A Critical Analysis of Factors Affecting Performance of Gravel Road Projects Maintenance Management Strategies in Tanzania

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ABSTRACT

Effective maintenance management strategies are essential for improving the performance of gravel road maintenance projects in Tanzania. However, many of these projects face challenges that compromise their economic viability, such as inadequate monitoring, poor assessment of maintenance needs and interventions, and failure to meet expected performance outcomes, often resulting in reduced user satisfaction. To address these issues, it is crucial to identify and evaluate the key factors influencing gravel road maintenance management strategies that significantly affect overall project performance. This study investigates these factors using Partial Least Squares Structural Equation Modelling (PLS-SEM). The analysis identified engaging environmental considerations and community needs (IM5) as the most critical factor, followed by maintaining proper road inventory records (IM2), both under the integrity management (IM) strategy, which emerged as the most influential maintenance management strategy. Furthermore, cost considerations were the most prominent hard performance measures, with key indicators including adequate fund allocation based on actual maintenance needs (C5) and accurate budget estimates based on road condition survey reports (C2). For soft performance measures, the social and relational dimension (R) had the greatest impact, driven by indicators such as overall user and stakeholder satisfaction (R3) and adherence to health and road safety measures (R2). In conclusion, this study offers valuable insights into the critical factors that enhance the performance of gravel road maintenance management strategies in Tanzania and other regions facing similar challenges. It is recommended that policymakers integrate these influential factors into maintenance management frameworks to achieve better outcomes in gravel road maintenance projects.

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1.0 Introduction

Given the various definitions of maintenance management strategies for gravel roads, this paper defines them as systematic processes and actions undertaken to preserve their functionality and condition (IR, 2019). The Low-Volume Roads Manual (2016) of the United Republic of Tanzania defines gravel roads (GR) as roads designed to accommodate low-volume traffic of typically less than 300 Average Annual Daily Traffic (AADT) and constructed to meet the social and economic needs of surrounding communities. Over the past seven years, the condition of gravel roads in Tanzania has shown gradual improvement, particularly in the proportion of roads classified as being in "good" condition. For example, an inventory and condition survey conducted in November 2017 reported that 21.94% of gravel roads were in good condition, 34.39% in fair condition, and 43.67% in poor condition. A follow-up survey in November 2024 indicated progress: 27.63% were in good condition, 37.73% in fair condition, and 34.64% in poor condition. Despite this positive trend, the data shows that over 65% of gravel roads remain in fair or poor condition. This highlights an urgent need for continued investment in road development and maintenance to establish a reliable and functional road network (Anon., 2024).

Although substantial investments have been made in the development and maintenance of gravel roads, several persistent challenges still continue to undermine their effectiveness. These include inadequate monitoring, poor assessment of maintenance management needs and proper intervention, and the difficulty of achieving desired performance outcomes, often resulting in low user satisfaction (NAOT, 2023). Both road authorities and users have reported only moderate satisfaction with gravel road project maintenance outcomes, a situation attributed to suboptimal maintenance management strategies (Mukasa, 2013). Nearly a decade later, the Controller and Auditor General's report for the financial year ending June 30, 2022, reiterated these concerns, identifying three major issues: delays in project completion, cost overruns, and substandard road quality (NAOT, 2022). Projects frequently exceed planned timelines, resulting in delayed public benefits; budgets are often surpassed; and road quality deteriorates prematurely due to flaws in design, construction, and maintenance management strategies (NAOT, 2023).

These issues are further exacerbated by the dynamic and evolving nature of gravel road maintenance requirements, combined with institutional and technical constraints. A critical shortage of effective maintenance management expertise persists, largely due to the incomplete implementation of institutional reforms, limited human resource development, and a lack of innovation in factors influencing the performance of maintenance management strategies. These management strategy shortcomings exist even before addressing core technical challenges, such as the selection of appropriate construction materials, the adoption of efficient construction methods, and the development of comprehensive decision-support systems (Mwaipungu *et al.,* 2012). This situation is especially concerning in the broader African context, where the sustainability of vast unpaved road networks is increasingly being questioned under current maintenance management practices and technological limitations. In Tanzania, the existing framework for planning, designing, and contracting gravel road maintenance projects has not been able to ensure long-term, safe, and reliable access to essential services (NAOT, 2023).

Addressing these systemic deficiencies requires a critical evaluation of key factors affecting maintenance management strategies, along with critical analysis of respective impacts on performance indicators in terms of time, cost, quality, social and relational aspects, and environmental concerns. Current practices are largely empirical and lack technical rigour and optimisation. Therefore, this study aims to critically explore factors affecting maintenance management strategies for gravel road maintenance project practices in Tanzania. A Partial Least Squares Structural Equation Modelling (PLS-SEM) approach was used to analyse the relationships between the factors affecting maintenance management strategies and key performance measures, and this is the first empirical study in Tanzania applying PLS-SEM, aiming to enhance gravel road projects' maintenance management practices.

