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Comparative Evaluation of the TANROADS Road Maintenance Management System (RMMS) against MCDA Practice: Systematic Review - A Case of Tanzania

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ABSTRACT

The RMMS employed by TANROADS provides a structured, multi-criteria analysis (MCA) framework for prioritising maintenance interventions on trunk and regional roads. This study reviewed the literature to assess RMMS effectiveness against international MCDA practice, identify implementation barriers, and propose optimisations amid constrained resources and climate vulnerabilities. A PRISMA-guided systematic literature review searched academic databases and journals, using targeted keywords related to RMMS, MCA in road maintenance, and challenges in Tanzania and comparable contexts. About 60 peer-reviewed articles and reports were retained after screening for relevance, yielding an inductive content analysis of RMMS decision-making, priority logic, success factors, barriers, and international comparisons. The reviewed literature indicates RMMS is best suited to high-traffic corridors, with documented limitations on regional roads, including persistent traffic-centric bias, inadequate integration of climate vulnerabilities, insufficient GIS modelling, institutional capacity constraints, partial funding disbursements, and poor adaptability of MCA weights and HDM-4 models. Comparative analysis with MCDA systems in Indonesia (AHP-GIS for spatial), Australia (optimised hybrids for climate resilience), the United States (LCA-integrated equity), and Nigeria/South Africa (rural-focused GIS-MCDA) highlights RMMS as less equitable and climate-responsive. Recommendations include recalibrating MCA weights to enhance rural equity and climate resilience, adopting digital tools and GIS for improved data quality, implementing targeted training and capacity building, securing full funding alignment, and piloting hybrid models such as fuzzy-AHP. These enhancements could foster more proactive and sustainable maintenance priorities across Tanzania's regional network.

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1.0 Introduction

The prioritisation of regional road maintenance involves a complex decision-making process that considers technical, economic, environmental, and social factors. In the absence of systematic prioritisation frameworks, road agencies often resort to ad hoc or politically influenced decisions, resulting in the inefficient allocation of scarce maintenance resources and accelerated infrastructure deterioration.

Road condition assessment remains a central determinant of maintenance prioritisation, involving the evaluation of pavement distress, structural integrity, and surface roughness to identify intervention needs (Farhan Fwa, 2013; Huang *et al.,* 2024). Traffic volume and freight significance further shape priorities, as failure to maintain heavily trafficked corridors can cause substantial economic disruption (Prajapati *et al.,* 2024). Safety considerations, particularly for accident-prone segments, also play a critical role in determining maintenance urgency (Almaliki *et al.,* 2025). Additionally, climate vulnerability—including flooding, erosion, and extreme temperature exposure—accelerates road deterioration and increases maintenance expenses if not systematically integrated into planning (Kawamura & Zhang, 2021). Given limited budgets, many road agencies adopt life-cycle cost analysis and multi-criteria decision analysis (MCDA) to optimise fund allocation (Hasan Jaber, 2024).

In Tanzania, regional road maintenance prioritisation faces significant constraints due to limited funding, an expanding network, and rising climate-related risks. The national road network totals approximately 181,190 km (as of recent estimates up to 2022–2024, with ongoing expansions), of which TANROADS manages about 37,225 km of trunk and regional roads, while TARURA oversees the remainder (primarily district, urban, and feeder roads). Although the Road Fund Board allocates funds—with a historical emphasis on TANROADS—actual disbursements often fall well short of requirements. For instance, in recent financial years (including 2023/24), funding releases to TANROADS and TARURA have been partial (e.g., around 47% in some audited periods), leading to deferred maintenance, incomplete implementation of planned interventions, and a persistent backlog (NAOT, 2024). To address these challenges, TANROADS employs the Road Maintenance Management System (RMMS) to guide prioritisation decisions. RMMS integrates road inventory, condition, traffic, and works history data with a multi-criteria analysis (MCA) framework that incorporates economic (e.g., traffic/cost), population served, production centres, social services, connectivity, road class, and tourism factors (TANROADS, 2017).

Within TANROADS, RMMS allocates constrained budgets of TANROADS' trunk and regional networks, with competing needs (TANROADS, 2017). Despite some successes in data-driven prioritisation approaches through RMMS, there are persistent challenges related to usability and integration with financial systems, as well as climate-responsive needs that must be addressed to assess its effectiveness (Kindole *et al.,* 2025; Mombia *et al.,* 2024). This study examines how RMMS supports the prioritisation across TANROADS' trunk and regional networks, with particular focus on system effectiveness, integration of key indicators, and implementation challenges under constrained resources.

The thematic search and literature review were guided by the need to gather evidence relevant to answering the three specific RMMS-focused research questions. How effectively does the current RMMS prioritise road maintenance interventions in TANROADS? What are the critical success factors and barriers in RMMS implementation in the Tanzania context? How can the RMMS be optimised to improve maintenance prioritisation in resource-constrained Tanzanian regional contexts?

2.0 Literature Review

According to the Road Maintenance Management System (RMMS) used by TANROADS, the decision-making process can be divided into several integral stages: pre-survey preparation, data collection, data analysis, decision-making, implementation, and monitoring. Each stage plays a critical role in ensuring that maintenance decisions are based on accurate, relevant, and timely information. The MCA in the process is used to integrate technical data with strategic socioeconomics. The weighted MCA scores with prioritisation are used to determine the maintenance fund sequencing.

This literature aims at analysing the methodological framework used for maintenance optimisation, identifying gaps and establishing a conceptual framework for structure analysis. The systematic review of the literature is best based on prioritisation methods, identification of factors that moderate RMMS, implementation strategies that yield the best results and determination of statistically robust recommendations for improvement.

2.1 RMMS Decision-Making Frameworks

The prioritisation of regional road maintenance is a critical yet complex process, particularly in the face of growing demand and climate vulnerabilities. According to Rifai *et al.* (2018), maintenance optimisation in Indonesia, which integrates prediction models with maintenance optimisation to transform maintenance planning from a static to reactive exercise in a single DSS framework, unlike the traditional RMMS, makes decisions easier than the traditional.

Empirical studies highlight the value of structured decision-support tools in maintenance prioritisation. For instance, Han *et al.* (2025) developed an Analytic Hierarchy Process (AHP)-based model integrating structural condition, traffic importance, and economic value, leading to improved budget efficiency. Similarly, Ayeni *et al.* (2026) demonstrated the effectiveness of GIS-based prioritisation models in post-disaster road maintenance in Japan, emphasising accessibility and emergency response. According to VU and Mathew (2025), maintenance decision-making in India is optimised using an algorithm linked with GIS on pavement condition indices. It's a policy integration and multidimensional for maintenance prioritisation (Chaipetch *et al.,* 2025).

