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Investigating the cost of mechanized unpaved road maintenance operations in Uganda

Andrew Moses Obeti [a,*], Lawrence Muhwezi [b], John Muhumuza Kakitahi [a], Chris Bic Byaruhanga [a]

[a] *Department of Civil and Environmental Engineering, Kyambogo University, Kampala, Uganda*
[b] *Department of Civil Engineering, Kabale University, Kabale, Uganda*

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ABSTRACT

Force Account Mechanism (FAM) is the predominant road maintenance system in Uganda's local government setup and a similar, though slightly different approach, is used in some large private sector agriculture plantations. With the Uganda Road Fund (URF) 2021/2022 annual report and previous research citing challenges in cost management and efficiency of the FAM method of road maintenance, it becomes paramount to analyse how FAM is implemented in government-led operations, in comparison to similar private sector approaches, while proposing possible solutions to these challenges. This research offered to analyse unpaved road maintenance cost drivers alongside providing a cost model solution to improve on cost prediction of the FAM system. Gulu District Local Government (DLG) and Kakira Sugar Limited (KSL) were selected as case study areas. Two descriptive research methods were used: observations and case study approach. The selected case study areas were accessible and reachable in terms of data. Control parameters affecting unpaved mechanized road maintenance were identified as machine repair costs, tool costs, labour costs, material costs, fuel costs and machine fuel costs. Unpaved mechanized road maintenance costs at KSL and Gulu DLG were computed as a cost/km ratio of 26,442,032Ugx/km (6,958.4USD/km) and 32,674,895Ugx/km (8,598.65USD/km) respectively. The Uganda National Roads Authority (UNRA) unpaved road maintenance costs were calculated as an average of 34,987,122.9Ugx/km (9,165USD/km) while the World Bank ROCKS database provided a comparable figure of 7,971USD/km (30,553,440.83Ugx/km). A USD to Ugx conversion rate of 3,800 was used. Two linear regression cost models with a 0.679 and 0.687 R^2 value were computed, and these can be used in preliminary road maintenance cost prediction. The study recommends the need for an effective, digital road maintenance cost database system for mechanized unpaved road maintenance works, cost driver analytics and management, alongside improvement in aspects of maintenance processes at both the DLG and KSL. Further research can be conducted on equipment condition level prediction and analytics in the private sector and at the DLG.

Introduction

Infrastructure plays a key role in all three dimensions of sustainable development: the economy, the environment and society (impact.economist.com, 2019). Road access opens numerous opportunities to services (Jacoby, 2000) whereas high transportation costs due to poor infrastructure tends to constrain development (North, 1958; Krugman, 1991). Subsistence agricultural-based economies, with poor infrastructure usually experience high transportation costs, which further impede more productive sectors of the economy (Gollin and Rogerson, 2014). In Ethiopia, increased access to all-weather roads has greatly increased consumption and improved poverty alleviation rates (Dercon et al., 2009). On the contrary, it has been discovered that high transport costs to ports significantly reduce agricultural production (Limi et al., 2019).

The United Nations (2015) Sustainable Development Goal 9, aims to build resilient infrastructure, promote sustainable industrialization, and foster innovation, thus encompassing the issue of all-season road access, with the target to 'develop quality, reliable, sustainable and resilient infrastructure, including regional and *trans*-border infrastructure' (SDG-9.1) (United Nations, 2018). It is a fact that developing countries face transport connectivity challenges (Organisation and Economic Cooperation for Development-OECD, 2018). These transport deficiencies

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* Corresponding author.
E-mail address: andrew.obeti@wfp.org (A.M. Obeti).

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impact opportunities for economic growth, industrialization, and development in some African countries (OECD, 2018).

Teravaninthorn and Raballand, (2009) estimated that 70 % of Africa's rural population lives more than 2 km from an all-weather road and 14 % of the global population lives more than 2 km away from the nearest road network. The highest road access gaps were identified in sub-Saharan Africa and Southeast Asia. A massive capital investment of approximately USD 700 billion over the course of a decade, would ensure that at least 90 % of the population in every country has road access (Wenz et. al., 2020).

One of the main difficulties confronting developing countries, is satisfying the demand for new infrastructure that results from an increase in population, whilst sustaining and rehabilitating old infrastructure. Without proper maintenance, roads will deteriorate and eventually become unusable (George et al., 2019; Smith et al., 1993). A case in point is Uganda, where Community Access Roads (CAR) comprise approximately 79,947 km, corresponding to almost 50 % of the total road network in Uganda (MoWT, 2020p.4), and with Uganda's rural population comprising approximately 76 % of the country's overall population, this emphasizes the necessity to fix existential gaps in road maintenance strategies in Uganda, with attention on rural unpaved roads. Agriculture is one of Uganda's leading economic and income generating sectors, employing over 72 % of the population, with a greater number being women and youth, besides making a significant contribution of close to 23.5 % to Uganda's Gross Domestic Product (GDP) (MAAIF, 2018p.1).

Uganda's 2003 Public Procurement and Disposal of Public Assets Act 1, set up the Public Procurement and Disposal of Public Assets Authority (PPDA) as the principal regulatory body for public procurement and disposal (the PPDA Act, 2003). An amendment was then legislated in 2014 to make provision for Force Account Mechanism (FAM) as a method, among others, of implementing public works, including construction maintenance works by government entities. The Force Account Mechanism (FAM) generally refers to an organization or entity, internally contracting/carrying out its works, through their own personnel and equipment. It is sometimes referred to as "direct labour/work" or "departmental workforce" (Satyanarayana, 2012). Local government entities are mandated to implement infrastructure/road maintenance activities using the FAM method, while ensuring the use of the Ministry of Works and Transport (MoWT) and PPDA guidelines. FAM is majorly used in routine mechanized maintenance, periodic maintenance, and lastly, road resealing works.

An equipment inventory survey of eight UNRA stations (Gulu, Lira, Moroto, Fort Portal, Moyo, Masaka, Mbarara, and Luwero) revealed that none of the stations had two complete sets of the key equipment in good condition. Only 37 % of the sampled stations had at least one complete set of key equipment in good condition. Thus, the available equipment did not match the maintenance needs of the road network under their management. In addition, the equipment was associated with frequent mechanical break downs and high maintenance costs. This affected the timely and adequate execution of maintenance works (BMAU, 2017).

Gongera and Petts (2003), argued that the Force Account system does not fully reflect the full cost of road maintenance; as other expenses namely staff salaries, associated maintenance costs and equipment initial purchase costs are absorbed by government, thus making the true overall project cost arduous to ascertain.