1.1 Basic Characteristics of Gravel Roads

Gravel roads in developing countries typically accommodate low-volume traffic and primarily serve rural populations. As defined by Jones (2003), these roads are characterised by vehicles travelling directly on unpaved gravel surfaces. They consist of a layer of selected natural soil or gravel material, imported and constructed to meet specified standards, providing an adequate all-weather driving surface. The vertical and horizontal alignments are generally improved to meet desirable design standards. Maintenance of gravel roads is conducted regularly and systematically to ensure a higher level of service; however, road roughness can vary significantly over time, depending on the type and frequency of maintenance treatments applied (NITTR, 2009). According to the Tanzania Manual (2016), a typical gravel road structure consists of three primary layers: the road surface, the gravel layer, and the subgrade layer. The structural characteristics of unpaved roads, including earth tracks, earth roads, and gravel roads, are well documented in various design manuals. For gravel roads, specific grading requirements are recommended for the aggregate base course, along with the use of fine aggregates with sufficient cohesion for the wearing course. These specifications help minimise loose materials, reduce permeability, and improve compaction (Jahrem, 2001). Technical guidelines from the South African Department of Transportation recommend a soaked California Bearing Ratio (CBR) of 15% at 95%. Proctor compaction is adequate to provide a stable and trafficable surface for gravel roads. However, exceptions may occur in areas with poor surface drainage, where water ponding can compromise road performance. According to the Low-Volume Roads Manual (2016) of the United Republic of Tanzania, gravel roads should be constructed with an appropriate crossfall of 5–7% to facilitate effective surface drainage and prevent water accumulation on and around the road. The same manual highlights the critical importance of material selection, particularly for the wearing course. Using inappropriate materials can result in several performance issues, such as surface deformation, corrugation, slipperiness in wet conditions, rapid gravel loss, and excessive dust generation. To address these challenges, the manual specifies detailed material requirements aligned with the Tanzanian Pavement and Design Manuals and emphasises the necessity of achieving proper compaction at at least 95% of the maximum dry density (MDD). This level of compaction is essential to ensure a durable, stable, and trafficable gravel road surface.

1.2 Current Gravel Roads Maintenance Management Practices in Tanzania

Gravel roads, also referred to as unsurfaced, unsealed, unimproved, or unpaved roads, lack surface treatments such as cement, asphalt, or concrete. These roads typically comprise a load-bearing subbase and a gravel wearing course, both of which are crowned to create a crossfall for effective drainage into roadside ditches. The Annual Average Daily Traffic (AADT) is a key factor in determining the appropriate management approach for gravel roads (Tarimo *et al.,* 2017). Due to their low traffic volumes, usually less than 300 vehicles per day, gravel roads are not economically viable for surfacing. Nevertheless, they play a vital role in serving rural populations, supporting local businesses, and enabling recreational activities. Globally, gravel roads form a significant portion of road networks. In Tanzania, for example, over 75% of the national road network consists of gravel or earth roads (Anon., 2023).

The Tanzanian Pavement and Materials Design Manual (2000) recommends using gravel roads when AADT is below 300 vehicles per day (Tarimo *et al.,* 2017). Paving becomes economically justifiable when traffic volumes reach approximately more than 300 vehicles per day, considering factors such as road user costs (RUCs), environmental impacts from dust, and maintenance expenses (Clemmons *et al.,* 2011). Although many gravel roads have an AADT below 400, a considerable number exceed this threshold. According to updated AASHTO guidelines, roads with an AADT of 200 or fewer vehicles are classified as low-volume roads (AASHTO, 2019).

It can be recognised that common defects on gravel roads include dust, potholes, corrugation, rutting, inadequate drainage, gravel disintegration, loose surface material, and frost damage. The frequency and severity of these issues are influenced by factors such as traffic volume and composition, climate, and vehicle speeds (Alzubaidi *et al.,* 2002). A centralised road condition information system can significantly enhance real-time monitoring, enabling better maintenance planning and decision-making (Kans *et al.,* 2021). In practice, defects like dust and loose gravel are often assessed subjectively, whereas geometric features such as crossfall and road edges are evaluated using more objective criteria. Given the widespread occurrence of these defects, regular maintenance management is essential to restore gravel roads to an optimal condition, extending their service life and overall value. Maintenance planning for gravel roads aims to deliver a desired level of service by focusing on condition assessments, identifying priority roads, and implementing appropriate interventions. Notably, gravel road maintenance accounts for approximately 17% of the total road maintenance budget, which includes expenditures on paved roads, bridges, tunnels, and ferries (Alzubaidi, 2002). Typical maintenance management strategies for gravel roads include grading or reshaping, re-gravelling, dust control treatments, and vegetation management, often performed at least once per year.

Gravel road maintenance management strategies may include reactive (worst-first) maintenance, scheduled intervals, coordination benefits, and traffic minimisation. Grading or reshaping is a primary maintenance strategy that restores road geometry, improves drainage, and enhances ride comfort (Alfelor *et al.,* 1989). Indicators of road deterioration include surface roughness, gravel loss, rutting, and loose surface material. Problems such as improper camber, potholes, and corrugation can also be addressed through grading. Moisture is sometimes applied before these operations when the road is excessively dry (Tanzania Road Works Specifications, 2000). Moreover, vegetation trimming improves drainage, while aggregate recycling reduces environmental impact and lowers maintenance costs. Re-gravelling is required when gravel thickness falls below the specified minimum. Since gravel road strengthening and re-gravelling are high-cost interventions, timely and targeted maintenance is essential to delay these interventions as long as possible. Dust control can be achieved by maintaining optimal moisture levels through appropriate dust suppression methods.