Traffic load intensity, particularly from heavy commercial vehicles, accelerates pavement deterioration and necessitates targeted maintenance (Ubg and Otobobg, 2025). Objective tools such as the Pavement Condition Index (PCI) and International Roughness Index (IRI) are increasingly used to inform decisions (Setiaputri *et al.,* 2021). Nepal has adopted SDI (Surface Distress Index) because the PCI needs more survey data and calculation, which is more labour-intensive (Shrestha *et al.,* 2025). However, climate-related risks—including flooding, erosion, and landslides—remain inadequately integrated in many African road management systems, despite their growing impact on infrastructure sustainability (Mastaki *et al.,* 2025). Institutional factors such as funding adequacy, technical capacity, and the availability of asset management systems further influence the effective application of prioritisation frameworks (Latjemma and Teknik, 2023).

2.1.1 Traffic Volume and Economic Implications

In the RMMS framework as detailed in the data collection manual (TANROADS, 2017) and integrated into the system's prioritisation logic, traffic volume is captured primarily through Annual Average Daily Traffic (AADT). This data is collected via field surveys at strategic locations, processed with Traffic Adjustment Factors (TAFs) from the Traffic Information Database (TIDB), and entered into the RMMS database to compute AADT for each road link or sub-link. Within the Multi-Criteria Analysis (MCA), traffic volume serves as the dominant component of the economic factor, which is assigned the highest weight of 40% in the overall MCA prioritisation score (TANROADS, 2017). The economic factor is specifically calculated as: Economic Feasibility (EF) = AADT / Unit Cost of the proposed maintenance treatment for that homogenous road section.

The remaining 60% of the MCA score is distributed across six non-traffic/socio-economic factors (population served 10%, production centres 10%, social services 5%, connectivity 15%, road class 10%, and tourism 10%) (TANROADS, 2017), ensuring that low traffic but socially critical roads are not entirely overlooked (Nugraha *et al.,* 2025). Independent secondary sources corroborate the core structure of this logic.

Mwaipungu and Allopi (2014), reviewing gravel road maintenance management across sub-Saharan Africa, report that TANROADS' prioritisation approach—sourced from the agency's 2009/2010 report and the PMORALG 2010/2011 plan—uses the same seven parameters identified in this study, with AADT/unit cost as the primary economic surrogate, followed by access to social services, network connectivity, population served, access to production centres, road classification, and access to tourist centres. This confirms the seven-factor structure and the primacy of the AADT/unit-cost criterion in earlier TANROADS documentation, predating the 2017 manual. However, TANROADS (2017) remains, to our knowledge, the only publicly available primary specification of the precise 40% economic weight and the exact percentage allocation among the six socio-economic factors; we were unable to identify an independent secondary source that explicitly corroborates these specific numerical weights, and this is noted as a minor limitation of the available documentation. According to Toolkos (2025), the maintenance prioritisation in TANROADS is a reactive process rather than a proactive risk analysis with high spatial resolution data. Despite the clear framework provided by RMMS, challenges remain in data collection consistency, integration efficacy, and the ability of the system to adapt to changing traffic conditions and climate impacts (Batterman *et al.,* 2015; Chaipetch *et al.,* 2025).

The emphasis RMMS places on AADT as a prioritisation driver is consistent with practice elsewhere in the pavement-management literature. Traffic-volume estimation has increasingly moved toward data-driven and machine-learning approaches in other jurisdictions to estimate traffic volume at minor road intersections where direct counts are impractical (Tawfeek and El-Basyouny, 2019), an approach that could offer a future upgrade path for RMMS's reliance on field-survey-based AADT collection in data-sparse rural sections.

Traffic volume is treated as a dominant or heavily weighted criterion in comparable pavement-prioritisation systems internationally, such as the hybrid prioritisation framework developed for Wyoming County road networks in the United States (Yamany *et al.,* 2025), suggesting that RMMS's 40% economic weighting is not unusual by international standards. On the data-processing side, techniques such as clustering and radial basis function modelling have been used elsewhere to manage and interpret large traffic datasets (Hernández *et al.,* 2021), pointing to methods RMMS could draw on as it seeks to improve TAF processing and AADT computation consistency.

2.1.2 Safety Considerations

The system supports safety improvements through structured data collection and prioritisation practices that help protect human life and reduce accident-related costs (Shrestha *et al.,* 2014). In the RMMS Data Collection Manual (2017) during paved road condition surveys, field teams visually assess and record parameters such as surface distresses, rutting, bleeding, and loss of surfacing (Ambunda and Sinclair, 2022; Mitiku *et al.,* 2025; Musa *et al.,* 2020). Urgent repairs are needed; a specific field is noted for segments requiring immediate attention due to severe defects posing an imminent safety hazard. For unpaved roads, visual ratings include overall condition, drainage, gravel thickness and spot improvements, many of which correlate with safety risks such as corrugation (causing vehicle instability), ruts, dust clouds reducing visibility, or washouts from poor drainage (Das *et al.,* 2019). The Multi-Criteria Analysis (MCA) does not include a standalone "safety" or "accident history" parameter among its seven weighted factors. Safety is indirectly embedded through: Condition-related data feeding into treatment recommendations (poor condition often implies higher accident risk, influencing the need for intervention). Urgent flags in condition surveys that can elevate sections for immediate action outside or alongside standard MCA scoring (Batterman *et al.,* 2015; Chakrabarti *et al.,* 2025). Broader network connectivity and road class factors, which may implicitly favour safer, more reliable links for essential services (e.g., access to hospitals). Traffic data further supports safety considerations indirectly: higher AADT (especially on freight-heavy or high-speed routes) increases the potential severity and frequency of accidents if maintenance is deferred, reinforcing prioritisation via the dominant economic factor (AADT / Cost).

2.1.3 Climate Vulnerabilities Assessment

RMMS captures various aspects of road condition and drainage but lacks dedicated climate-specific modules or advanced modelling of future climate risks. Lungu (2023), in a study on the sustainable prioritisation of asphalt road maintenance in Zambia, challenged the traditional assumptions in level 2 of the criteria and combined the effects of traffic level and environmental factors. The RMMS mandates that field teams visually assess the adequacy and effectiveness of drainage systems for both paved and unpaved roads. Assessments include ratings for drainage conditions, categorised on a scale from "Very Good" to "Very Poor". Identification of blocked drains, inadequate culverts, eroded channels, and instances of waterlogging. Documentation of issues that could exacerbate flooding and erosion, which are increasingly relevant under climate change scenarios due to more frequent heavy rainfall events (Al-Rubaee *et al.,* 2025).