Furthermore, contrasting with private firms that deliver prior to payment, financial allocations to force account endeavours are usually not output bound. Albeit efficiency can be improved upon through a reform regime. The private sector will, however, always outcompete the FAM system in efficiency (Stock and Jan de Veen, 1996). Considering this, the research sought to establish the parallels and synergies that government led Force Account Method of road maintenance, shares with similar commercial private sector led initiatives, and what lessons can be drawn from both approaches.

Problem statement

With the Uganda government's acquisition of close to 1,425 pieces of new road maintenance equipment, a policy shift was made in June 2012, from contracting to FAM system of road maintenance works in Local Governments (LGs) (Budget Monitoring and Accountability Unit – BMAU, 2015).

Material and machinery related factors were identified by Muhwezi et al., (2020) as one of the most key factors affecting cost performance of unpaved road maintenance works in Uganda and deduced that considerable interest be paid to the key drivers under each of these factors during planning and implementation of road maintenance budgets. The MoWT, (2020) annual sector performance report for financial year FY 2019/20 indicated an 88.5 % average availability, for the newly acquired Japanese road equipment fleet, attained against a target of 90 %. Also, 47 % average availability was attained for the fairly old Chinese equipment fleet, against a target of 60 %.

The Uganda Road Fund (URF) has consistently listed low number of equipment, poor site supervision, high machine failure and subsequent downtime, low staffing/labour alongside low staff capabilities, funding challenges, fraud, poor records keeping, and management as some of the key identified challenges affecting road maintenance operations in Uganda (URF, 2022).

Uganda currently has a total national road network of 21,200 km, of which 6,133 km (29 %) are paved roads and 15,067 km are unpaved roads (UNRA, 2023p. 9). Ugandan national roads carry an average daily traffic exceeding 80 % and are a strong driver for national social-economic development (BMAU, 2019p. 1). Roads have always been synonymous with economic growth (Jacoby, 2000) and considering that agriculture is still an employment avenue for close to 72 % of Uganda's population, with approximately 76 % of Uganda's populus based in rural areas, the need to maintain community access roads and unpaved roads is therefore critical. Establishing the cost drivers affecting unpaved road maintenance and the overall costs involved, therefore becomes paramount.

A focus on local private sector initiatives with similarities to the government led FAM system, was explored while also delving into a district local government (DLG) station as a case study, to generate comparative cost models suited for prediction of unpaved road maintenance costs. The focus of this research was to conduct a comprehensive cost analysis review with the aim of ascertaining cost drivers for unpaved road maintenance works, associated costs, and prediction modalities.

Research objectives

The main objective of this research was to investigate the cost of mechanized unpaved road maintenance operations in Uganda.

The following were the specific objectives of this research.

i. To establish the factors affecting the cost of mechanized unpaved road maintenance works.
ii. To determine the costs of mechanized unpaved road maintenance operations.
iii. Develop a deterministic linear regression model to predict the costs of mechanized unpaved road maintenance operations.

Geographical and time scope

The study was conducted in two case study locations Kakira Sugar Limited (KSL) located in Jinja (Eastern Uganda) and Gulu District Local Government (DLG) located in Northern Uganda. Kakira Sugar Limited (KSL) was selected due to its robust road maintenance programme and to offer a private sector led perspective into unpaved road maintenance operations. Gulu DLG was selected to offer a government led comparison to the research findings thus creating a cross-case analysis to improve research validity. Considering that the research mainly focusses on the "Force Account Mechanism" which has been implemented in districts for over a decade, the research interest was mainly on cost data from the district engineering department. The ease of access alongside availability of data played a major role in determining these locations. Data from the government roads agency, Uganda National Roads Authority (UNRA) and the World Bank ROCKS database were also selected for cost comparison purposes.

The research was carried out in a total duration of ten months, starting in the month of December 2021 till June 2022 for KSL and September to November 2023 for Gulu DLG. Other data sources were considered in the same period.

Literature review

Relevant data connected to unpaved road maintenance activities was considered including, equipment and cost aspects involved, research by previous scholars and any other relevant source materials.

Maintenance of roads in Uganda

Maintenance can be categorised into; routine, periodic and emergency maintenance depending on their interval of application, labour application, machinery selection, and defect types to be corrected. For instance, gravel loss is classified under periodic maintenance due to the associated activity of road resurfacing (ERA, 2002).

Rural Access Index (RAI) is used to measure the proportion of the rural population living within 2 km of an all-season road. Uganda currently stands at a RAI of 53.1 (World Bank, 2022). As shown in previous studies, poor infrastructure does impact on the overall cost of living (Mukiibi, 2012). This is attributable to several interrelated reasons including but not limited to low road maintenance budgets, government preference for new construction over maintenance, a weak maintenance culture, weak institutional systems, ineffective rural road asset management systems and poor road maintenance policies (Burrow, et al., 2016).

With the Uganda government's policy change to use FAM as a road maintenance system, financial allocations have been made to that effect. An example is in the financial year FY 2020/21, where approximately UGX 172.154 billion (45 million USD) was allocated towards district, urban and community (DUCAR) access roads which constitute approximately 30 % of the total road maintenance budget (URF, 2022).

With FAM being implemented using the guidelines provided by the Ministry of Works and Transport (MoWT) and PPDA (Public Procurement and Disposal of Public Assets) authority, Local governments (LGs) are mandated to carryout road maintenance works primarily using Force Account Method (FAM).

Construction contracting processes have often been faulted for having long lead times, and financially costly to the end users, dependent on the nature of procurement (Valdovinos and Lorick, 2013). According to existing literature, FAM was introduced to alleviate such obstacles. The FAM system generally works more efficiently when there is equipment available, materials, labour, and proper supervision within the client organization. According to Gongera and Petts (2003), FAM tends to conceal certain cost drivers since cost expenses like salaries, infrastructure maintenance and initial cost of equipment acquisition are catered for by the end-user entity/government. Other associated cost elements like initial equipment financing and taxation alongside project overheads are masked and hence the true total cost over an implementation period is arduous to ascertain, though achievable.

Regarding risk, FAM has been cited as exposing the client organisation to the greatest degree of risk, since it cannot transfer risk to another entity (Satyanarayana, 2012). Other critical areas include FAM inefficiencies due to financial indiscipline (not profit driven) and the existence of supplementary budget allocations which leads to cost overruns unlike in private firms that are profit oriented, with rigid budget constraints. The output-before-payment nature of private firms also differentiates it from the government led FAM system. With increasing policy reform, FAM can however improve on its efficiency but is unlikely to attain private sector efficiency levels run on the contracting approach (Stock and Jan de Veen, 1996).