Maintenance management of gravel roads typically involves multiple stakeholders. In Tanzania, road development and maintenance are managed by two main agencies: the Tanzania Rural and Urban Roads Agency (TARURA), responsible for district roads (including collector, feeder, and community roads), and the Tanzania National Roads Agency (TANROADS), which oversees regional and national trunk roads. Both agencies mainly rely on contractors for maintenance activities implementation. In this study, TARURA, a predominant affiliation, has been used as a case study for the development of the structural model applied to analyse the factors affecting the performance of gravel road projects' maintenance management strategies in Tanzania. It should be understood that effective planning requires considering the needs of all stakeholders; accurate condition forecasts allow road authorities to plan better, enable timely contractor maintenance interventions, and reduce costs for all parties involved. A stakeholder-based approach to management, as proposed by Campos *et al.* (2020), is therefore essential for clarifying stakeholder roles and addressing their specific needs within the gravel roads maintenance management framework. An optimised gravel road maintenance management model aims to balance road user and maintenance costs while encouraging timely maintenance interventions. Such a system supports investments in effective equipment, skilled labour, durable road structures, efficient drainage, and quality materials to minimise road defects (Oladele, 2014). One promising approach for a sustainable strategy for road maintenance is performance-based contracting, which has received increasing attention in recent years. Unlike traditional contracts that compensate based on work volume, performance-based contracts reward contractors for meeting predefined performance standards (Sultana *et al.,* 2012). These long-term contracts incentivise innovation, as contractors bear full responsibility for delivering services that meet agreed quality levels. Under this model, contractors handle the planning, design, and implementation of maintenance activities at a fixed price and with defined risk allocation. According to Sultana *et al.* (2012), such contracts have been successfully applied in both developed and developing countries, offering advantages over traditional procurement by promoting shared risk, ensuring quality, and increasing efficiency.

In Tanzania, current gravel road planning, design, and contracting practices reveal the need for more innovative, performance-orientated approaches. With gravel roads comprising over 75% of the national road network, prioritising factors for effective maintenance management strategies is essential to improving long-term service delivery.

1.3 Gravel Road Maintenance Management Strategies

Several studies have identified a range of factors that influence the performance of strategies for maintaining gravel roads. For instance, Mwaipungu *et al.* (2012) emphasised key determinants, such as traffic volume, climatic conditions, material quality, maintenance frequency, and the methods employed. These factors significantly impact gravel road projects' performance in terms of cost, quality, and timeliness, which ultimately affect the overall satisfaction of road users. A strong performance across these dimensions can enhance user satisfaction, address social and relational concerns, and contribute to environmental sustainability.

According to the TARURA Maintenance and Operational Guidelines Manual (2019), Road Works Specifications (2000), and the Annual Performance Agreement (APA, 2023), which outlines TARURA's operational plans, several critical pre-maintenance operations must be undertaken. These include investigations and surveys that form the foundation for developing maintenance management strategies for gravel road needs. Such strategies generate essential data on the current condition and historical performance of gravel roads, particularly in terms of surface quality and the road's capacity to meet the social and economic needs of the surrounding communities. Key pre-maintenance management strategies include conducting road inventories and condition surveys, as well as defining performance measures, as summarised in Table 1.

Table 1
Gravel Road Maintenance Management Strategies

Maintenance Operational Phase	Maintenance Management Strategies	Source
Road Inventory information	Carrying out road network inventory given the available network data	APA (2023)
Road Condition Survey	Determining road importance and maintenance needs to get available condition and prioritized list of roads for maintenance Determine elements required to perform maintenance activities Prepare road maintenance plan	APA (2023)
Management strategies	Matching maintenance works with resources Road maintenance tender and contract documents Road maintenance time schedules Monitoring and evaluation Contract administration	APA (2023)
Performance measures	Time-frame, cost, quality Safety, social and relational aspects Works certification Physical and financial progress follow up	APA (2023)

2.0 Materials and Methods

2.1 Factors Affecting Performance of Gravel Road Projects Maintenance Management Strategies

The primary objective of this study was to critically analyse factors affecting maintenance management strategies that significantly influence the performance of gravel road maintenance projects in Tanzania. The maintenance management strategy is conceptualised as a systematic process involving the planning, organising, and controlling of monitoring maintenance management interventions related to the upkeep of physical infrastructure, such as functioning gravel roads. This research employed a quantitative methodology, following a structured approach consisting of five main steps: (1) literature review, (2) Delphi study, (3) development and administration of structured questionnaires, (4) presentation of results and discussions, and (5) conclusions and recommendations drawn from the findings of the study. A similar methodological framework has been utilised in previous studies, such as Kavishe and Chileshe's (2019), with the exception of the Delphi study methodology. Data collection was conducted using structured, close-ended questionnaires designed to capture information on maintenance management strategies specific to gravel road maintenance projects. The questionnaires were divided into two sections: the first section collected demographic information from the respondents, while the second section sought their perceptions of gravel road projects' maintenance management strategies, as identified through the literature review and Delphi methodology. The effectiveness of these maintenance management strategies was evaluated using a 5-point Likert scale, where 1 = "Strongly Agree", 2 = "Agree", 3 = "Neutral", 4 = "Disagree", and 5 = "Strongly Disagree". These scaled factors were adopted due to their effective use in a similar study conducted by Ishaq *et al.*