Inadequate drainage directly contributes to infrastructure degradation, exacerbated by climate-induced rainfall variability (Pathan *et al.,* 2024). The Genetic Algorithm (GA)-based decision framework for pavement maintenance planning in Sri Lanka incorporates a Climate Risk Index (CRI) to address climate vulnerabilities (Madushani *et al.,* 2024). The CRI is derived as a function of probability (historical climate event data over the last 20 years for floods and landslides, along with topography), severity and criticality.

These defects can be exacerbated by flooding or erosion, leading to further deterioration if not addressed promptly (Ahmed *et al.,* 2023; Pan *et al.,* 2018). The manual incorporates mechanisms for flagging segments that require immediate attention due to significant hazards, such as erosion-undermined sections. These urgent repairs are crucial for addressing acute vulnerabilities in infrastructure that could result in accidents if left unattended (Ientile *et al.,* 2020). Lacking the systematic climate integration data collection outlined in the RMMS, explicit climate vulnerability assessments or projections are notably absent. The Multi-Criteria Analysis (MCA) framework within RMMS, which includes parameters such as economic/traffic, population, and tourism, does not allocate any weight or scoring for climate resilience, environmental risks, or sustainability-focused indicators. The implications of this absence include that without dedicated climate scoring, explicit vulnerabilities related to extreme weather are not accounted for in maintenance prioritisation, which could lead to incomplete assessments of road safety and longevity. Historical climate data and future projections are crucial for understanding how climate change will likely impact road infrastructure over time. The absence of this data hinders proactive risk management and adaptation strategies (Gerardo *et al.,* 2025). Integrating climate data without risk mapping, the RMMS fails to create a comprehensive picture of vulnerabilities or to develop adaptive design criteria necessary for robust infrastructure (Wijaya *et al.,* 2023).

The RMMS organises data collection into three main sections (inventory & condition surveys, MCA data, and traffic counts), each providing clear instructions on how to conduct surveys, including information on teams, equipment, forms, safety rules, and quality assurance (QA) steps.

2.1.4 MCA Integration with Financial Systems

One significant barrier is the usability of existing data-driven models, which may be complex and resource-intensive (Dobson *et al.,* 2014). The Iraqi framework employs the Fuzzy Best-Worst Method (BWM) integrated with VIKOR to achieve balanced fund allocation (Hasan and Jaber, 2024). This approach stands out for its comprehensive set of 20 criteria, ensuring a holistic and reliable decision-making process under uncertainty. The integration of these models with financial management systems is often unattended, which hinders their implementation (Hasan and Jaber, 2024). MCA techniques have a disconnect between analysis and actionable funding because they do not accommodate the complex outputs generated (XIAO *et al.,* 2016).

According to XIAO *et al.* (2016), the Chinese CVSEE framework and the scale methods integrate with fuzzy weight and use multi-source data with a simplified scale method. It's less biased and has lower subjectivity compared to RMMS with MCA.

2.2 Theoretical Framework for Maintenance in TANROADS

RMMS implemented by the Tanzania Roads Agency (TANROADS) is grounded in systematic asset management principles and MCA score calculation. The framework links prioritisation needs assessment through structured data collection, encompassing three primary components: inventory and condition surveys, Multi-Criteria Analysis (MCA) data (Šelih *et al.,* 2008), and traffic counts. By integrating concepts from the Highway Development and Management (HDM-4) model (Kerali and Mannisto, 1999a), the RMMS makes decisions by ranking road sections for maintenance. It uses seven factors: economics, connectivity, population served, production centres, road class, tourism, and social services. Each factor is scored on a 1-5 scale (very low to very high) based on qualitative/quantitative bands. This section makes explicit the three theoretical traditions RMMS draws on and how each maps to the seven-factor structure.

RMMS's economic factor is a simplified derivative of HDM-4's life-cycle cost–benefit logic. Where HDM-4 properly evaluates maintenance options through multi-year deterioration prediction, road-user cost modelling, and net present value ranking of treatment alternatives (Chamorro and Tighe, 2019; Kerali and Mannisto, 1999), RMMS collapses this to a single-period ratio — economic feasibility (EF) = AADT / Unit Cost — evaluated at the point of prioritisation rather than across the asset's life cycle. This is a defensible simplification for a resource-constrained agency, but it means RMMS inherits HDM-4's economic logic without its temporal or risk-adjustment machinery.

The RMMS scoring method is formally a Simple Additive Weighting (SAW) model, a special case of Multi-Attribute Utility Theory (MAUT) in which a composite priority score is calculated as a linear combination of weighted criterion scores (Taherdoost, 2023): Priority Score = $\Sigma_i\ w_i x_i$, where w_i is the fixed weight assigned to factor i (Economic 40%; Population, Production, Road Class, Tourism 10% each; Connectivity 15%; Social Services 5%) and x_i is that factor's 1–5 band score (TANROADS, 2017).

This positions RMMS within the same MCDA family as the AHP, TOPSIS, and ELECTRE-based systems reviewed, but with one structural difference: those systems typically derive their criterion weights through pairwise comparison (AHP), distance-to-ideal-solution ranking (TOPSIS), or outranking relations (ELECTRE)—procedures that make the weighting process traceable (Hwang and Yoon, 2012). RMMS weights, by contrast, are fixed at the manual level (TANROADS, 2017) without a documented derivation procedure. We treat this as the methodological root of the "traffic-centric bias"; the 40% economic weight is not an emergent output of a comparative judgement process but a static input, which is why recalibration is proposed as a parameter change rather than a re-elicitation exercise.

RMMS's grounding in "systematic asset management principles" corresponds to the ISO 55000 asset management standard (ISO, 2014). The four organisational elements are value (assets exist to deliver value to the organisation and its stakeholders), alignment (asset management objectives are derived from organisational objectives), leadership (workplace culture and delegated authority determine realised value), and assurance (asset management activities meet requirements through fit-for-purpose processes and continual improvement) (ISO, 2014). Mapped against this standard, RMMS's seven factors substantially address value (economic, population, production, and tourism) and alignment (connectivity, road class, and social services), consistent with an asset-management orientation. However, RMMS has no explicit mechanism corresponding to ISO 55000's assurance element—there is no formal audit, sensitivity testing, or continual-improvement loop built into the MCA scoring process itself. This theoretical gap corresponds directly to the empirical findings on data-quality deficiencies and institutional capacity constraints: those are not independent operational problems but the observable symptom of an unaddressed assurance function in RMMS's asset-management design.