Road maintenance challenges in Uganda

According to Petts (2013), the cost range for road network maintenance in developing countries should range from 0.2 to more than 1 % of the GDP, while the total road sector budget should range from 3 to 5 % GDP. Gravel roads usually quickly deteriorate in the absence of any maintenance works and this in turn affects the Vehicle Operating Cost (VOC) of equipment using that road (Mbabazi, 2019).

Muhwezi et al., (2021) identified insufficient funding, delayed financial releases, and inadequate equipment as some of the factors that hinder effective rural road networks management. Mbabazi et al., (2020) also identified lack of predictable funding for maintenance, as the biggest challenge facing local authorities in the establishment of sustainable road asset management.

Byaruhanga et al., (2017) identified inadequate financial resource allocations as one of the reasons for slow service delivery at UNRA. A five-year study by Cross-Roads Secretariat, a donor funded roads initiative, also identified poor equipment usage, maintenance, and inefficient operation as one of the challenges facing the roads sector in Uganda (Booth et al., 2015).

In 2008, the Uganda Road Fund (URF) was established by an Act of Parliament to finance routine and periodic maintenance of public roads in Uganda with the objective of ensuring that public roads are always maintained through provision of adequate and stable financing for routine and periodic road maintenance undertaken by Designated Agencies (DAs). The planned main source of funding was road user charges, and the URF system became operational in January 2010. According to the URF 2021/22 annual performance report, the public roads network was being managed by 177 Designated Agencies (DAs). The DA's and sub-agencies collectively looked after a total of 107,020 km of public roads made up of 21,020 km of national roads under UNRA management; 2,103 km of Kampala Capital City Authority (KCCA) roads; 30,000 km of district roads; 8,500 km of urban roads managed by town councils; 4,500 km of urban roads managed by Cities and Municipal Councils; and 42,250 km of Community Access Roads (CARs) managed by sub-counties (URF, 2022).

The Uganda Road Fund (URF) annual report for financial year 2021/22 also highlighted inadequate road maintenance funding as one of the key reasons for deferment of scheduled maintenance, especially periodic maintenance, referencing that only 24 % of the required funding was received.

Low number of equipment, poor site supervision, high machine failure and subsequent downtime, low staffing/labour alongside low staff capabilities, funding challenges, fraud, poor records keeping, and management were key identified challenges faced during road maintenance operations in Uganda.

Factors affecting efficiency of road construction and maintenance projects

Existing literature indicates that various research works have been undertaken to identify factors that affect the efficiency of construction projects. Shobana and Ambika, (2016) identified poor communication/coordination, insufficient labour, material shortages, material pipeline breaks, poor site inspections, skill deficiencies, project financing challenges as some of the factors affecting the operation and maintenance costs of construction projects in India.

Oke et al., (2017) also identified inexperienced contractors, skill deficiencies, poor site supervision, communication gaps, inadequate planning, inexperienced project managers, inefficient plant management and multiple uncoordinated design changes as key factors affecting construction operation and maintenance costs in Swaziland.

According to Enshassi et al., (2009), many construction stakeholders interviewed stated that multitasking various projects, material pipeline breaks, poorly trained staff, poor equipment operation and maintenance, and project cost overruns affected the efficiency of road construction and maintenance projects. Iyer and Jha, (2006) conducted a questionnaire survey and identified onsite disputes, inclement weather, inexperienced project managers, unfair procurement processes, as the key factors affecting operation and maintenance costs of construction projects. In the Malaysian construction industry, lack of quality assurance specialists, and quality assurance checks, top-down bullish management structures, poor planning and low skill levels were responsible for affecting maintenance cost budgets (Sohu et al., 2018).

Oyedele et al., (2015) investigated factors affecting operation and maintenance costs of construction projects in Nigeria and identified poor construction materials, poor worker skills, inexperienced contractors, poorly planned project costs, poor design making, and poor site supervision. Other factors identified by Ahmed and Yusuff, (2016) included unclear client needs regarding end-product design, material selection, poor project stakeholder coordination and improper equipment use.

Using an Artificial Neural Network (ANN) based model, Marinelli et al., (2014) was able to predict condition levels of earthmoving trucks with a 94 % accuracy. A correlation was found between equipment condition levels and the kilometres travelled alongside the equipment maintenance levels. Machine age and capacity were found to have negligible impact.

While assessing factors affecting cost deviations in construction work in Iraq, Al-Agele and Al-Hassan, (2016) studied eight different completed projects and identified lowest-bidder selection, poor planning, poor cashflow management/projections as key factors. This was identical to the findings by Ahmed et. al., (2014). Oguya and Muturi, (2016) established that poor competency levels among contractors, cashflow management, adequate construction resource mobilisation, and poor dispute resolution as the major factors affecting performances of road projects in arid and semi-arid areas of Kenya. Alinaitwe et al., (2013) investigated and established that, poor work scope management, cashflow and payments issues, poor supervision, security concerns, and political instability were the key factors contributing to construction delays and cost overruns in Uganda. In addition, Otim et. al., (2013) identified contractor payment issues, poor decision making, material pipeline breaks, and inadequate equipment as cost control factors.

According to Langlands classification system, the NEMA (2009) map of major Ugandan soils indicated that the soil type in Gulu consists of ferruginous soil (Acric Ferralsols) with a high percentage of sandy soils, making it susceptible to erosion. Being sand, the soils have low water retention capacity and a high rate of water infiltration. The natural soils in Jinja are mostly Nitisols. Nitisols are normally deeper than 150 cm and dusky red or dark red in colour. They are well drained soils with a clayey subsurface horizon that is deeply stretched and has a typical nutty or polyhedric blocky structure with shiny ped heads. Nitisols are less strongly weathered than associated ferralsols.

Based on the literature review, the researcher grouped these factors into the following categories.

a) Site-related factors.

Inadequate site working condition coupled with poor information flow and remoteness of operational locations are key factors that may affect equipment efficiency. Rough and rugged terrain may accelerate equipment failure and deterioration, alongside fuel usage and if not properly maintained, will lead to sudden machine failure. Key site assessment information regarding the site terrain may alleviate this (Arditi et al., 1997; Edwards et al., 1998). Remoteness of the location and the general terrain may influence the equipment type and the nature of transportation used (Day and Benjamin, 1991). Site remoteness also affects procurement lead-time for spare parts and MTTR (Mean Time To Repair).

b) Equipment-related factors.

