzzy-AHP," "Decision Support System (DSS)," "Maintenance Strategy," "Meter Gauge Railway," and "Railway Infrastructure Maintenance" were employed. To narrow down the search results and eliminate papers that weren't relevant, boolean operators (AND, OR) were used.

Criteria for Inclusion: Research centered on using fuzzy-AHP to choose maintenance strategies, research on DSS in relation to railroad infrastructure and peer-reviewed conference papers and journal articles from 2013 to 2023 (excluding foundational works) was included in the inclusion criteria.

Exclusion Criteria: The criteria were on research that does not use fuzzy-AHP, articles that concentrate on broad frameworks for decision-making that aren't relevant to railway maintenance, editorials, opinion pieces, and articles that are not subjected to peer review.

The screening and selection process: Started with 1,250 articles, which were then reduced to 995 articles after 90 duplicates, 80 automation-based exclusions, and 85 studies that did not fit the criteria were eliminated. Titles, abstracts, and full texts were then reviewed, bringing the total down to 94 studies. A final subset of 10 highly relevant papers was chosen because they were directly related to fuzzy-AHP and DSS in MGR maintenance (Table 4.1).

Data Analysis

The analysis involved both quantitative and qualitative techniques. Descriptive statistics were used to summarise the characteristics of the included studies, such as the distribution of publication years, geographic focus, and types of maintenance strategies evaluated. Qualitative analysis was performed to interpret the thematic content, with a focus on identifying common trends, challenges, and gaps in the literature. Additionally, a comparative analysis was conducted to evaluate the effectiveness of different maintenance strategies as reported in the studies, highlighting the advantages and limitations of using Fuzzy-AHP within a DSS

framework for MGR infrastructure maintenance.

Co-Authorship Network

For this study, a total of 275 authors were involved in 94 papers. A threshold of 1 paper was set for an author, and the unit of analysis is the author. Of the 275 authors, all met the threshold, having published at least one paper for each collaboration. After conducting the co-authorship analysis, 22 co-authorships were found to have linkages with each other. These 22 items were found to have the highest total strength link (72) and were categorized into Four (4) clusters. The classification details of the clusters are shown in Table 1.

Table 1: Clusters for Co-Authorship Network.

Cluster 1 (6 items)	Cluster 2 (6 items)	Cluster 3 (5 items)	Cluster 4 (5 items)
Antucheviciene, j	Alkharabsheh, a	Badi, i	Ayyildiz, e
Antucheviciene, j	Campisi, t	Pamucar, d	Bouraima, mb
Mardani, a	Duleba, s	Puska, a	Qiu, y
Mousavi, sm	Moslem, s	Stevic, z	Simic, v
Turskis, z	Ortega, j	Veskovic, s	Yildiz, a
Zavadskas, ek	Oubahman, l		

Cluster Connectivity Analysis

Figure 1 illustrates the co-authorship network (Overlay Visualization) between clusters 1 to 4. Clusters 1 and 4 are interconnected, and this connection is influenced by the correlation existing between researchers. Within these two clusters, Bouraima et al. (2023) emerge as the core researchers indicated by the largest node in the network. This suggests extensive collaboration with others and thus a strong correlation. The primary research topic for Bouraima et al. (2023), was an integrated fuzzy MCDM model for prioritising strategies for successful implementation and operation of the bus rapid transit system in *Records of Operations, Springer*, cited by 34 (34.00 per year) and several measures were recommended to produce a more effective maintenance plan for the urban public transportation services namely regular bus, BRT, and rail rapid transit.

In cluster 1, all nodes are of equal size, indicating that all researchers in that cluster have contributed in the research. In cluster 2, Moslem (2020) stands out with a large node, demonstrating significant contributions to publications. Their recent publications mainly focus on a systematic review of analytic hierarchy process applications to solve transportation problems from 2003 to 2022 (Moslem, et al., 2020). AHP is when a decision support system is needed (decision structure is important or decisions that involve a lot of uncertainties). The high uncertainty is recommended to be handled by a properly selected methodology, most likely by fuzzy AHP, the influence of various variables on Fuzzy-AHP-based DSS implementation, with most studies coincides. The other authors in the cluster have nodes of almost equal size.

In cluster 3, Stević, Z. has collaborated with all authors in that cluster and has a large node, indicating substantial contributions compared to other researchers. One of his recent publications, was on the location selection for roundabout construction using Rough BWM-Rough WASPAS approach based on a new Rough Hamy aggregator (Stević, et al., 2018). The authors use a combination of fuzzy AHP. Conversely, in cluster 4 again, all nodes have almost the same size, suggesting that all researchers have contributed equally in terms of

publications related to Fuzzy-AHP-based DSS for MGR infrastructure maintenance.

Keyword Co-occurrence Network

The co-occurrence network of the author's keywords constituted the network linkage of keywords for 58 keywords out of 450 keywords, which were obtained by setting a minimum number of occurrences of a keyword to greater than 13 appearances. After applying this threshold, the keywords were clustered into 6 groups, numbered from 1 to 6 depending on the size of the group, as shown in Table 2. Figure 2 and Figure 3 illustrate the Keywords co-occurrence networks and co-occurrence network for journals respectively.