This review assesses how RMMS's structural design shapes prioritisation outcomes and where it diverges from comparator systems, while also acknowledging the implementation challenges and limitations.

2.2.1 HDM-4 Theory Data Limitation

The Highway Development and Management Model (HDM-4) is widely used as a strategic planning tool to identify road sections requiring improvement and to establish investment priorities (Kerali and Mannisto, 1999a). The model assists transportation agencies on predicted pavement deterioration and life-cycle costs designed to be adjusted with regional parameters, including climate and environmental conditions (Chen and Lin, 2013).

Nepal has integrated HDM-4 into its Road Asset Management System (RAMS), combined with GIS modelling, to support network-level decision-making (Shrestha *et al.,* 2025). This system differs from the Road Maintenance and Management System (RMMS), which relied more heavily on socioeconomic factors and multi-criteria analysis (MCA) for prioritisation. In contrast, Nepal's current RAMS framework addresses local data gaps and specific conditions by complementing the deterministic HDM-4 deterioration models with probabilistic machine learning (ML) approaches, such as Markovian hazard-based models, to better capture uncertainty and improve long-term performance predictions (Shrestha *et al.,* 2025). This hybrid approach aligns with HDM-4 theory by maintaining its core life-cycle analysis framework while enhancing its predictive capability through advanced statistical techniques.

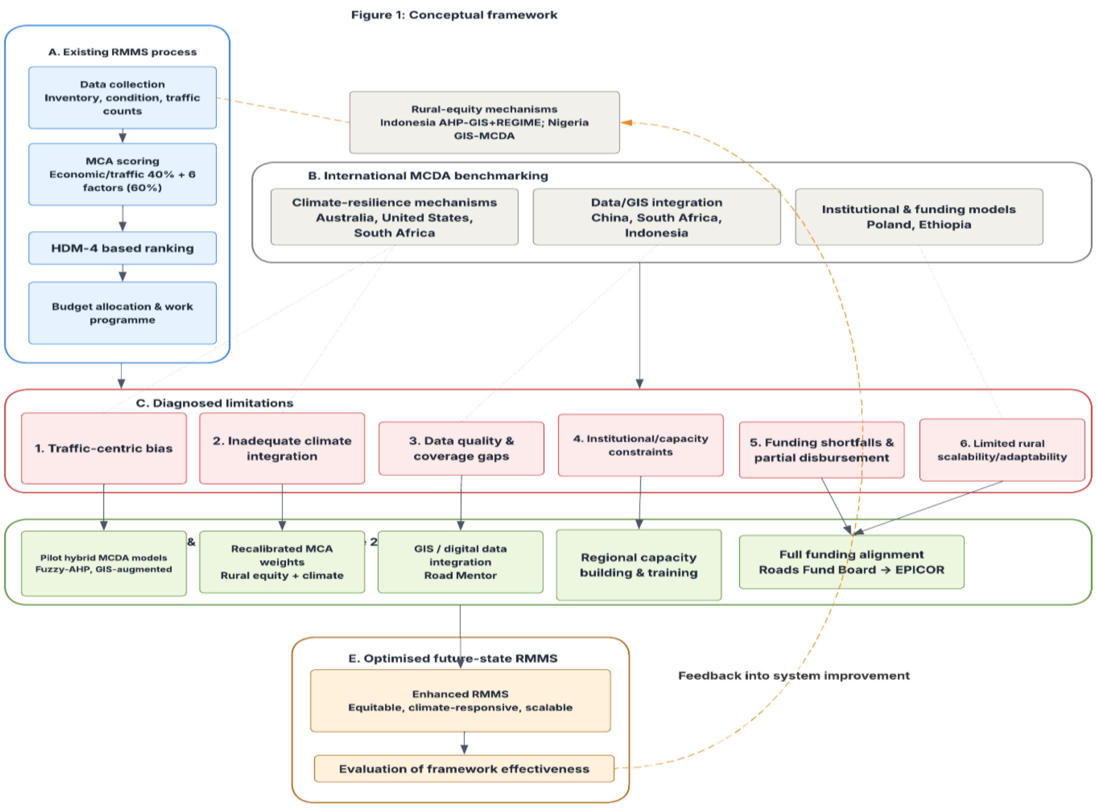
The model also provides performance modelling tools that help forecast the effects of different maintenance strategies, starkly showcasing the impact on road performance and user costs (Chamorro and Tighe, 2019). The model provides a structured methodology for assessing the needs of the road network, prioritising investments that yield the greatest benefits in terms of connectivity and economic development. The HDM 4 applied in Taiwan has its user modification adjusted with region parameters; hence, it is applicable in different regions at suitable thresholds (Chen and Lin, 2013). Additionally, the adaptability of HDM-4 facilitates region-specific adjustments, addressing local conditions and needs effectively (Kerali and Mannisto, 1999).

The model also provides performance modelling tools that help forecast the effects of different maintenance and rehabilitation (M&R) strategies, clearly illustrating the trade-offs between pavement condition, agency costs, and road user costs over the entire life cycle (Chamorro and Tighe, 2019). By simulating these long-term impacts, HDM-4 offers a structured methodology for assessing the needs of the road network and prioritising investments that yield the greatest net benefits in terms of connectivity, economic development, and social welfare.