Downtime (DT) is the time when an equipment is not operational due to repairs or mechanical adjustments. Downtime tends to increase with equipment usage (Nwanya et al., 2017). Availability refers to the period when equipment is in production or available for production. Company policies coupled with equipment usage by operators, equipment age (machine hours worked), can affect equipment breakdown rates and efficiency. Previous research by Moses Obeti et al., (2023) found average machine availability at KSL was approximately 97.3 %. Also, a strong negative correlation of r = -0.847 between equipment cumulative hours and MTBF, alongside a negative linear relationship between MTTR and machine cumulative hours (r = -0.674) was found. KSL's MTTR data was also ranging between 1 and 2 h. The complexity of the equipment under use also affects the rate of failure (due to poor operation/use), breakdown, repair, and maintenance (Elazouni and Basha, 1996; Arditi et al., 1997). Equipment managers should therefore ensure that operators are fully trained on the equipment use and operational manuals.

c) Crew-level factors.

Operator skill and level of morale/motivation are key in work performance and can impact on work efficiency (Arditi et al., 1997; Elazouni and Basha, 1996; Edwards et al., 2000). Operator negligence during equipment use, coupled with inadequate training may accelerate equipment failure and thus lead to lower productivity onsite (Pathmanathan, 1980).

Worker fatigue due to tight deadlines, high workload, and low staff morale can also affect work output negatively (Cooper, 1994; Roberts and Alfred, 1974). When worker renumerations, services, allowances and general wellbeing is not considered, this may result in decreased work productivity (Maloney and McFillen, 1985).

d) Force majeure.

Unanticipated events, usually of natural occurrence and beyond one's control may result in lower productivity onsite due to work disruptions and associated equipment damage caused. Factoring in a contingency risk management feature in contracts to cater for any such occurrences, may help alleviate the impact of force majeure (Pathmanathan, 1980).

e) Company standard operating procedures and policies.

Company policies towards equipment maintenance and management, alongside procurement, do reflect an organisation's priorities regarding output and strategic plans (Sözen and Giritli, 1987). These policies may in turn affect fleet management systems, equipment downtime and productivity levels at the workplace.

f) Project-level factors.

Ensuring that alternative machine are available, spare parts are easy to procure or already stockpiled, maintenance teams are readily available thus reducing the MTTR, are all examples of project level factors that affect productivity. Other project requirements like client preferences, and prevailing market conditions can affect work productivity to an extent (Day and Benjamin, 1991). Also ensuring the right equipment and contract specifications are followed can improve productivity.

g) Site management actions.

Proper work planning, reducing MTTR and ensuring equipment are properly maintained thus reducing MTBF (Mean Time Before Failure), are examples of practices that help reduce equipment failure and increase work productivity. Also, offering staff additional worktime without boosting morale may have negligible impact on work productivity, leading to more onsite errors and reworks (Thomas and Raynar, 1997; Eden et al., 2000). Selection of compatible onsite equipment may accelerate productivity and reduce equipment downtime (Day and Benjamin, 1991).

Methodology

The research used descriptive research design to describe the phenomenon as it exists with descriptive research being selected due to its ease in identifying trends, characteristics, frequencies, and categories (Siedlecki, 2020). The research focussed on observations and case study approach during data collection. Case study approach is usually selected when concrete, contextual, in-depth knowledge about a specific real-world subject is sought. It allows exploration of key data characteristics, connotations, and inference of the case (Yin, 2018). Case studies can be single or multiple case (for comparison purposes) and elucidate different aspects of a research problem. Zainal, (2007) mentioned the flexibility of case study approach in that it is permissive of the use of both qualitative and quantitative data analysis methods. The choice for a case study design was due to its ability to collect a lot of detail that would not normally be easily obtained by other research designs. Multiple-case design research approach was adopted within the qualitative and quantitative research paradigm, with the aim of corroborating and interpreting collected data for unpaved road maintenance works. The benefits of this approach include among others, a wider discovery of theoretical evolution and research questions (Gustafsson, 2017). It also allows the researcher to delve deeper into the study subject with the generated data being robust and reliable. The benefits of the multiple case study design outweigh the limitations according to Gustafsson (2017). The major limitation cited by Gustafsson (2017), is the costly and time-consuming nature of this approach. Amin, (2005) cited the benefits of using the quantitative approach since it permits numeric data collection on observable individual behaviour of samples, before carrying out statistical analysis. Semi-structured interviews, observation (participant and non-participant), document review, and archival records were all used to have multiple sources of evidence that would aid in collecting rich data sets, which would in turn be useful while generating a model, offer direct access to the research phenomena, and have high levels of flexibility in application.

Semi-structured interviews were used, and all collected information was transcribed and analysed using inductive content analysis. Marshall and Rossman (2011) describe the idea of content analysis as an "objective and neutral way" to secure qualitative descriptive data.

Written notes in text during the process of interviews and re-reading these before input in SPSS and Excel softwares was used to clarify content (Elo and Kyngas, 2008).

All collected data was stored as field notes, photographs, videos, sketches, copies of official company records, and written statistical data (Clark and Creswell, 2010; Thomas, 2006). These were later transferred to Microsoft Excel and IBM SPSS v26 for analysis and processing.

Also, to ensure a chain of evidence was followed, all data collected was conforming to the earlier prepared research questions in the case study protocol. Care was also taken to avoid data from questionable or unvalidated sources like social media platforms, newspapers or unvalidated websites.

The case research design adopted the Eisenhardt (1989) framework in Fig. 1, that provides the context in which the guidelines for the development of the CSP (Case Study Protocol) were created. The Eisenhardt framework was selected, as it is the most ideal where there is a need to build a theory through the development of a conceptual framework (Hilangwa and Graham, 2005).

Case study protocol

Yin, (2018) defines a Case Study Protocol (CSP) as a set of guidelines that are used to structure and govern a case study research project. Research projects involving multiple researchers will find this approach valuable, since it ensures uniformity in data collection and analysis (Yin, 2018). This consistency can also be evidenced in situations where data is to be collected in multiple locations over an extended duration. CSP also contains data collection research instruments that may either be qualitative, quantitative or both, depending on the research design and the problems under consideration, if the research design permits a pluralist approach (Mingers, 2001). This research adopted the quantitative research method.