(2021). To ensure a comprehensive and representative analysis, a total of 385 structured questionnaires representing the targeted total population were distributed to professionals engaged in gravel road construction and maintenance, including engineers, quantity surveyors, architects, environmental engineers, and civil technicians. The sample size was determined using Yamane's sampling procedure, as has been presented in Equation (1):

$$Sample\ size\ (n) = \frac{N}{(1+Ne)^2} \qquad (1)$$

Where 'n' is the corrected sample size or minimum number of required respondents, 'N' is the population size identified, and 'e' is the margin of error, which is the level of acceptance or precision. To ensure the strength of the research methodology, a two-stage questionnaire survey was conducted. The first stage involved a pilot study conducted in Dar es Salaam City, Tanzania. This is because conducting a pilot study is considered a best practice for evaluating the measurement instrument's validity before its implementation in the main study (Van *et al.,* 2010). The second stage comprised the main study conducted in regions and districts of mainland Tanzania, where the theoretical hypotheses were tested based on the findings from the pilot study. Initially, 40 questionnaires were distributed to professionals in the road sector operating under the Tanzania Rural and Urban Roads Agency TARURA in the Dar es Salaam Region of Tanzania. The purpose of the pilot study was to get feedback on the initial version of the questionnaires before formulating an improved one, which was used in the main survey. In this study, Delphi study procedures were employed with a panel of 10 experts from mainland Tanzania, comprising engineers and quantity surveyors whose task was used to generate and group maintenance management strategies and key performance indicators or measures. The procedure encompassed two stages: expert selection based on expertise and knowledge and generation of responses and feedback through rounds 1 and 2 in order to group gathered information into gravel road works maintenance management strategies and maintenance performance measures. These maintenance management strategies and performance measures were analysed as outlined in Tables 2 and 3 of the Delphi study. In this study and in light of strategies for managing gravel road maintenance, the Delphi study methodologies presented in Tables 2 and 3 were adopted and categorised into two phases, namely, the road inventory and condition survey phase and the road management phase for the identification of factors affecting maintenance management strategies pertaining to gravel roads.

The maintenance management strategies were further grouped into risk, integrity, and off-prism management phases. The risk management strategy concerns the identification of risk items by quantifying their impacts and taking actions to mitigate them. The off-prism management strategy is defined as the use of proactive methods for engaging external participants that can influence performances, while the integrity management strategy is categorised for ensuring checks and balances are in place to maintain outside pressures that can cause optimistic biases in gravel road projects' maintenance management (MsCready, 2007). The off-prism and integrity management strategies have high correlation values, as was demonstrated in a study by Kindole *et al.* (2024), which concluded that the two management strategies have high correlation value amongst others. Similarly, the key performance measures of gravel road maintenance were categorised into two phases, namely, the hard and soft performance phases, as asserted by Luvara *et al.* (2020).

Table 2
Maintenance Management Strategy for Gravel Roads Projects

Maintenance management (Phases)	CODE	Strategy's or factor
	RIC1	Gravel materials thickness on road surface
	RIC2	Rutting removal
	RIC3	Corrugation removal
	RIC4	Potholes removal
	RIC5	Stoniness removal
	RIC6	Gravel materials lost
	RIC7	Drain condition
	RIC8	Vegetation type (Open, medium, dense)

Maintenance management (Phases)	CODE	Strategy's or factor
Road Inventory and Condition Survey (RIC)	RIC9	Road signs conditions
	RIC10	Borrow pit gravel materials quality
	RIC11	Maintenance records (Costs and interventions)
	RIC12	Travel times between points
	RIC13	Extent of damage of drainage structures
	RIC14	Population served by the road
	RIC15	Access to economic centers
	RIC16	Access to social centers
	RIC17	Traffic class
	RIC18	Connectivity
	RIC19	Agricultural output of the area served
	RIC20	Prevalence condition level of the road
	RIC21	Political influence
	RIC22	Mobility
	RIC23	Maintenance cost
	RIC24	Change of land use
	RIC25	Rate of road deterioration
	RIC26	Vehicle operating costs
	RIC27	Societal riot
Risk Management (RM)	RM1	Change in material prices
	RM2	Change in the road's requirements of beneficiaries
	RM3	Corruption
	RM4	Limited construction materials
	RM5	Erroneous in cost estimation
	RM6	Lack of new information
	RM7	Absence of ties or good coordination
	RM8	Poor Project timing
	RM9	Contract conditions changes during implementation
	RM10	Delay of payments of raised payment certificates
	RM11	Use of low cost and non-standard materials
	RM12	Delay in issuing works certification
	RM13	Design changes
	RM14	Poor quality control
Off-Prism Management (OM)	OM1	Awareness of value increment techniques
	OM2	Introducing new management techniques
	OM3	Maintaining life cycle value
	OM4	Equitable allocation of risks
	OM5	Continuous learning from experience of past projects
	OM6	Socially responsible designs
	OM7	Continual quality of maintenance management system
	OM8	Regular training of technical staffs and communities involved in road sector
	OM9	Integrated follow up of maintenance plans by all key stakeholders
Integrity Management (IM)	IM1	Coordination of road condition survey activity and its reports
	IM2	Proper road inventory records
	IM3	Appropriate gravel roads maintenance prioritization
	IM4	Identifying road maintenance planning processes
	IM5	Engaging environmental considerations and community needs for gravel roads maintenance implementation
	IM6	Timely measurement and payment certification of works
	IM7	Reducing time for tendering procedures
	IM8	Facilitating works funding timeline