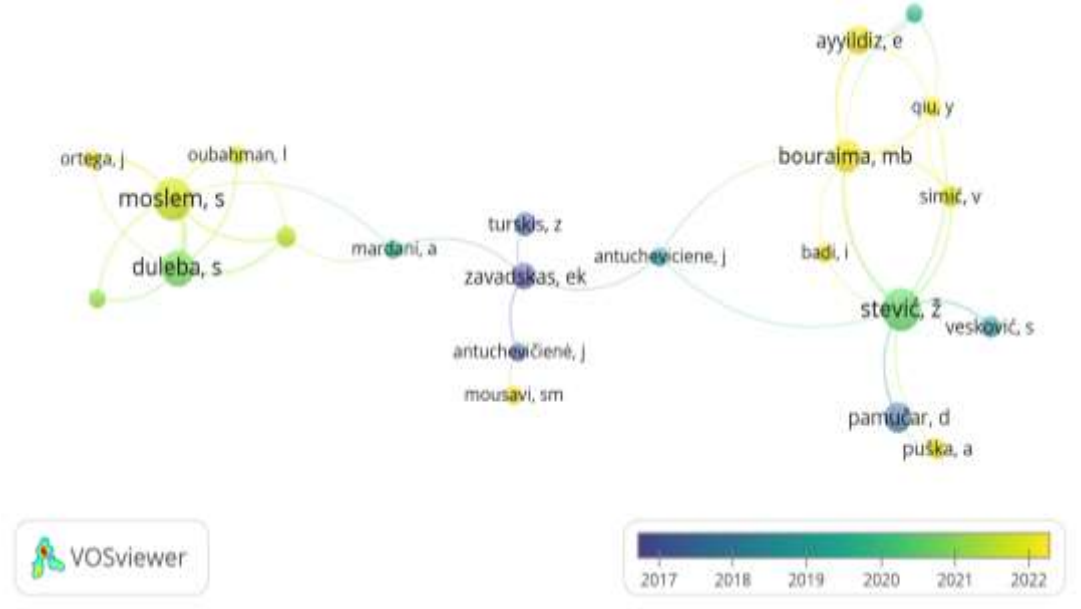

Figure 1: Co-authorship network.

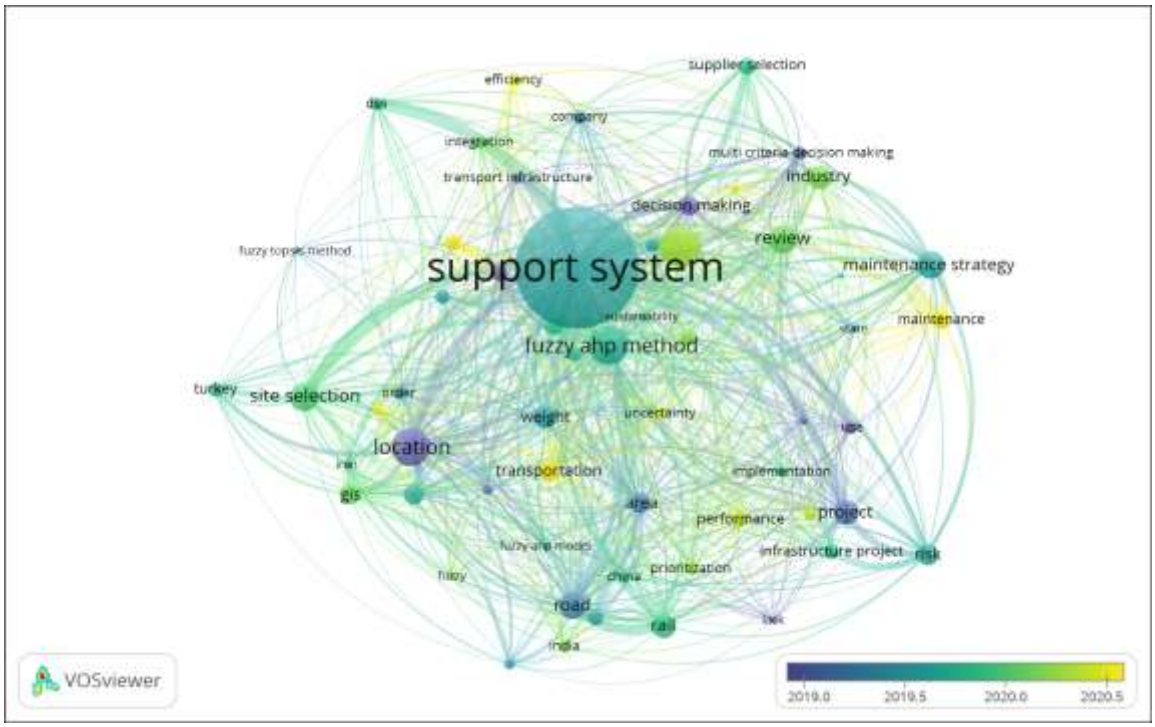

Figure 2: Overlay Visualisation of Keywords Co-occurrence network.