2.2.2 MCA Application in Road Maintenance

Indonesia uses the Analytic Hierarchy Process (AHP) combined with Geographic Information Systems (GIS) to prioritise infrastructure projects spatially (Nugraha *et al.,* 2025; Prasertsri and Sangpradid, 2020). This method facilitates systematic project selection, which scores various criteria based on qualitative and quantitative assessments, including environmental factors (Sayadinia and Beheshtinia, 2021). Data scarcity in rural areas hinders comprehensive evaluations, necessitating a greater integration of national sustainability policies to support effective decision-making processes in road maintenance (Buburanda *et al.,* 2023). China has adopted a hybrid MCA approach combining AHP and TOPSIS for road project rankings and routing options (Liu *et al.,* 2024; Więckowski *et al.,* 2023). Deep learning integrated with TOPSIS significantly enhances defect detection and prioritisation processes (Tripathi *et al.,* 2022; Zhong and Ren, 2025). The deep learning models are trained on extensive datasets captured through vehicle-mounted cameras or drones, enabling them to detect common issues like potholes and pavement cracking effectively (Heidari *et al.,* 2022; Yu *et al.,* 2020). Poland applies the Multi-Criteria Analysis (MCA) using the Analytic Hierarchy Process (AHP) along with modifications, as well as TOPSIS, DEMATEL, PROMETHEE, and ELECTRE for variant ranking. The criteria include environmental impact (Dou *et al.,* 2009). In India the application of fuzzy MCDM methods allows for prioritising regional challenges, while AHP is used for evaluating strategies (Feizizadeh and Ghorbanzadeh, 2017; Noviani and Saputra, 2024). It addresses diverse regional needs, highlighting the importance of adaptive decision-making frameworks in the Indian context (Li *et al.,* 2020). In the US, MCA is employed by states to guide project selection and climate-resilient planning, typically adhering to federal guidelines. The analysis integrates life-cycle assessments, evaluating criteria such as cost, environmental impact, and community benefits (Veeramani *et al.,* 2022). Utilising hybrid MCDA models, Australian strategies evaluate criteria including environmental protection and risk mitigation (Song *et al.,* 2021). Nevertheless, challenges persist due to the vast rural networks and climate extremes such as bushfires, which complicate decision-making processes and the long-term planning of resilient infrastructure systems (Natsagdorj *et al.,* 2020).

Figure 1
Conceptual Framework



3.0 Materials and Methods

3.1 Review Approach

This study employs a systematic literature review to evaluate and refine the Road Maintenance Management System (RMMS) decision-making framework used by the Tanzania National Roads Agency (TANROADS), with particular attention to low-volume and rural regional roads. The approach integrates a comprehensive systematic literature review with conceptual mapping of the RMMS process, drawing on secondary sources to assess effectiveness, identify critical success factors and barriers, and propose optimisations. This study is a secondary-source review. No primary data were collected from TANROADS regional offices; findings on institutional and operational conditions derive entirely from published audit, technical, and peer-reviewed sources.

The literature review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. The literature was searched using targeted keywords and phrases, including "Road Maintenance Management System TANROADS Tanzania", "RMMS prioritisation Tanzania", "multi-criteria analysis road maintenance Tanzania and other countries", "TANROADS Mbeya Region road maintenance", "rural road asset management Tanzania", "HDM-4 integration TANROADS", and combinations incorporating terms like "challenges", "effectiveness", "optimisation", and "2023-2026".

3.2 Stages of Review

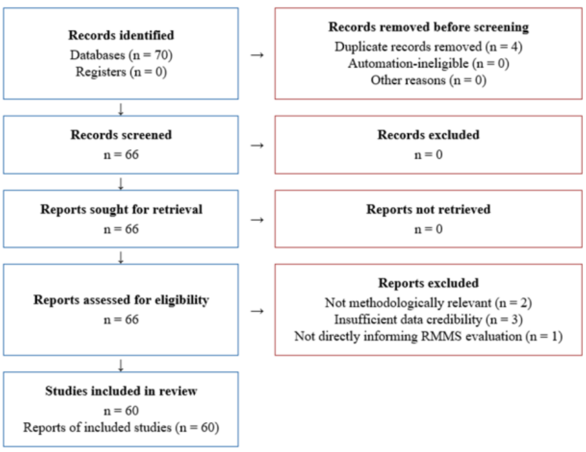
Advanced search includes Google Scholar articles and citations, ResearchGate, Academia.edu papers, university repositories, journal publisher websites (Springer, MDPI, Wiley, Elsevier, and Taylor & Francis), and international organisation sites (World Bank (Li *et al.,* 2020)). The search yielded approximately 70 initial results across the queries, which were screened first by title and abstract, then by full-text review. After deduplication and quality assessment (e.g., for methodological relevance and data credibility), the final 60 keys were retained for in-depth analysis.

The breakdown of exclusions by stage — duplicate records removed, records excluded at screening, reports not retrieved, and reports excluded at eligibility by reason — is shown in Figure 2. These 60 sources focused on themes such as frameworks for prioritising road maintenance, MCA/MCDA methodologies, climate vulnerability, safety considerations, data management, and applications in resource-constrained or rural contexts (e.g., Tanzania, the Mbeya Region, or similar developing settings). The selection emphasises peer-reviewed articles, technical reports, and foundational works that directly inform RMMS evaluation, gaps, and optimisations.

Table 1
Eligibility Criteria for Source Selection

Criterion	Inclusion	Exclusion
Publication type	Peer-reviewed journal articles, conference proceedings, technical/institutional reports (e.g., TANROADS, NAOT)	Non-peer-reviewed blog posts, opinion pieces, unverified preprints without institutional affiliation
Topical relevance	Road/pavement maintenance prioritisation, MCA/MCDA methodologies, RMMS/HDM-4, climate vulnerability in infrastructure, rural/low-volume road asset management	Sources with no substantive connection to maintenance prioritisation or decision-support methodology
Geographic scope	Global — with priority given to East Africa and comparator MCDA-implementing countries (Indonesia, China, Ethiopia, Poland, India, Nigeria, US, Australia's, South Africa, Taiwan)	None (no geographic exclusion; comparators selected for MCDA relevance)
Publication date	Primary emphasis 2013–2026, with foundational/methodological sources pre-2013 retained where directly cited (e.g., Kerali & Mannisto, 1999; Šelih *et al.,* 2008)	Superseded/outdated sources where a more recent equivalent was available and cited instead
Methodological transparency	Sources reporting a defined method, dataset, or decision-support framework	Sources lacking any stated methodology or data basis for their claims

Figure 2
PRISMA 2020 Flow Diagram



These sources provided updated insights into RMMS structure, data flows, MCA modelling, HDM-4 integration, institutional challenges, and rural applications, extending beyond the pre-2010 limitations noted in earlier frameworks (Chen and Lin, 2013; Mwaipungu and Allopi, 2014). An inductive content analysis was then applied to the selected sources. This open coding identified key concepts related to RMMS stages (e.g., pre-survey preparation, data collection, analysis, decision-making, implementation, and monitoring); prioritisation logic (e.g., MCA weighting and scoring); effectiveness metrics (e.g., backlog reduction, rural equity); success factors (e.g., data integration, capacity building); barriers (e.g., funding shortfalls, data inaccuracies); and optimisation strategies (e.g., fuzzy enhancements, GIS upgrades) (TANROADS, 2017). Through axial coding, higher-level patterns were synthesised into a hierarchical structure, mapping literature findings directly onto the RMMS framework. This process facilitated a literature-grounded evaluation of the research questions, ensuring that assessments of effectiveness, factors/barriers, and optimisations were traceable to empirical evidence.