Table 3

Gravel Roads Maintenance Projects Performance Criteria

Performance Criteria	CODE	Key Performance measure
Cost (C)	C1	No addition works and variations
	C2	Accurate budgets estimate as per roads condition survey reports
	C3	No maintenance scope creep
	C4	No maintenance scope changes
	C5	Adequate funds allocation considering actual maintenance needs
Time (T)	T1	Minimum or no disputes for maintenance projects
	T2	Adequate timing of maintenance activities
	T3	Timely payments for works dully executed by clients
Quality (Q)	Q1	No hike in construction materials due to inflation
	Q2	Proper project planning and control
	Q3	Good risk management
	Q4	Quality and conditions of construction materials
Social and Relational (R)	R1	Overall, personal relationships among road maintenance members (employee-employee, Management employee relationships) are continually good
	R2	Overall achievement on adherence to health and safety measures on gravel roads

Performance Criteria	CODE	Key Performance measure
		projects well maintained
	R3	Overall satisfaction of road users and other stakeholders
Environmental (E)	E1	Overall achievement of influence by local communities on environmental improvement for gravel roads maintenance projects sites
	E2	Overall achievement of training programs on environmental issues related to gravel roads management
	E3	Overall achievement of completed gravel roads maintenance projects' sites being environmentally protected

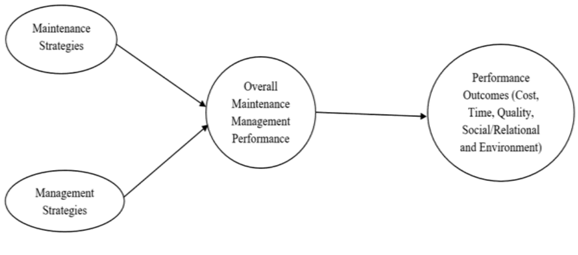
2.2 Structural Model for Ranking Factors Affecting Maintenance Management Strategies against Gravel Road Projects Key Performance Measures

The internal consistency of the data used in the structural model, measured in terms of validity and reliability, was evaluated using Cronbach's Alpha, Rho-A, Composite Reliability, and Average Variance Extracted (AVE), utilising the Smart-PLS software. Additionally, normality was assessed through the Kolmogorov-Smirnov and Shapiro-Wilk tests, while Pearson's chi-square tests were used to determine the correlation between variables related to maintenance management strategies and performance criteria, thereby illustrating the relationships between these variables. Given the complex nature of this study, which aims to analyse the relationship between maintenance management strategies and the performance of gravel roads (GR), Partial Least Squares Structural Equation Modelling (PLS-SEM) was adopted (Hair *et al.,* 2016). PLS-SEM was chosen for its capability to handle multiple independent and dependent variables simultaneously. Structural models using SEM are particularly useful in such cases, as they can accommodate a wide range of analytical complexities, including interaction effects, nonlinear relationships, multicollinearity among independent variables, measurement errors, correlated error terms, and the presence of multiple latent constructs, both independent and dependent, each measured by multiple observed indicators.

Unlike linear or multiple regression techniques, which are limited in their ability to analyse relationships involving latent and observed variables, particularly when nonlinearities are present, SEM offers a more comprehensive analytical framework (Oke *et al.,* 2015). Consequently, SEM enabled the study to describe and test relationships among several measurable endogenous and exogenous variables. In this study, factors affecting maintenance management strategies were treated as exogenous variables, while the maintenance performance criteria served as endogenous variables. As noted by Amaratunga *et al.* (2010)*,* SEM is a valuable tool for addressing measurement errors in variables, while Byrne (2010) characterised SEM as a robust non-experimental research technique. Moreover, Yuan *et al.* (2011) acknowledged SEM as a widely accepted and preferred method for data analysis.

Within the context of PLS-SEM, the measurement model defines the relationship between latent constructs (in this study, factors affecting performance of maintenance management strategies and performance criteria) and their observable indicators (Sarstedt *et al.*, 2014). Building upon these foundations, this study employed the PLS-SEM algorithm to assess the interrelations between factors affecting maintenance management strategies and gravel road maintenance performance metrics. This approach is particularly appropriate because PLS-SEM is designed to detect statistically significant causal relationships, supports theoretical model construction, and enables the exploration of relationships among research variables through a reflective measurement model. This research primarily investigates the factors affecting the performance of gravel road maintenance management strategies and overall performances, evaluated in terms of cost, quality, time, social and relational aspects, and environmental concerns. The study, therefore, is guided by the hypothesis that factors in line with maintenance management strategies have a direct impact on performance outcomes, as illustrated by the conceptualised framework shown in Figure 1.

Figure 1
Conceptual Framework



3.0 Results and Discussions

3.1.0 Analysis of the Structural Model Constructs and Maintenance Management Strategies

The analysis included four (4) constructs with factors representing maintenance management strategies and five (5) constructs representing key performance criteria, all linked through an overall performance construct. A total of 27 factors related to road inventory and condition surveys and 31 factors related to maintenance management strategies, namely risk, off-prism, and integrity management, were analysed. To build the model, both inner and outer model constructs were developed. The model was analysed using the Partial Least Squares (PLS) algorithm and bootstrapping techniques to evaluate the path coefficients and their significance levels, as defined by p-values. The statistical significance of each activity was determined based on indicator loading/outer loading values and corresponding p-values. Indicators with outer loading values below 0.7 and p-values greater than 0.02 were excluded from further analysis, as per the recommendations of Hair *et al.* (2016). Out of the 58 initially selected factors affecting maintenance management strategies, 40 (representing 68.96%) were excluded from further analysis due to indicator or outer loading values < 0.7 and p-values > 0.02. The remaining 18 were found to be statistically significant and were retained to form the model constructs related to gravel road maintenance management practices. These constructs were used to develop the relationship model depicted in Figure 2. For the key performance factors, only two items were excluded for the same reasons. Table 4 presents the structural model's path coefficients, indicating whether the hypothesised paths are statistically significant. Since all p-values in Table 7 are ≤ 0.02, all model constructs, including their associated strategies or indicators, are considered statistically significant and therefore acceptable for interpretation.