Table 2: Keywords Co-occurrence network.

Cluster 1 (13 items)	Cluster 2 (11 items)	Cluster 3 (10 items)	Cluster 4 (8 items)	Cluster 5 (8 items)	Cluster 6 (8 items)
Alternative	Area	Cost	Fuzzy	Decision Making	Fuzzy AHP Model
Choice	China	Implementation	Integration	Fuzzy AHP Technique	GIS
Company	Fuzzy AHP Approach	Infrastructure Project	Order	Industry	Iran
Decision Maker	Fuzzy AHP Methodology	Maintenance	Prioritisation	Integrated Approach	Location
DSS	India	Maintenance Strategy	Support System	MCDM	Site Selection
Efficiency	Lack	Project	Time	Multi Criteria Decision Making	Spatial Decision Support System
Fuzzy AHP Method	Performance	Review	Transportation Infrastructure	Strategy	Turkey
Fuzzy Topsis Method	Port	Risk	Uncertainty	Supplier Selection	Weight
Location Selection	Rail	State			
Railway Infrastructure	Road	Use			
Sustainability	Transportation				
Topsis					
Transport Infrastructure					

Keyword Clusters Analysis

Cluster 1: This cluster mainly encompasses keywords related to decision support systems (DSS) and maintenance strategy selection for MGR infrastructure. It includes keywords such as alternative, choice, company, decision maker, DSS, efficiency, fuzzy AHP method, fuzzy topsis method, location selection, railway infrastructure, sustainability, topsis and transport infrastructure. These keywords highlight the importance of utilising Fuzzy-AHP-based DSS for selecting the optimal maintenance strategy for MGR infrastructure. The inclusion of terms like sustainability, efficiency and decision-maker underscores the aim of achieving efficiency and effectiveness in the maintenance of decision-making processes.

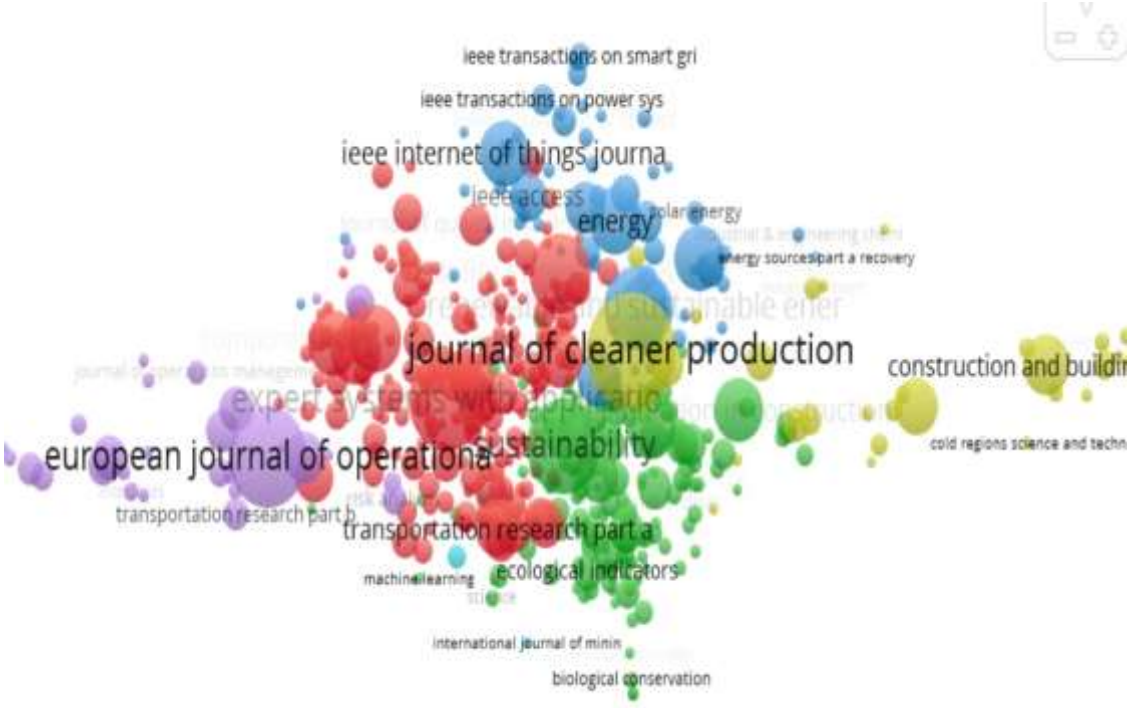

Figure 3: Co-occurrence Network for Journals.

Cluster 2: The geographical locations (China, India) and particular application domains (ports, rail, and roads) where Fuzzy AHP techniques are being used were highlighted in this cluster. Performance and filling in the gaps (missing) in the current methods were also mentioned. Keywords such as Fuzzy AHP Approach, Fuzzy AHP Methodology, and Transportation indicate the importance of studies with a focus on particular regions and evaluations of the effectiveness of fuzzy AHP implementations in various transportation scenarios. The studies show that this will help in enhancing infrastructure performance indicators and adjusting methods to local situations, and it could be the main area of research in the future.