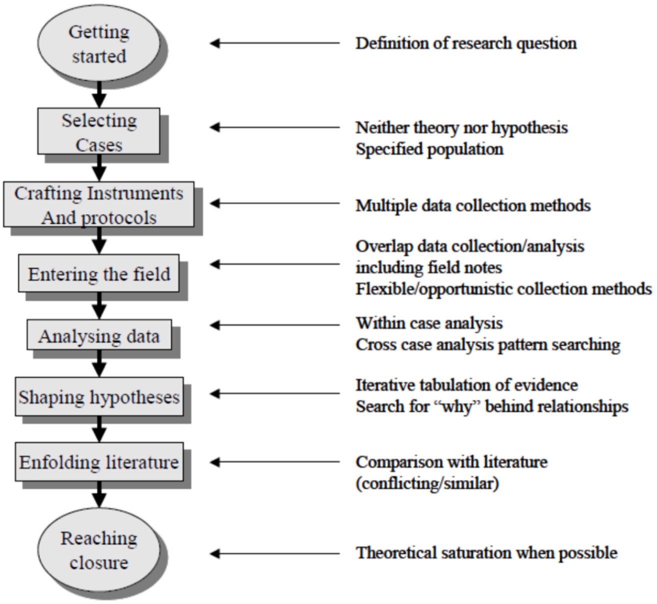

Fig. 1. Adopted Research framework. .
Source: Adopted from Eisenhardt, (1989)

Data collection instruments

Field observations (participant and non-participant) were used alongside semi-structured interviews as primary data source tools. Photographs, videos, and written notes were taken during the use of both data collection instruments.

Participant observation was used when the researcher joined the road maintenance team in compiling dumper truck haulage data, fuel records and number of trips delivered. It also included measuring quantities of material loaded onto the trucks at the quarry site, machine hours of the grader, earthmover, and roller compactors.

Non-participant observation involved observing and recording time taken for mechanics to arrive on site, repair a damaged equipment and get it functioning again (basically measuring Mean Time To Repair-MTTR). Non-participant observation also manifested while monitoring ongoing equipment repair works at the main garage. In all this, photographs, field notes and video evidence were collected for compilation and processing.

Company records in the form of fuel records, machine maintenance and repair records, machine mileage and hours worked records, active staff/personnel records, machine insurance records, km of unpaved road maintained was collected and analysed by the researcher, besides literature review, for additional information.

Ethical implications and how they were addressed

Ethical considerations in research are a set of principles that guide your research designs and practices. This can be achieved by keeping up with related research, ensuring accuracy, striving for credibility, and understanding and divulging the needed methodological qualifiers and limitations to your work (Yin, 2018). The researcher ensured voluntary participation, informed consent, confidentiality, were all maintained and also carried out a TURNITIN plagiarism check (17 % score).

Schematic diagram for methodological approach

From the schematic diagram in Fig. 2, the case study area was selected basing on location, duration and ease of research, data availability and available road maintenance equipment. The maintenance cost drivers were then determined using the indicated data collection

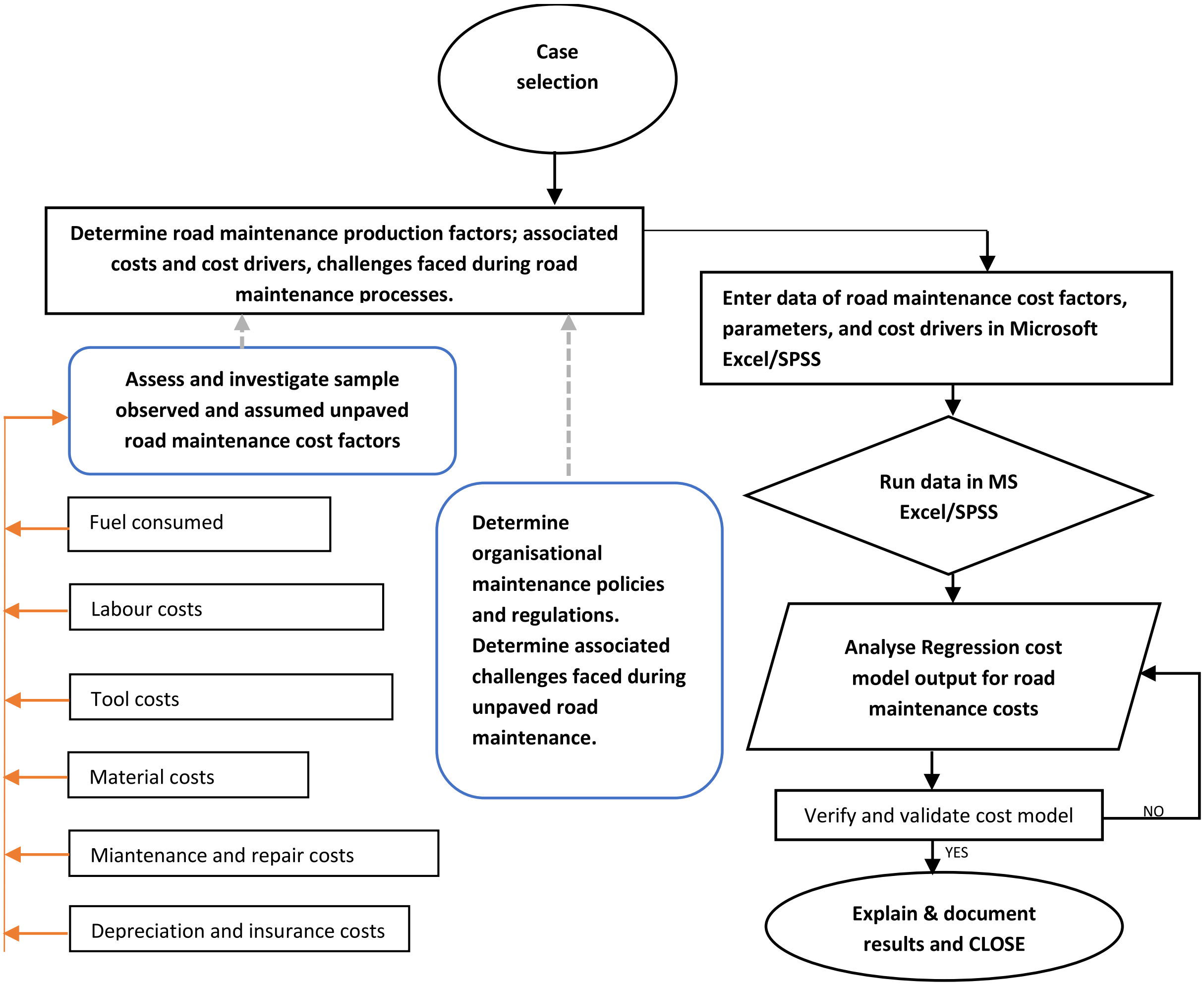

Fig. 2. Schematic diagram for methodological approach.

methods. The collected data was input in MS Excel spreadsheet /SPSS statistical software while incorporating all the necessary cost parameters and factors. A road maintenance cost output was then generated from the MS Excel spreadsheet. The maintenance cost was a computation of the cost factors obtained from KSL and Gulu District Local Government machine daily logs, maintenance and repair records, and project priced bills of quantities. All data obtained was analysed in SPSS and MS Excel Software, then compared with previous research findings and other agency road maintenance costs (UNRA, ROCKS database). Explanations for all findings obtained were given and scientific conclusions made.