Table 4
Structural Model Constructs' Path Coefficients

Path Name	Original sample (O)	Sample Mean (M)	Standard Deviation(STDEV)	T Statistics (IO/STDEVI)	P-Values
OM->OMP	0.221	0.211	0.133	1.661	0.001
IM->OMP	0.465	0.468	0.130	3.568	0.000
RM->OMP	0.170	0.176	0.039	4.359	0.001
RIC->OMP	0.265	0.269	0.053	4.998	0.000
OMP->C	0.706	0.708	0.048	14.800	0.000
OMP->E	0.796	0.795	0.031	25.674	0.000
OMP->Q	0.669	0.674	0.048	13.916	0.000
OMP->R	0.846	0.844	0.026	32.514	0.000
OMP->T	0.586	0.592	0.064	9.171	0.000

3.1.1 Reliability and Validity Test

The internal consistency or reliability of the data was assessed using Cronbach's Alpha, Rho_A, Composite Reliability (CR), and Average Variance Extracted (AVE). According to Hair *et al.* (2016), the recommended threshold values are ≥ 0.70 for Cronbach's Alpha, Rho_A, and Composite Reliability, while the AVE should be ≥ 0.50. The results, as presented in Table 5, indicate that all constructs met or exceeded these thresholds, confirming their suitability for further analysis, except for the Cronbach's Alpha value of the cost construct, which was 0.004 below the required minimum. However, this slight deviation is considered negligible and unlikely to affect the overall reliability of the analysis.

Therefore, the results demonstrate that the validity and reliability tests were satisfactorily met, indicating that the research instrument (questionnaire) used for data collection is appropriate for analysis and for drawing meaningful conclusions.

Table 5
Reliability and Validity Test Result Summary

Constructs name	Item code	Rho-A	Cronbach's alpha	Composite reliability	AVE
Cost	C	0.714	0.696	0.814	0.521
Off-Prism Management	OM	0.984	0.983	0.986	0.884
Environment	E	0.979	0.978	0.984	0.938
Integrity Management	IM	0.985	0.984	0.986	0.899
Risk Management	RM	0.752	0.716	0.817	0.529
Road Inventory and Condition Survey	RIC	0.923	0.912	0.926	0.513
Quality	Q	0.762	0.759	0.847	0.581
Social and Relational	R	0.942	0.941	0.962	0.894
Time	T	0.794	0.791	0.878	0.707
Maintenance performance	MP	1.000	1	1	1
Acceptable value		**≥ 0.70**	**≥ 0.70**	**≥ 0.70**	**≥ 0.50**

3.1.2 Normality Test

To assess whether the data followed a normal distribution, normality tests were conducted using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Moreover, Pearson's Chi-Square test was employed to determine whether there was a significant relationship between variables. The results, presented in Table 6, indicate that the data were normally distributed, as the skewness and kurtosis values computed were within the acceptable range. Kurtosis measures the "peakedness" or "flatness" of the distribution, with values close to zero indicating a distribution shape similar to the normal curve. Skewness, on the other hand, measures the extent to which values deviate from symmetry around the mean.

In connection with the normality tests, Pearson's Chi-Square test was also used to examine the association between factors affecting maintenance management strategies and key performance outcomes. The test produced a Chi-Square value of 0.135, indicating a moderate positive relationship. This result provides a basis for further investigation into the hypothesised relationships between the studied variables.