Cluster 3: Infrastructure project pricing, implementation, and maintenance procedures were the key topics of this cluster. Risk and state-level applications were also covered. This cluster focusses on obstacles and solutions related to the implementation of decision support systems and maintenance strategies for MGR infrastructure. Keywords such as cost, implementation, infrastructure project, maintenance, maintenance strategy, project, review, risk, state, and use indicate a growing interest in identifying and overcoming challenges encountered during the implementation of infrastructural maintenance. Fuzzy-AHP techniques were highlighted as potential approaches to overcoming challenges in infrastructure maintenance decision-making. Future research could concentrate on risk management, cost-effective maintenance techniques, and the useful application of fuzzy AHP in major infrastructure projects. Evaluating the success of current tactics can yield insightful information.

Cluster 4: Prioritisation, managing uncertainty in transportation infrastructure projects, and the incorporation of fuzzy logic into support systems were all covered under this cluster. This cluster comprises keywords related to the methodologies and approaches commonly used in research on decision support systems and maintenance strategy selection for MGR infrastructure. Keywords such as fuzzy, integration, order,

prioritisation, support system, time, transportation infrastructure, and uncertainty were used and highlighted in this cluster. Research could focus on establishing strategies to handle uncertainty in infrastructure planning and maintenance, enhancing prioritization processes, and investigating sophisticated fuzzy logic integration approaches in DSS. All this can be used to explore real-world applications and challenges in this field.

Cluster 5: The keywords in this cluster are fundamental tools and concepts essential for implementing decision support systems and maintenance strategies in railway infrastructure management. Keywords such as decision making, fuzzy AHP technique, industry, integrated approach, MCDM (Multi-Criteria Decision Making), strategy, and supplier selection highlight key aspects of the decision-making process. This cluster focuses mainly on decision-making methods, particularly the Fuzzy AHP method, and how they are applied in different industries, such as integrated approaches and supplier selection. Multi Criteria Decision Making and Fuzzy AHP Technique, a widely used tool/technique in the process of optimisation, underscores the importance of streamlining maintenance processes for efficient and sustainable infrastructure management. Future studies could look into how multi-criteria decision-making (MCDM) techniques, such as fuzzy AHP, are used more broadly in other industries to create integrated strategies that use a variety of decision-making tools.

Cluster 6: This cluster focusses on the application of fuzzy AHP models for site selection in geographic information systems (GIS) and spatial decision support systems (SDSS). It covers areas, such as Turkey and Iran. In this cluster, the following keywords were highlighted Fuzzy AHP Model, GIS, Iran, location, site selection, spatial decision support system (SDSS), Turkey, and weight. Future research can concentrate on improving Fuzzy AHP models for more effective spatial decision-making and GIS-based site selection. Studies could also investigate how these models affect local infrastructure development and how they are applied in particular regions.

Frequency of Occurrence of Keywords in Publications

The following were some of the terms that appeared most frequently in the articles that were gathered and examined, according to the analysis done with VOS Viewer 1.6.20, as indicated in Table 3 and key-words density in Figure 4. According to the analysis, a substantial amount of literature has been published in the field of Fuzzy-AHP-based decision support systems (DSS). However, in some areas, like maintenance strategy assessment, there is a conspicuous dearth of comprehensive study. This emphasises the necessity of creating a thorough decision support tool especially made for choosing the best or optimal maintenance strategies for MGR infrastructure, filling in the gaps, and utilising technological breakthroughs.

Table 3: Frequency of Occurrence of Keywords in Publications.

Keyword	Frequency of occurrence
Fuzzy AHP	59
Decision Support System (DSS)	50
Maintenance Strategy	24
Meter Gauge Railway (MGR)	16
Infrastructure Management	10
Multi-Criteria Decision Making (MCDM)	6

RESULTS AND DISCUSSION

Literature Search Results

The initial search yielded a total of 1250 articles as shown in Figure 5, which were further screened based on titles and abstracts to select studies that met the inclusion criteria. The following was a sample of sets of papers came out after the initial literature search related to the application of Fuzzy-AHP-based DSS for the selection of optimal maintenance strategies for Meter Gauge Railway (MGR) infrastructure. These references include studies on Fuzzy-AHP, DSS, and maintenance strategies in the context of railway infrastructure, as shown in Table 4.