Reliability of the data

The researcher used a holistic, multiple case research design with quantitative methods used in data collection and analysis. Caution was exercised to ensure that data quality tests of data validity (construct, internal and external validity) and reliability were complied with. Internal validity mainly focusses on the causal relationships between variables. The researcher therefore sought to establish key conditions/parameters prior to establishing any associated causal effects. The explanations developed where built on previous literature covered in the literature review. Regression models and graphical data were presented to clearly explain complex phenomena in an unambiguous way.

Construct validity was addressed by using multiple sources of evidence during data collection. This involved the use of different research tools and sources (literature review, archival records, semi-structured interviews, direct observation, and participant observation) alongside further review of the draft case study research report by other technical colleagues. External validity was addressed on the principle of replication logic. The study carried out at the primary pilot (KSL) had to be replicated at Gulu DLG. This involved replicating data collection processes, and compiling relevant cost data that would be later used to validate the regression models developed under the KSL study.

The credibility of the research findings was founded on triangulation principles supported by the semi-structured interviews and participant observation approach, besides literature review. Data triangulation refers to gathering data from different sources with the aim of corroborating data and compensating for any inherent weaknesses by the strengths of other data sources. This is a key concept in case study research (Farquhar, 2012). Marshall and Rossman, (2011) define triangulation as the act of combining various data types/sources to converge at a single point. The multiple case study design enabled data sources/participants involved in unpaved road maintenance to be examined in different contexts, thus achieving a more accurate, comprehensive, and objective data representation.

The case study protocol used, helped in ensuring the chain of evidence was maintained, with all collected data stored in the form of notes, videos, sketches, and statistical records obtained. This ensured reliability of the collected data. The collected data was then input in SPSS statistical package software and tested for correlation, normality, and equality of variance. Correlation analysis was used to determine the strength and association/relationship between different variables. Normality analysis was used to determine if the collected data had a normal distribution, with a histogram of residual values plotted for the dependent variable as a confirmation. Equality of variance was used to support assumptions made about variance and this was achieved by plotting residual values against predicted values.

Data analysis

Collected data was analysed using IBM SPSS Statistics version 26, while relying on descriptive and inferential statistics methods. Correlation, normality, and equality of variance were used as data reliability checks. The goal was a development of linear regression cost models for different locations/contexts, with similar variables predicting unpaved road maintenance costs.

Results and analysis

At KSL, 6 different types of machines usually involved in unpaved road maintenance were considered for the research. These included dumper trucks, roller vibrators, roadside excavators, front end wheel loaders, motor graders and bulldozers. Equipment records spanning over 10 years were available, for these equipment and other related equipment. This offered the researcher a more accurate and representative data set. Also, over 10 unpaved roads were considered at Gulu DLG for cost analysis and model generation. Although not using FAM system, the fact that UNRA maintains unpaved roads provided a good opportunity for cost comparison. Therefore, UNRA data collected for comparison purposes was focussed on 21 unpaved road maintenance projects from multiple locations around Uganda (UNRA, 2022p.1–94). Also, data from the World Bank Road Costs Knowledge System (ROCKS) database was used for overall cost comparison purposes. The database was last updated in 2008, according to the source website (datacatalog.worldbank.org, 2008).

Factors influencing cost of mechanized unpaved road maintenance works

Kakira Sugar Ltd estate management is divided into satellite stations which help manage the estate more efficiently. Karongo Satellite station was selected for this study because it houses the largest KSL road maintenance fleet and is also the office location for the KSL road maintenance engineer.

The unpaved road maintenance process at Kakira Sugar Limited (KSL) is mostly mechanized, as shown in Fig. 3, with a few components like roadside clearance, sweeping of roads, removal of fallen sugarcane or twigs etc done by paid labourers. Unpaved roads requiring maintenance are inspected by the roads engineer who assesses their degree of damage and then recommends appropriate action depending on the level of maintenance required. The road construction/maintenance process at KSL consists of; quarry excavation, loading and transportation, spreading and levelling, and compaction. The road maintenance section of the Agriculture engineering department has a vehicle fleet consisting of TATA lorries, road compactor, motor grader, front end loader, bulldozer, and an excavator. These equipment are assigned to each satellite station and therefore there is no choice in what type of equipment to use depending on the conditions of the road. Operators at KSL had minimum grade G and F driving permits for agricultural and engineering equipment operation.

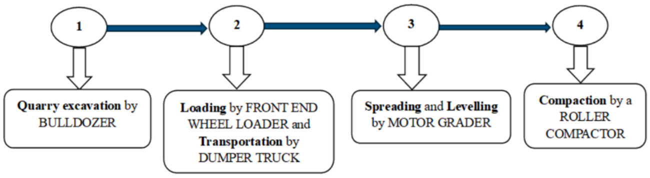

Fig. 3. Road maintenance process at KSL.

Gulu District, based in Northern Uganda, is bordered by Lamwo District to the north, Pader District and Omoro District to the east, Oyam District to the south, Nwoya District to the southwest, and Amuru district to the west. The district headquarters in the city of Gulu are approximately 333 km, by road, north of Uganda's capital city, Kampala (Wikipedia,accessed, 2024). Being under local government jurisdiction, roads in Gulu district are maintained under a Force Account Mechanism as per the Ministry of Works and Transport guidelines, alongside the PPDA Act. Gulu DLG has several road maintenance equipment provided by the government. These include motor graders, dumper trucks, roller compactors, backhoe excavators, water bowsers and bulldozers. There are a fixed number of these equipment and therefore the DLG works with what it has in in its fleet.

The main objective of this research was to investigate the cost of mechanized unpaved road maintenance operations in Uganda. This was achieved by first establishing the factors affecting the cost of mechanized unpaved road maintenance works in Uganda. The factors were obtained using data collected through field observation and literature review of organisational equipment logs/ existing researched material. Field observations (participant and non-participant) were used alongside semi-structured interviews as primary data source tools. Photographs, videos, and written notes were taken during the use of both data collection instruments. Participant observation was used when the researcher joined the road maintenance team in compiling dumper truck haulage data, fuel records and number of trips delivered. It also included measuring quantities of gravel material loaded onto the trucks at the quarry site, machine hours of the grader, earthmover, and roller compactors.