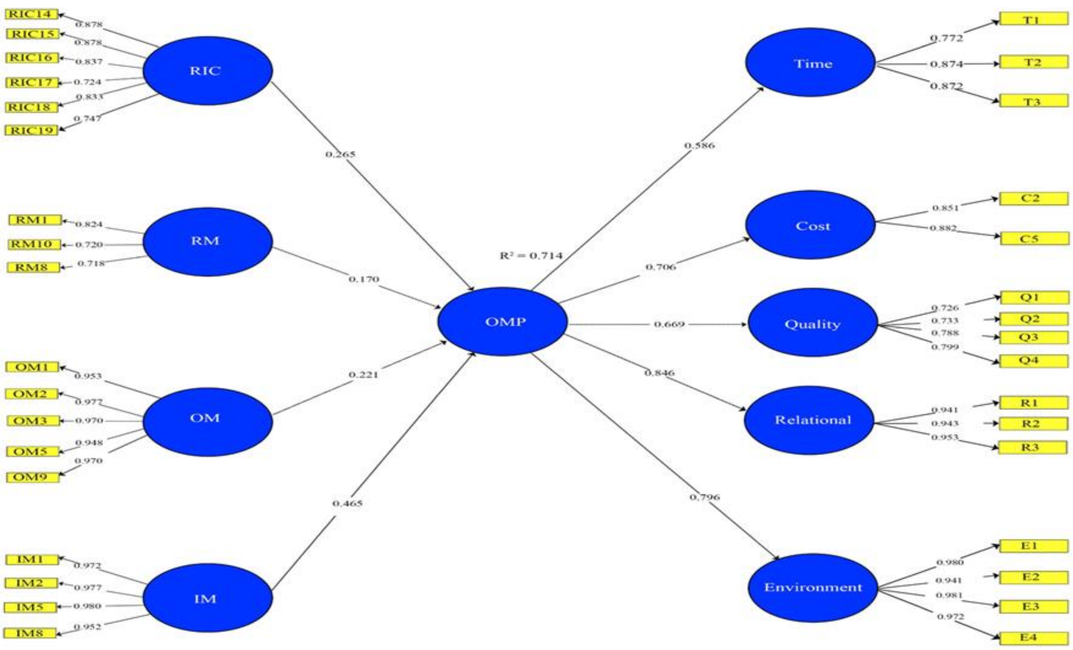
Table 6

Normality Test Result Summary for Measurement Items

	Kolmogorov-Smirnov			Shapiro-Wilk		
Measurement Item	Statistic	df	Sig.	Statistic	df	Sig.
Cost	0.072	213	0.000	0.963	213	0.000
Off-prism management	0.169	213	0.000	0.875	213	0.000
Environment	0.200	213	0.000	0.791	213	0.000
Integrity management	0.180	213	0.000	0.845	213	0.000
Risk management	0.080	213	0.000	0.976	213	0.000
Road inventory and condition survey	0.109	213	0.000	0.941	213	0.000
Maintenance performance	0.066	213	0.000	0.961	213	0.000
Quality	0.096	213	0.000	0.965	213	0.000
Social and relational	0.203	213	0.000	0.824	213	0.000
Time	0.172	213	0.000	0.919	213	0.000
Acceptable value			**<0.001**			**<0.001**

Figure 2

A Structural Model for Maintenance Management Strategies Path Coefficients



A detailed analysis of the structural model depicting the relationship between factors affecting maintenance management strategies with respect to influencing overall maintenance performance was conducted to confirm that the model is well-characterised and adequately explained by all the necessary requirements for assessing structural model fit in SmartPLS. This was essential to ensure that both quality and strength criteria were met. Accordingly, the analysis included an evaluation of indicator loadings, construct path coefficients, discriminant validity using the Fornell-Larcker criterion, and correlations assessed through the Heterotrait-Monotrait (HTMT) ratio. The model fit was tested using the Standardised Root Mean Square Residual (SRMR) and d_ULS for both the saturated and estimated models, along with evaluations of the model's predictive power and coefficient of determination (R^2).

The results presented in Table 10 for the HTMT test show that 91.67% of the model constructs exhibit HTMT values less than or equal to 0.85, which falls within the acceptable threshold according to Hair *et al. (2014).* Furthermore, the results of the Fornell-Larcker discriminant validity test, as presented in Table 11, indicate high correlations among several constructs. Notably, the constructs related to social and relational aspects and the integrity management strategy demonstrated a Fornell-Larcker value of 0.974, suggesting a strong relationship. This implies that social and relational factors can be effectively integrated with integrity management strategy practices factors, which focus on maintaining checks and balances and minimising external pressures in managing gravel road maintenance projects.

These findings are further supported by the path coefficient values of the constructs. As presented in Figure 2, the Integrity Management Strategy (IM) emerged as the most influential construct, with a path coefficient value of 0.465, followed by Road Inventory and Condition Management (RIC) with a coefficient value of 0.265. Risk Management (RM) and Off-Prism Management (OM) strategies, with coefficient values of 0.221 and 0.170, respectively. The SmartPLS analysis further explains the degree of influence among latent variables and the percentage of variance explained. The coefficient of determination (R^2) results, summarised in Table 9, indicate that factors concerning maintenance management strategies significantly impact the overall performance of gravel road maintenance projects. The adjusted R^2 value for overall gravel road maintenance performance is 0.71 (or 71%), which is considered strong, as Hair *et al.* (2014) suggest that R^2 values above 0.2 are acceptable.

Further model fit assessment, shown in Table 7, evaluated the SRMR and d_ULS values. The results indicate that the model's goodness-of-fit lies within acceptable ranges. Specifically, the SRMR value for the estimated model is 0.192, and for the saturated model, it is 0.159. Although the SRMR values exceed the preferred threshold of 0.08, they may still be considered acceptable depending on the model complexity and context. A lower d_ULS value is preferred, and the values obtained suggest a reasonably good model fit.

Finally, in accordance with Hair *et al. (2014),* assessing the model's predictive relevance is essential. SmartPLS results showed a Q^2 value of 0.319 for overall gravel road project maintenance performance as a result of factors subjected to analysis. Since a Q^2 value greater than 0 indicates acceptable predictive relevance, the findings suggest that the independent constructs have significant predictive power over the dependent constructs.

Table 7
Structural Model Fit Test Result Summary

Fitness test	Saturated Model	Estimated Model
SRMR	0.159	0.192
d_ULS	34.915	50.725

Table 8
Maintenance Management Strategies Constructs Path Coefficients Values Rank

Construct name	RIC	RM	OM	IM
Path coefficient	0.265	0.170	0.221	0.465
Rank	2	4	3	1

Table 9
Coefficient of Determination (R^2) Results of the Structural Model

Construct name	Code	R^2	R^2 adjusted
Cost	C	0.498	0.496
Environment	E	0.634	0.633
Overall maintenance performance	OMP	0.714	0.710
Quality	Q	0.448	0.445
Relational	R	0.715	0.714
Time	T	0.344	0.341

Table 10
Heterotrait-Monotrait HTMT Ratio Values

	C	OM	E	IM	RM	RIC	Q	R
C								
OM	0.427							
E	0.311	0.919						
IM	0.386	0.788	0.778					
RM	0.603	0.227	0.153	0.208				
RIC	0.737	0.493	0.400	0.468	0.544			
Q	0.843	0.294	0.203	0.261	0.740	0.622		
R	0.409	0.797	1.008	0.615	0.217	0.489	0.272	
T	0.815	0.198	0.119	0.174	0.543	0.587	0.983	0.186