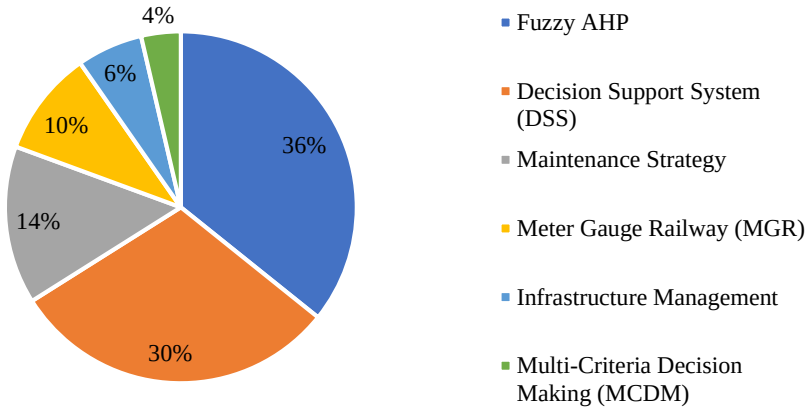

Figure 4: Keywords density

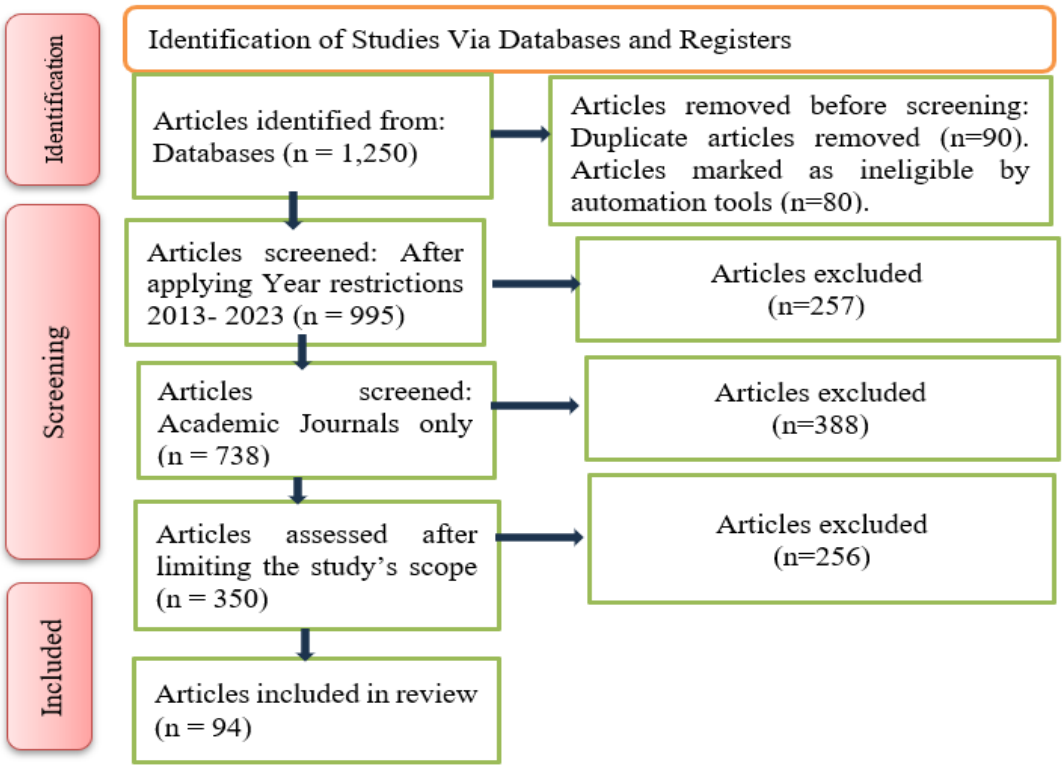

Figure 5: Literature Search Results

Table 4: Sample Papers Selected

Paper	Focus of paper
Patra and Espling (2009)	Maintenance strategy selection for railway infrastructure: A case study.
Kahraman *et al.* (2003)	Multi-criteria supplier selection using Fuzzy AHP: Logistics Information Management.
Tsang (2002)	Strategic dimensions of maintenance management: Journal of Quality in Maintenance Engineering.
Ahmad and Kamaruddin (2012)	An overview of time-based and condition-based maintenance in industrial application: Computers & Industrial Engineering
Guo *et al.* (2021)	Fuzzy AHP-Based Security Evaluation for Wireless Integrated Access System
Zhang and Lu (2010)	A framework for railway infrastructure maintenance management; Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit.
Wang *et al.* (2018)	A Risk-Based Maintenance Decision-Making Approach for Railway Asset Management
Alyamani and Long (2020)	The Application of Fuzzy Analytic Hierarchy Process in Sustainable Project Selection
Liu and Rodríguez (2014)	A fuzzy envelope for hesitant fuzzy linguistic term sets and its application to multicriteria decision making
Szabo *et al.* (2021)	An Analytic Hierarchy Process Approach for Prioritisation of Strategic Objectives of Sustainable Development

Trends of Research Publication

The trend of research in the areas of Fuzzy-AHP-based Decision Support Systems (DSS) for the selection of optimal maintenance strategies for Meter Gauge Railway (MGR) infrastructure is growing, as can be seen in Figure 6. The number of publications in the year 2013 was 23. In 2014 and 2015, the total publications were 52. It is noticed that as time progressed, the number of publications also increased. The low number of studies on Fuzzy-AHP DSS in the years 2013 and 2014 might be because research in this area was still in its early stages.