4.0 Results and Discussion

4.1 Overview of Key Findings

In the initial stages of this review, three specific research questions were formulated to guide the identification of decision criteria for the sustainable prioritisation of road maintenance using Multi-Criteria Analysis (MCA) within the Road Maintenance Management System (RMMS) at TANROADS. These questions focused on the effectiveness of current systems, the critical success factors and barriers in RMMS implementation in the Tanzanian regional context, and potential optimisations to improve maintenance prioritisation, particularly for low-volume regional roads.

The conceptual framework shown in Figure 1 was developed through a systematic literature review conducted across multiple electronic databases and academic journals. A total of 70 publications were initially retrieved from various global academic sources and institutional repositories. After screening by title, abstract, and full-text evaluation, 60 papers were selected for in-depth inductive content analysis. This process enabled the synthesis and hierarchical structuring of the key decision criteria and sub-criteria that form the foundation of the framework. The results for each method, including its application outcomes and associated challenges, are summarised in Table 3.

4.2 Limitations of the RMMS Decision Framework

The literature reveals that while the Road Maintenance Management System (RMMS) provides a structured, multi-criteria framework for road maintenance prioritisation at TANROADS, its effectiveness remains moderate to low in practice. Below is a structured overview of the six major limitations identified, with a comparison to how similar MCDA-based systems perform in other countries.

Analysis shows that the system has a persistent traffic-centric bias in prioritisation. Despite the seven-factor MCA model, traffic volume and economic criteria (weighted at 40%) dominate scoring. Low-traffic rural roads which serve critical agricultural, social, and poverty-reduction functions consistently receive low priority, leading to chronic backlogs and inequitable access. In Indonesia, the AHP-GIS + REGIME model focuses on traffic-heavy areas but integrates road function and rural equity, allowing for better prioritisation of feeder roads. In Australia, MCDA with optimisation hybrids performs the weighting of social equity and rural connectivity, reducing traffic bias in vast rural networks. In the United States, MCDA + LCA incorporates community benefits and equity criteria, leading to more balanced outcomes than pure traffic-based systems.

Table 2
Distribution of Reviewed Sources by Theme

Theme	No. of Sources	Illustrative Sources
Rmms Process/Stages	12	TANROADS (2017); Chamorro & Tighe (2019); Setiaputri *et al.* (2021); Shrestha *et al.* (2014); Dobson *et al.* (2014); Huang *et al.* (2024)
Prioritisation Logic (Mca Weighting/Scoring)	18	TANROADS (2017); Šelih *et al.* (2008); Nugraha *et al.* (2025); Sayadinia & Beheshtinia (2021); Chaipetch *et al.* (2025); Hasan & Jaber (2024); Farhan & Fwa (2013); Yamany *et al.* (2025)
Effectiveness Metrics	8	Kindole *et al.* (2025); Mombia *et al.* (2024); Chamorro & Tighe (2019); Ngene *et al.* (2021); Beukes *et al.* (2011); Lungu (2023)
Success Factors	7	Kerali & Mannisto (1999); Rifai *et al.* (2018); Ayeni *et al.* (2026); VU & Mathew (2025); Shrestha *et al.* (2025); Kolkos (2025)
Implementation Barriers	9	NAOT (2024); Mwaipungu & Allopi (2014); Kindole *et al.* (2025); Chan *et al.* (2018); Ubong & Otobobg (2025); Buburanda *et al.* (2023); Ndebele & Benhura (2023)
Optimisation Strategies	6	Hasan & Jaber (2024); Madushani *et al.* (2024); Nugraha *et al.* (2025); Ayeni *et al.* (2026); Yamany *et al.* (2025); Rifai *et al.* (2018)

Table 4 synthesises the preceding comparative analysis into a single consolidated framework. It maps the fourteen prioritisation criteria observed across the international MCDA systems reviewed in Table 3 (economic, social, connectivity, population, productivity, GIS, environmental, safety, technical/pavement condition, cost/budget constraints, risk mitigation, accessibility, operational efficiency, and institutional/political factors) against their current treatment within TANROADS' RMMS and their proposed treatment under the "Future RMMS" recommendations. This side-by-side structure makes explicit which criteria RMMS already addresses at parity with international practice (e.g., economic, social, connectivity, population, and productivity); which it addresses only partially or informally (e.g., GIS, environmental, technical/pavement condition, and institutional/political factors); and which it omits entirely (e.g., safety, risk mitigation, accessibility, and operational efficiency)—providing the criterion-level basis for the recalibration recommendations that follow.

Table 3
Comparative Analysis of MCDA-Based Road Maintenance Prioritisation Systems

Country	Method	Criteria	Application Outcomes	Challenge	Literature (Authors)
Indonesia	AHP-GIS, REGIME	Pavement condition, traffic volume, road function, economic impact, environmental factors.	Prioritized periodic maintenance programmes, equitable allocation	Rural Indonesia faces chronic data gaps. Poor or incomplete data propagates errors into spatial prioritisation, potentially misdirecting maintenance funds.	(Nugraha *et al.*, 2025; Pradjoko *et al.*, 2018)
China	AHP-TOPSIS, GIS-AHP	Pavement condition, maintenance costs, traffic volume, safety, environmental impact.	Ranked preventive strategies, recommended new rail lines	The multi-step process (AHP weights TOPSIS ranking GIS visualisation). Results may appear overly technical, reducing trust and adoption, especially when rankings conflict with political or local priorities.	(Sayadinia and Beheshtinia, 2021; Liu *et al.,* 2024)
Ethiopia	Fuzzy AHP + TOPSIS (or AHP-based MCDA	Pavement condition, traffic load, safety hazards, economic benefits, environmental impact, budget availability, political priority.	Ranked highway rehabilitation and rural road maintenance projects; supported national road fund allocation decisions	Political and institutional interference in ranking; limited technical capacities for fuzzy modelling; incomplete traffic and condition data in rural regions.	(Ayalew *et al.,* 2022; Mitikie *et al.,* 2026)
Poland	AHP, TOPSIS, DEMATEL, PROMETHEE, ELECTRE	Environmental impact, economic viability, safety, land use, and social acceptance.	Selected environmentally favourable routes.	The complexity, time, cost, and communication barriers. Agencies adopt simplified subsets (e.g., AHP + TOPSIS or PROMETHEE alone) or use commercial software with pre-configured templates to reduce the burden.	(Nugraha *et al.,* 2025; Sayadinia and Beheshtinia, 2021; Subbarao *et al.,* 2020)
India	Fuzzy MCDM, AHP AHP	Implementation barriers, operational efficiency, safety, accessibility, and environmental sustainability.	Identified challenges and ranked strategies for BRT systems.	Fuzzy MCDM + AHP well-suited to handling uncertainties and sustainability criteria in complex, multi-stakeholder environments like BRT.	(Mavi *et al.,* 2018; Sayadinia and Beheshtinia, 2021)
Nigeria	GIS-MCDA (AHP-based) + Weighted Overlay	Road condition index, traffic volume, accessibility to settlements, agricultural connectivity, flood/erosion risk, cost of intervention.	Prioritized rural feeder road upgrading and maintenance.	Severe data scarcity and poor road inventory in rural areas, inconsistent local government participation and funding gaps	(Adebimpe and Usman, 2022; Agunbiade, 2024; Muodum, 2022)