Non-participant observation involved observing and recording time taken for mechanics to arrive on site, repair a damaged equipment and get it functioning again (basically measuring Mean Time To Repair-MTTR). Non-participant observation also manifested while monitoring ongoing equipment repair works at the main garage. In all this, photographs, field notes and video evidence were collected for compilation and processing. Company records in the form of fuel records, machine maintenance and repair records, machine mileage and hours worked records, active staff/personnel records, machine insurance records, km of unpaved road maintained was collected and analysed by the researcher for additional information.

Several factors affecting the cost of unpaved road maintenance works were identified. These were grouped into site related, equipment related, crew level, company processes/policies, site management, project related, and force majeure factors. The key factors were identified as fuel costs, labour costs, machine repair costs, tool costs, length of road to be maintained, and the cost of material to be used. Cost data from KSL has been placed in Table 4, while Table 6 has Gulu DLG cost data. Other cost data can be got in the appendix/additional source material provided. Spearman correlation coefficient (ρ) was used in grading the factors since it measures the strength and direction of association between two ranked variables. Objective 1 was therefore successfully achieved. These factors can also be applied to other road projects since they are not specific to unpaved roads. However, more research needs to be done on equipment availability at the District Local Governments (DLGs) since data was not readily available for this category of the case study.

Determining the cost of mechanized unpaved road maintenance operations

The earlier identified cost driver factors affecting unpaved road maintenance were computed basing on data collected through field observation, road maintenance bills of quantities, equipment usage data logs, literature review of organisational equipment logs, company records and government agency annual report data. The fixed and variable costs for Kakira Sugar Limited (KSL) and Gulu DLG mechanized unpaved road maintenance operations, was computed, and provided as a cost/km ratio of 26,442,032Ugx/km (6,927USD/km) and 32,674,895Ugx/km (8,559USD/km) respectively (*Data logs have been provided as* supplementary *research material*). The Uganda National Roads Authority (UNRA) unpaved road maintenance costs were calculated as 34,987,122.9Ugx/km (9,165USD/km) obtained from the UNRA 2022Project status report (UNRA, 2022p.1–94). The ROCKS database provided an average cost/km of 4,142USD/km between 1998–2002. Factoring in inflation, the computed figure is 7,971USD/km (30,553,440.83Ugx/km) calculated using smartasset.com, an online inflation calculator (SmartAsset, 2019). When compared, all the costs average at 8,156USD/km (30,992,800Ugx/km). There is a 32 % cost difference between UNRA and KSL rates, 24 % for the Gulu-KSL comparison and 15 % for the ROCKS-KSL comparison. KSL rates appearing seemingly lower could be attributed to the fact that KSL owns quarry sites and thus does not purchase gravel, besides the fact that KSL also possesses maintenance garages and thus does not need to outsource any repair/maintenance works. Besides that, UNRA and the DLG incur an extra cost of road maintenance labour cost allowances, which KSL does not incur since its workers are only paid monthly salaries. The second research objective was therefore successfully achieved and set a foundation for the cost model in the third research objective.

Develop a deterministic model to predict the costs of mechanized unpaved road maintenance operations

Cost models were generated basing on the equipment specific data sets obtained. These had significant R^2 values ranging from 0.679 to 0.687 thus improving the reliability of the research. The generated combined cost model for KSL had a 0.679 R^2 value.

The data sets obtained from Gulu DLG were used to create an amalgamated cost model factoring in all equipment used. The researcher used project costs assigned to the earlier identified factors in objective 1 for each road maintenance project. This created a cost/km system of evaluating the maintenance costs, to create a unified basis for comparison with other cost models. Data logs in the main text and attached supplementary material, indicate a breakdown of these costs. The main predictor variables at the DLG were fuel consumed, km maintained, labour costs, tool costs and gravel purchased. All linear regression models used had very significant R^2 values with the least being 0.679 and the highest being 0.687. The models were therefore deemed successful. The KSL and Gulu DLG model can be used in preliminary cost prediction of unpaved road maintenance total cost. Since the third research objective was to "Develop a deterministic linear regression model to predict the costs of mechanized unpaved road maintenance operations.", the researcher sought a uniform factor that could be considered at the district local government and the private sector environment. km of roads maintained was considered a uniform, globally acceptable way of measuring such works. It also offered a simplified approach to preliminary cost estimation, thus its use in the model.

The models are limited to preliminary cost prediction of unpaved maintenance costs and cannot be used to predict detailed maintenance costs, since they only account for some of the factors deemed relevant to the study. The research focus and interest did not delve deep into equipment breakdown analysis, forecasts, and modelling. This may also be an important area to delve into, in future research endeavours, to arrive at a more accurate cost model. There is also further need to develop simple yet multi-facetted models that can accurately predict unpaved road maintenance costs alongside individual factor costs for various equipment types used in unpaved road maintenance.

Linear regression cost model for Gulu DLG

The deterministic cost model predicting maintenance costs considered kilometres of unpaved road maintained, and the overall road maintenance costs, as research parameters. These were later developed as linear regression cost models in the statistical package IBM SPSS. The main focus was on km maintained and maintenance cost since km maintained is a globally accepted key parameter. For instance, the World Bank ROCKS database uses a cost/km system in USD as a measure/parameter. Also, since one of the objectives of this research was to develop a model for predicting road maintenance costs, further simplifying it to a singular factor (km maintained) would lessen the complexity of the arithmetic involved. This has been done on the KSL and Gulu DLG models.

From Table 1, a Pearson correlation coefficient was cyphered to assess the linear relationship between the km of unpaved roads maintained and the maintenance cost of 15 data sets. There was significant evidence of a linear relationship between the two variables, with Pearson's bivariate correlation coefficient showing a very strong positive linear relationship between the two variables ($r = 0.824$, $p < 0.001$). The high correlation however is not evidence of causation. Further research analysis is required to analyse the causal factors.

Considering regression data in Table 3;

The Problem: To investigate if km maintained has an impact on overall road maintenance costs.

Hypothesis:

H1: km maintained has an impact on overall road maintenance costs.