Journals Used in Publications

Several journals have been publishing studies on Fuzzy-AHP-based Decision Support Systems (DSS) to select the optimal maintenance strategies for Meter Gauge Railway (MGR) infrastructure. Of all the 13 journals reviewed in the study, the *Journal of Infrastructure Systems* is leading with a high number of publications in this area. The journal has published a total of 17 articles, as indicated in Figure 7, followed by the *International Journal of Railway Technology* with 11 papers and the *Journal of Transportation Engineering* with 10 papers. The rest of the journals have published fewer than 10 papers each. The journals with only one publication include the *Journal of Applied Mathematics*, *Decision Support Systems Journal*, *European Journal of Operational Research*, *IEEE Transactions on Systems*, *Expert Systems with Applications*, *Transportation Research, Journal of Transportation Safety and Security*, *Procedia Computer Science*, *Procedia*

Engineering, and *Advances in Mechanical Engineering*.

Academic Databases Used in Publications

The academic databases used to collect papers for the study are *Emerald Group Publishing Limited, Elsevier, IEEE, MDPI, Springer, Taylor and Francis*. Of all the databases used, Elsevier is leading with a high number of publications. The database has published 41 articles, followed by MDPI with 18 articles, Springer with 15 articles, Taylor and Francis with 10 articles, Emerald with 5 articles and Elsevier with 5 articles, as shown in Figure 8. This indicates that Elsevier has published several articles in the areas related to Fuzzy-AHP-based Decision Support Systems (DSS) for the selection of optimal maintenance strategy for Meter Gauge Railway (MGR) infrastructure.

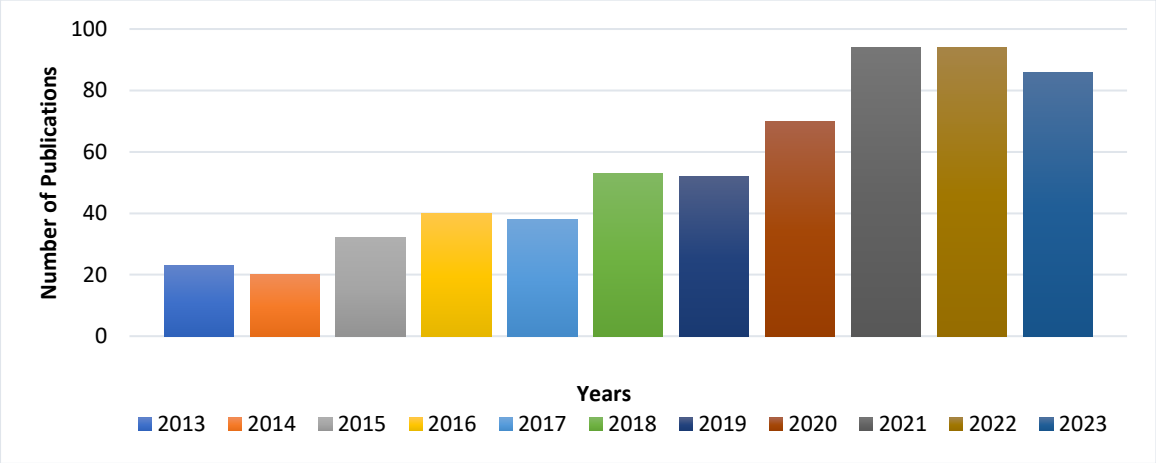

Figure 6: Trends of Research Publications (Number of Publications Vs Number of Years).

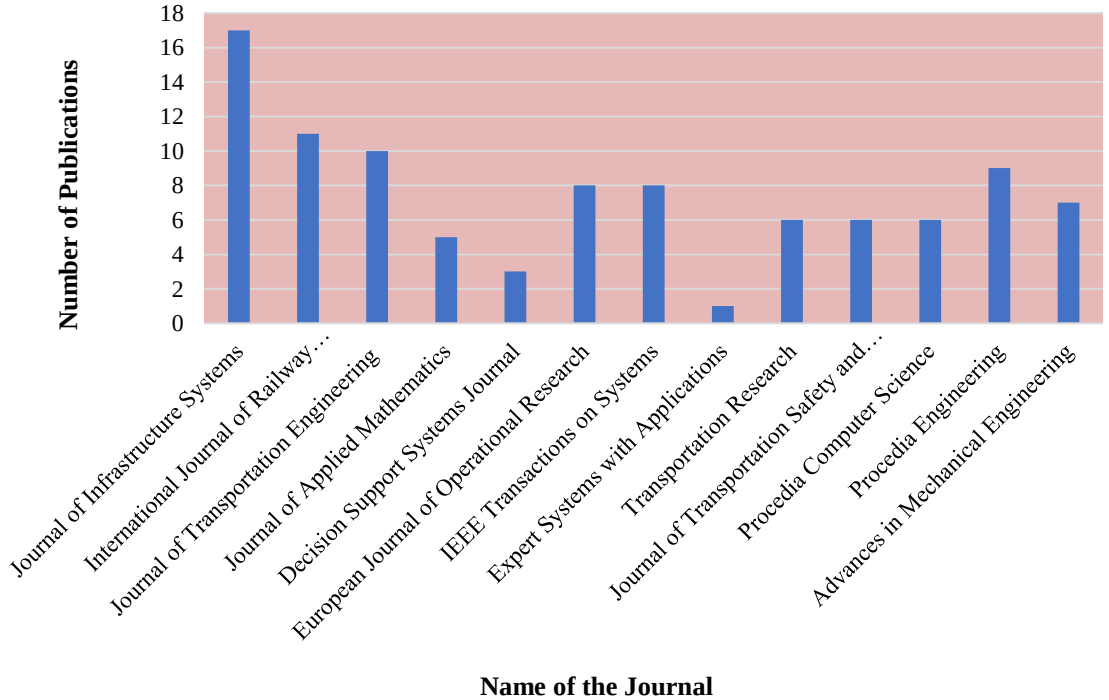

Figure 7: Journals Used in DSS in Railway Maintenance Publications.