Table 11
Correlation of Latent Variables and Discriminant Validity (Fornell-Larker Values)

	C	OM	E	IM	RM	RIC	OMP	Q	R	T
C	0.867									
OM	0.348	0.964								
E	0.254	0.903	0.969							
IM	0.314	0.969	0.957	0.971						
RM	0.417	0.203	0.144	0.189	0.756					
RIC	0.577	0.470	0.386	0.447	0.436	0.818				
OMP	0.706	0.831	0.796	0.830	0.419	0.651				
Q	0.680	0.258	0.182	0.230	0.530	0.520	0.669	0.762		
R	0.327	0.959	0.968	0.974	0.194	0.459	0.846	0.235	0.946	
T	0.598	0.174	0.106	0.153	0.399	0.495	0.586	0.726	0.162	0.841

3.2 *Ranking Factors Affecting Maintenance Management Strategies against Key Performance Measures*

Maintenance management strategies, which encompass a series of activities including initiation, planning, execution, monitoring, and evaluation, have a positive and significant influence on improving the performance of gravel road maintenance projects. A range of maintenance management strategies with appropriate factors can be implemented to enhance the effectiveness of such projects in Tanzania. The structural model presented in Figure 2 illustrates a variety of individual strategies and factors/indicators along with their corresponding outer loading (influence contribution) values and path coefficients. Based on the analysis, Integrity Management (IM) strategy emerged as the most influential management phase, with a path coefficient value of 0.465. Within this phase, the factor IM5 (*engaging environmental considerations and community needs for gravel road maintenance implementation*) was identified as the most critical factor, with an outer loading value of 0.980, followed closely by factor IM2 (*proper road inventory record*), with an outer loading value of 0.977.

Among the performance measures, cost consideration had the highest influence under the SmartPLS assessment, with a path coefficient of 0.706. The most critical cost-related performance metric was C5 (*adequate funds allocation considering actual maintenance needs*), which had an outer loading value of 0.882, followed by C2 (accurate budget estimates as per road conditions survey reports) with an indicator loading value of 0.851, all representing the most impactful hard performance measure. For soft performance measures, the social and relational aspect ranked highest, with a path coefficient value of 0.846. The key performance metric measure identified under this construct was R3 (*overall satisfaction of road users and other stakeholders*), which emerged as the most critical soft performance indicator/strategy with an indicator loading value of 0.953, followed by R2 (overall achievement on adherence to health and road safety measures) with an indicator loading value of 0.943.

In summary, the structural model in Figure 2 can be used to rank critical factors affecting the performance of gravel road project maintenance management strategies based on their contribution to targeted performance measures. This allows practitioners to align specific factors and strategies with the performance outcomes they aim to achieve. For all management strategies assessed, as illustrated in Figure 2 and detailed in Table 12, the top-ranked factors for each independent model construct include IM5 (*Engaging environmental considerations and community needs for gravel road maintenance implementation*), RIC14 and RIC15 (*Population served by the road* and *Access to economic centres),* OM2 (*Introducing new management techniques*), and RM1 (*Change in material prices*). These strategies were identified as the most influential in driving improved key performance outcomes in gravel road maintenance projects.

Table 12
Ranking of the Top Ranked Maintenance Management Strategies for Each Independent Constructs

Model path name	Path coefficient values	Strategy code	Strategy outer loading value	Rank based on path coefficient value
IM5-IM-OMP	0.465	IM5	0.980	1
RIC14-RIC-OMP	0.265	RIC14	0.878	2
RIC15-RIC-OMP	0.265	RIC15	0.878	2
OM2-OM-OMP	0.221	OM2	0.977	3
RM1-RM-OMP	0.170	RM1	0.824	4

4.0 Conclusions and Recommendations

This study concludes that although a wide range of factors influence the performance of gravel road maintenance management strategies, only a subset of these factors has a significantly greater impact on performance outcomes. The most critical among them are the *engagement of environmental considerations and community needs* and the *maintenance of proper road inventory records*. These are closely linked to the most impactful performance metrics, including *adequate fund allocation based on actual maintenance needs*, *accurate budget estimates derived from road condition survey reports*, and the *satisfaction of road users and stakeholders*, as well as adherence to *health and road safety measures*. Other key strategies, ranging from project appraisal to implementation, can be strategically prioritised in alignment with these high-impact factors. The structural model used in this study highlights strong factor loading values, indicating the close alignment of these elements in achieving optimal performance outcomes. Moreover, the study emphasises that *adequate and well-targeted fund allocation* is essential for the effective implementation of these strategies, particularly in enhancing cost-related performance outcomes. Based on these findings, it is recommended that road sector policymakers integrate the identified influential factors into maintenance management frameworks. Doing so will support the development of a comprehensive and coherent implementation strategy that aligns with critical elements within contractual, regulatory, and institutional frameworks governing gravel road maintenance. These insights are not only relevant for Tanzania but also offer practical guidance for other regions facing similar gravel road maintenance challenges, thereby extending the applicability of the findings beyond the local context.

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6.0 Conflict of Interest

The author reports no potential conflict of interest.

7.0 Data Availability Statement

Reviewed documents utilised for analysis in this study are accessible from the corresponding author upon request.

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