Country	Method	Criteria	Application Outcomes	Challenge	Literature (Authors)
United States	MCDA with life-cycle assessment	Cost, safety, environmental impact, community benefits, resilience to climate change, funding availability	Ranked projects for maintenance amid uncertainties.	Standard LCA is static and struggles with dynamic factors like evolving climate risks and changing traffic patterns. Integrating real-time big data (e.g., from sensors, connected vehicles) into LCA+MCDA remains rare	(Valle *et al.,* 2017; Yamany *et al.,* 2025)
Australia	MCDA with optimization hybrids	Economic returns, social equity, environmental protection, risk mitigation, strategic alignment.	Ranked road projects supporting resilient infrastructure	Vast rural networks, climate extremes	(Chan *et al.,* 2018; Sankargupta *et al.,* 2026)
South Africa	MCDA + GIS + Weighted Scoring	Pavement condition (IRI, PCI), traffic volume, safety risks, socio-economic impact, environmental sensitivity, budget constraints	Prioritized rehabilitation and maintenance programs for provincial and municipal roads, improved equity in low-income areas	Limited data availability in rural provinces, high cost of GIS implementation, political influence on final rankings	(Beukes *et al.,* 2011; Ngene *et al.,* 2021)
Taiwan	Hybrid AHP with fuzzy logic	Implementation, sustainability	Sustainability-focused prioritization for urban roads	Heavy computation, expert dependency, rank reversal risk, and difficulty scaling to large, low-data environments	(Li *et al.,* 2020)

The findings reveal that the RMMS does not adequately factor in the integration of climate and environmental risks (erosion, flooding, and landslides) or environmental resilience. Maintenance remains largely reactive, accelerating deterioration in regions such as Mbeya (Kindole *et al.,* 2025). Australia's MCDA with optimisation hybrids (Chan *et al.,* 2018) has strong integration of climate extremes, and risk mitigation is significantly more advanced than RMMS. In the United States, MCDA + LCA (Valle *et al.,* 2017) includes resilience to climate change and life-cycle environmental impacts. It heavily weighs environmental impact and land use, which leads to more climate-sensitive and informed decisions. In South Africa, it incorporates environmental and climate risks in provincial road prioritisation (Ngene *et al.,* 2021).

Findings reveal that frequent surveys are rare, manual data entry errors are common, GIS integration is limited, and rural unpaved roads have poor data coverage (Ndebele and Benhura, 2023). This compromises condition indexing, MCA scoring, and overall reliability. In Indonesia, AHP-GIS + REGIME faces similar chronic data scarcity in rural areas, leading to errors in spatial prioritisation (Nugraha *et al.,* 2025). In the United States, MCDA + LCA uses big data integration and sensor networks but still faces coordination challenges between federal and state levels. In Taiwan, the hybrid AHP with fuzzy logic uses fuzzy logic to better handle data uncertainties. South Africa benefits from better GIS coverage in urban/provincial areas (Li *et al.,* 2020).

Documented institutional constraints include capacity and training gaps in asset-management tool use, procurement delays, and weak inter-agency coordination (Kindole *et al.,* 2025; NAOT, 2025). India’s Fuzzy MCDM + AHP struggles with diverse regional needs and varying institutional capacity across states (Sayadinia and Beheshtinia, 2021), like Tanzania’s decentralisation challenges. The United States has strong federal-state coordination mechanisms, though it still experiences fragmentation. In Ethiopia, Fuzzy AHP offers limited technical capacity for advanced modelling and institutional interference constraints (Mitikie *et al.,* 2026). RMMS faces capacity constraints comparable to India but is less mature than systems in Poland and South Africa.

Funding gaps and partial actual disbursements from the Roads Fund Board are often partial (around 47% in audited periods), forcing reactive maintenance and undermining the system's credibility (NAOT, 2024). In Iraq, Fuzzy BWM-VIKOR also faces severe funding and political interference issues (Hasan and Jaber, 2024), like Mbeya. Australia's MCDA with optimisation hybrids has better funding stability and strategic alignment, allowing more consistent implementation.

The findings reveal that RMMS was designed primarily for trunk and regional paved roads. Its MCA weights and HDM-4 models are inadequately calibrated for the low-volume unpaved roads that make up much of Tanzania's regional network, lacking dynamic adjustment for rural equity, climate risk, or gravel roads. In Australia, MCDA with optimisation hybrids specifically designed for vast rural networks and climate extremes are far more adaptable than RMMS (Sankargupta *et al.,* 2026). Indonesia (AHP-GIS + REGIME) has spatial scalability for rural roads through GIS integration (Nugraha *et al.,* 2025; Wahyuni *et al.,* 2022). Taiwan Hybrid AHP with fuzzy logic is strong in urban settings but struggles with scalability in low-data rural environments. India (Fuzzy MCDM + AHP) and Nigeria GIS – MCDA + Weighted Overlay (Adebimpe and Usman, 2022) were designed for rural feeder roads, offering better adaptability than RMMS for low-volume contexts.