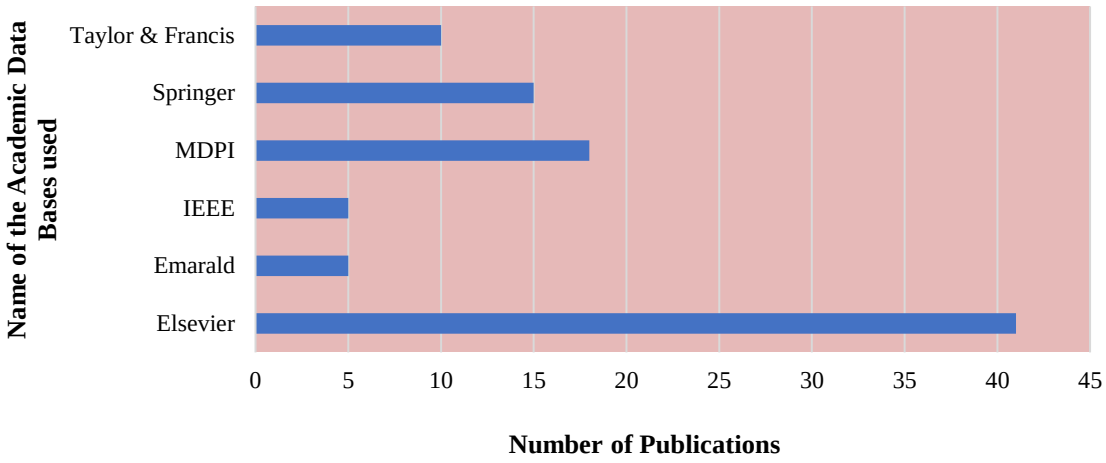

Figure 8: Academic Database Used in this Study Publications.

Publications of Papers Countrywide

Out of 94 papers analysed, China and India lead in publications related to Fuzzy-AHP-based Decision Support Systems (DSS) for the selection of optimal maintenance strategy for Meter Gauge Railway (MGR) infrastructure, with 36 and 25 publications, respectively. The number of publications in Africa is very low, with only 8 percent of publications coming from countries such as Egypt, South Africa, Tunisia, Zimbabwe, and Morocco. 48 percent of published papers are from developed countries, including Australia, Canada, France, Germany, Japan, the UK, and the USA. The remaining 43 percent of publications are from developing countries. Of all developing countries, publications from low-income countries account for 1 percent, which is from Zimbabwe, while the rest are from upper middle-income countries, as shown in Figure 9. This indicates a lack of publications on Fuzzy-AHP-based DSS for MGR infrastructure maintenance in Africa and developing countries, especially in low-income and lower-middle-income countries. The results are supported by studies such as Belhadi et al. (2018) who conducted their study in North Africa.

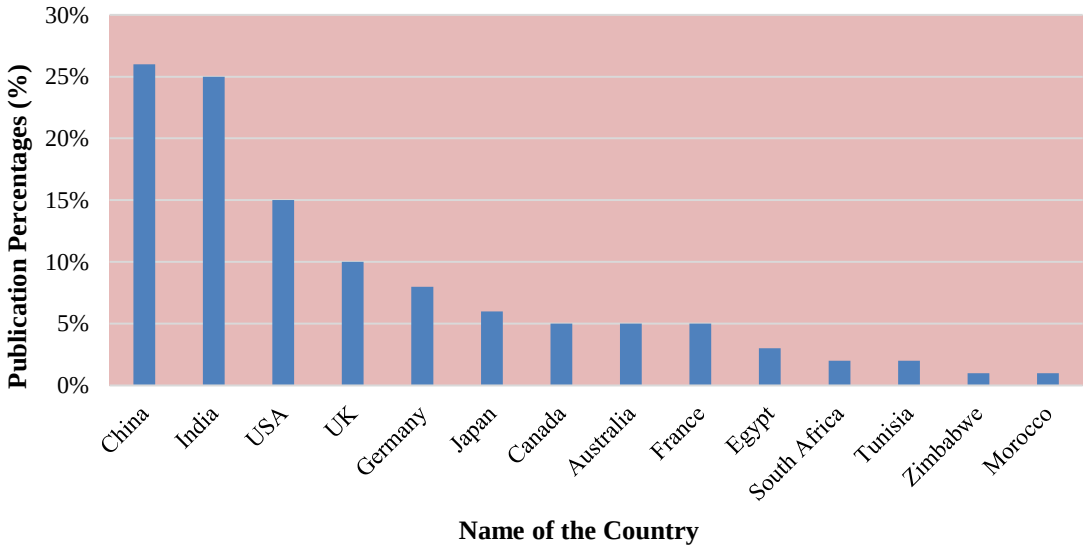

Figure 9: Publications of Paper Countrywide

CONCLUSION AND RECOMMENDATIONS

Conclusion

After evaluating several papers, a significant research gap was found on the application of decision support systems (DSS) to determine the optimal maintenance plan or strategy for the infrastructure of Meter Gauge Railways (MGRs), particularly in Tanzania and other low- and lower-middle-income developing countries. The majority of research concentrated on general infrastructure maintenance, with no specific DSS designed for MGR, according to the review, which evaluated the DSS models that were already in place. This disparity suggested that advanced decision support systems were not extensively employed for MGR infrastructure maintenance management in these locations. The lack of critical success criteria created especially for MGR infrastructure maintenance and implementation challenges are two reasons why these systems have not been adopted more widely.

The evaluation found that in order to close this gap, a decision support tool for choosing the best maintenance plans for MGR infrastructure needs to be created. This was in line with the more general requirement to improve MGR system maintenance management, as these systems are essential to the transportation networks of many developing nations. This tool has the potential to improve decision-making processes by offering a systematic way to manage the complexities and uncertainties associated with MGR maintenance by utilising the Fuzzy-AHP methodology. In order to provide a baseline understanding and identify areas that require improvement, the investigation of current maintenance procedures and the performance of MGR infrastructure highlighted the advantages and disadvantages of present approaches. The documentation of procedures that could be enhanced with advanced DSS, offered insightful information about the state of MGR maintenance as it stands today.

It was possible to identify the operational, technological, and environmental variables influencing outcomes by identifying the factors that enable and affect the maintenance performance of MGR infrastructures. This knowledge was essential for creating specialised maintenance plans that considered the particular difficulties MGR systems encountered. The decision support tool's efficacy and relevance were guaranteed by including these elements. Evaluating the efficacy of different solutions was made easier with the creation of modal criteria for MGR maintenance. According to the findings, the Fuzzy-AHP-based decision support tool was built on these KPIs and criteria, which allowed it to rank maintenance strategies according to how well they performed in comparison to predetermined ones. The review shows that the practical application of the Fuzzy-AHP-based decision support tool in real-world scenarios is required for its development and testing. Validating the tool's applicability and efficacy in enhancing MGR maintenance management is necessary, as is exposing areas for further improvement and offering empirical proof of its advantages.

Generally, this study provided a methodical approach to enhancing maintenance management in developing nations and filled a sizable research gap. The important part that MGR systems played in these regions' transportation infrastructure and the existing shortcomings in maintenance procedures highlighted the need for this study. According to several studies, this review helped improve the MGR infrastructure's dependability, reliability, safety, and efficiency.

Implications and Recommendations of the Study

Fuzzy-AHP-based Decision Support Systems (DSS) for choosing optimal maintenance techniques are a critical area of research to focus on to progress maintenance management in Meter Gauge Railway (MGR) infrastructure, especially in regions with limited adoption, such as Tanzania. To create specialised solutions, researchers should investigate the opportunities and problems found in these situations (Smith and Johnson, 2020). Effective implementation strategies include the identification and analysis of the enabling factors and challenges impacting the adoption of DSS (Brown et al., 2018). In low- and lower-middle-income developing nations, efforts should also be directed toward creating context-specific important success factors for the railway industry. Fostering cooperation between scholars, professionals, and policymakers will enable the dissemination of best practices and the exchange of knowledge, closing the gap between research and practice. By implementing these suggestions, railway operations can become much more effective, dependable, and safe.

One of the study's consequences is that it can help identify drivers and hurdles to the implementation of Fuzzy-AHP-based DSS, which is essential for getting over challenges and utilizing enablers. The research also aids in the creation of assessment instruments specifically designed for MGR infrastructure upkeep, allowing professionals to gauge how well maintenance plans are working.

These recommendations and implications will significantly advance the optimization of MGR infrastructure maintenance techniques, improving the sustainability and performance of railway systems.

Limitations of the Study

Numerous restrictions faced this study on the implementation of fuzzy-AHP-based Decision Support Systems (DSS) for choosing the best maintenance plans for the infrastructure of Meter Gauge Railways (MGR). Initially, relying only on the studied literature may have resulted in the exclusion of important material from websites that may have offered more insights into the perceptions and applications of DSS in MGR infrastructure maintenance by railway organisations.

Secondly, the literature search and retrieval for the study was mostly conducted using the Google Scholar database, which may have resulted in the exclusion of pertinent papers that may have been found in other academic databases like Dimensions and Web of Science. Thirdly, access restrictions to some articles that are not publicly available limited the scope of the literature evaluation, which may have influenced the study's conclusions.

The comprehensiveness and validity of studies on Fuzzy-AHP-based DSS for MGR infrastructure maintenance can be improved by addressing these constraints in subsequent research projects. Working together to explore a variety of publications and data sources, such as organisational/railways websites and several scholarly databases, can yield a more comprehensive grasp of the study topic.

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