Road maintenance with RMMS+MCA in TANROADS shows weaker region adaptability and scalability. The TANROADS RMMS+MCA performs moderately on high-traffic corridors but reveals systemic weaknesses when compared to international MCDA-based systems (Figure 1 and Table 3). It is particularly limited in rural equity, climate integration, data quality, institutional capacity, funding reliability, and adaptability to low-volume road challenges shared with Indonesia, China, and Iraq but better addressed in Australia, the United States, and Poland. Table 3 of the findings points out the importance of targeted reforms such as recalibrating MCA weights for regional and climate criteria, improving data systems, strengthening regional capacity, ensuring full funding disbursement, and adopting hybrid models (e.g., fuzzy AHP, GIS integration) to make RMMS more effective for Tanzanian regions such as Mbeya.

Table 4

Framework for the Effectiveness of RMMS Global vs Tanzania RMMS

Process / Criteria	Global Road Maintenance Systems (Selected Countries)	Tanzania (RMMS)	Future Tanzania (RMMS)
Economic	Included (China, Australia, Ethiopia)	Economic	Economic
Social	Included (Poland, India, South Africa)	Social	Social
Connectivity	Included (Indonesia, Nigeria)	Connectivity	Connectivity
Population	Included (Indonesia, India, South Africa)	Population	Population
Productivity	Included (Australia, Ethiopia)	Productivity	Productivity
GIS	Included (Indonesia, China, South Africa, and Nigeria)	Inventory (limited GIS)	GIS (full integration)
Environmental	Included (Poland, Australia, Taiwan)	Not adequately integrated	Environmental (fully integrated)
Safety	Included (China, Poland, India, South Africa, Ethiopia)	Not included	Safety (integrated as a core criterion)
Technical/ Pavement Condition	Included (China, Ethiopia, South Africa, Nigeria)	Condition surveys (limited weighting)	Technical / Pavement Condition (strong weighting)
Cost/Budget Constraints	Included (China, Australia, Ethiopia, South Africa)	Economic factor (40%)	Cost / Budget Constraints (balanced weighting)
Risk Mitigation	Included (Australia, South Africa)	Not included	Risk mitigation (climate + operational risks)
Accessibility	Included (India)	Not included	Accessibility (integrated)
Operational Efficiency	Included (India)	Not included	Operational Efficiency (integrated)
Institutional/ Political Factors	Included (Ethiopia, South Africa)	Political influence (informal)	Institutional / Political Factors (transparent weighting)
Output	Prioritised / aided prioritised decision (various MCDA methods)	Prioritized	Prioritised on an aided, prioritised decision (enhanced MCA)

5.0 Conclusion and Recommendations

This systematic review evaluated the design and documented the performance of RMMS in prioritising road maintenance at TANROADS. The TANROADS RMMS is located within three theoretical traditions: a simplified, single-period derivative of HDM-4's life-cycle economic logic; a Simple Additive Weighting (SAW) model whose criterion weights are fixed at the manual level rather than derived through pairwise elicitation, in contrast to the AHP/TOPSIS/ELECTRE systems reviewed in Table 3; and an asset-management orientation that substantially addresses ISO 55000's Value and Alignment elements but lacks a corresponding Assurance mechanism. The six limitations identified below, and the recommendations proposed to address them, follow directly from these three structural roots rather than constituting independent operational findings.

There is a persistent traffic-centric bias in prioritisation that undervalues the socio-economic importance of low-traffic rural areas, which has direct consequences for the SAW model's fixed, non-elicited economic weight identified in Section 2.2.

Inadequate integration of climate and environmental risks, leaving maintenance reactive rather than preventive in highland environments, is a structural consequence of RMMS's single-period HDM-4 derivative, which inherited HDM-4's economic logic without its temporal or risk-adjustment machinery.

Data quality, timeliness, and coverage deficiencies, especially on rural unpaved roads, reflect the absence of an ISO 55000 Assurance mechanism, since no audit, sensitivity testing, or continual-improvement loop is built into the MCA scoring process.

Institutional and operational capacity constraints, including staff shortages, turnover, and limited training, are the same assurance gaps manifesting at the organisational rather than data level.

Funding shortfalls and partial disbursements undermine planned priorities — an implementation-environment constraint external to RMMS's MCDA structure itself, rather than a design flaw in the framework.

Limited scalability and adaptability for rural contexts, with MCA weights and HDM-4 models poorly calibrated for regional roads — combining both the fixed-weighting and risk-adjustment gaps identified above.

To address the identified limitations and enhance RMMS effectiveness in regional contexts like the Mbeya Region, the following actionable recommendations are proposed.

Recalibrate MCA weights for rural equity and climate resilience. Conduct a participatory review (involving regional engineers, local governments, and rural stakeholders) to increase weights for populations served, production centres, social services, and climate vulnerability factors.

Strengthen data collection, quality, and coverage. Adopt low-cost digital tools (e.g., smartphones). Fully integrate GIS validation and real-time data linkage with Road Mentor to reduce errors and improve coverage.

Ensure full funding disbursement and alignment in advocating for ring-fenced rural funding streams within the Roads Fund Board and improve integration between RMMS planning and EPICOR financial execution to minimise partial disbursements.

Adopt hybrid MCDA models for regional adaptability. Pilot fuzzy-AHP or GIS-augmented prioritisation models to better handle uncertainty, data scarcity, and rural-specific criteria (e.g., gravel road behaviour and climate extremes). Explore integration with emerging tools (e.g., machine learning for deterioration prediction) to enhance accuracy.

Establish continuous monitoring and feedback mechanisms. Introduce post-implementation audits and stakeholder feedback loops to regularly evaluate RMMS outcomes against actual rural access and condition improvements. Use findings to dynamically refine MCA weights, survey protocols, and policy guidelines. Pilot implementation in a single region (e.g., Mbeya) would allow controlled evaluation before national rollout. These recommendations can transform RMMS into a more equitable, climate-responsive, and operationally robust system. Such reforms would reduce long-term costs and backlogs and enhance regional connectivity, economic productivity, and resilience, contributing meaningfully to Tanzania's sustainable development goals. Future research should validate these proposed enhancements through pilot testing, longitudinal impact assessment, and stakeholder-inclusive refinement in Mbeya and other regions.

This review is based entirely on secondary sources. Conclusions about RMMS's operational performance therefore reflect what is documented in audit reports, technical manuals, and peer-reviewed literature, not direct observation of regional practice. Claims regarding institutional capacity and data quality could not be verified against RMMS output data, which is not publicly available. Empirical validation through interviews with regional engineers and analysis of actual MCA scoring records remains necessary and is proposed as the next stage of this work.

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8.0 Declaration of Conflicting Interests

The authors declare no conflict of interest.

9.0 References

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