The hypothesis tested if km maintained can carry a significant impact on overall road maintenance costs. The dependent variable, overall road maintenance cost (USD) was regressed on predicting variable km maintained to test hypothesis H1. km maintained significantly predicted overall road maintenance cost (USD), $F(1,13) = 27.525$, $p < 0.001$, which indicates that the km maintained is a key factor in predicting the maintenance cost ($\beta = 0.824$, $p < 0.001$). These results clearly show the positive effect of the km maintained. The slope coefficient for km maintained was 3,296.579 implying that the maintenance cost increases by 3,296.579USD for every km maintained. The $R^2 = 0.679$ depicts that the model explains 67.9 % of the variance in maintenance cost (USD), with the remaining percentage explained by other independent variables. The developed regression model was:

$$\text{Road maintenance Cost}(USD) = 3{,}552.315 + 3{,}296.579x(\text{km maintained}) \tag{1}$$

With $p < 0.05$, the β –coefficient indicated was highly statistically significant. km maintained was a strong predictor with a beta coefficient of $\beta = 0.824$. The predictor variable had a variance inflation factor (VIF) below 10, indicating no multicollinearity issues.

Linear regression cost model for KSL

Similar to the Gulu DLG cost model, the KSL cost model considered kilometres of unpaved road maintained, and the overall road maintenance costs as research parameters and later developed them as linear regression cost models in the statistical package IBM SPSS.

From Table 2, a Pearson correlation coefficient was cyphered to assess the linear relationship between the km of unpaved roads maintained and the overall maintenance cost of 13 data sets. There was significant evidence of a linear relationship between the two variables with Pearson's bivariate correlation coefficient showing a very strong positive linear relationship between the two variables ($r = 0.829$, $p < 0.001$). The high correlation however is not evidence of causation. Further research analysis is required to analyse the causal factors.

Table 1
Gulu DLG Correlation analysis for unpaved road km maintained and overall road maintenance cost (primary data).

Correlations			
		maintenance_cost	km
Pearson Correlation	maintenance_cost	1.000	0.824
	km	0.824	1.000
Sig. (1-tailed)	maintenance_cost	.	0<.001
	km	0.000	.
N	maintenance_cost	15	15
	km	15	15

Table 2
KSL Correlation analysis for unpaved road km maintained and overall road maintenance cost (primary data).

Correlations			
		maintenance_cost	km
Pearson Correlation	maintenance_cost	1.000	0.829
	km	0.829	1.000
Sig. (1-tailed)	maintenance_cost	.	0<.001
	km	0.000	.
N	maintenance_cost	13	13
	km	13	13

Considering regression data in Table 5;

The Problem: To investigate if km maintained has an impact on overall road maintenance costs.

Hypothesis:

H1: km maintained has an impact on road maintenance overall road maintenance costs.

The hypothesis tested if km maintained can carry a significant impact on overall road maintenance costs. The dependent variable overall road maintenance Cost (USD) was regressed on predicting variable, km maintained to test hypothesis H1. km maintained significantly predicted overall road maintenance cost (USD), $F\ (1,13) = 24.172$, $p < 0.001$, which indicates that the km maintained is a key factor in predicting the overall road maintenance cost ($\beta = 0.829$, $p < 0.001$). These results clearly indicate the positive effect of the km maintained. The slope coefficient for km maintained was 3,331.828 implying that the road maintenance cost increases by 3,331.828USD for every km maintained. The $R^2 = 0.687$ depicts that the model explains 68.7 % of the variance in road maintenance cost (USD) with the remaining percentage explained by other independent variables.

The fitted regression model was:

$$\text{Road maintenance Cost}(USD) = 1{,}107.876 + 3{,}331.828x(\text{km maintained}) \tag{2}$$

Since $p < 0.05$, the β −coefficient indicated was highly statistically significant. km maintained was a strong predictor with a beta coefficient of $\beta = 0.829$. The predictor variable had a variance inflation factor (VIF) below 10 indicating no multicollinearity issues.

Methods of testing and validating the cost models

The methods of linear regression model testing (correlation analysis,

Table 3
Gulu DLG regression analysis for unpaved road km maintained and the road maintenance cost.

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients				95.0 % Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta		t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	3552.315	1233.970		2.879	0.013	886.484	6218.145		
	km	3296.579	628.346	0.824	5.246	0<.001	1939.120	4654.037	1.000	1.000

a. Dependent Variable: maintenance_cost

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.824[a]	0.679	0.655	1873.41169	0.679	27.525	1	13	0<.001	1.968

a. Predictors: (Constant), km
b. Dependent Variable: maintenance_cost

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	96604216.054	1	96604216.054	27.525	0<.001[b]
	Residual	45625727.679	13	3509671.360		
	Total	142229943.733	14			

a. Dependent Variable: maintenance_cost
b. Predictors: (Constant), km

Table 4
Sample KSL Karongo satellite station unpaved roads maintained and associated costs (primary data).

Road location	km	Fuel (ltrs)	Fuel cost (USD)	Labour (USD)	Repair costs (USD)	Maintenance cost (USD)	Cost/km (USD)
AA10	0.1	693	820.66	360.00	83.70	1,264.35	12,643.54
L21	0.3	1397	1,654.34	840.00	195.29	2,689.63	8,965.44
BU57	0.3	2027	2,400.39	720.00	167.39	3,287.79	10,959.29
PP9	1.3	3003	3,556.18	840.00	195.29	4,591.47	3,531.90
H19	0.6	2252	2,666.84	720.00	167.39	3,554.23	5,923.72
L20	0.3	1020	1,207.89	360.00	83.70	1,651.59	5,505.30
DD13	0.2	639	756.71	240.00	55.80	1,052.51	5,262.54
BU31	0.3	1054	1,248.16	240.00	55.80	1,543.96	5,146.52
G9	0.6	2367	2,803.03	840.00	195.29	3,838.32	6,397.19
H19	0.7	2972	3,519.47	720.00	167.39	4,406.87	6,295.52
ZAZA2	0.3	1033	1,223.29	240.00	55.80	1,519.09	5,063.62
VV2	0.3	903	1,069.34	360.00	83.70	1,513.04	5,043.46
JJ14	0.3	1439	1,704.08	360.00	83.70	2,147.77	7,159.25

Table 5
KSL regression analysis for unpaved road km maintained and the road maintenance cost.

Coefficients[a]

Model	Unstandardized Coefficients B	Std. Error		Standardized Coefficients Beta	t	Sig.	95.0 % Confidence Interval for B Lower Bound	Upper Bound	Collinearity Statistics Tolerance	VIF
1	(Constant)	1107.876	355.626		3.115	0.010	325.148	1890.603		
	km	3331.828	677.678	0.829	4.917	0<.001	1840.268	4823.388	1.000	1.000

a. Dependent Variable: maintenance_cost

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.829[a]	0.687	0.659	732.29796	0.687	24.172	1	11	0<.001	2.066

a. Predictors: (Constant), km
b. Dependent Variable: maintenance_cost

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12962644.697	1	12962644.697	24.172	0<.001[b]
	Residual	5898863.351	11	536260.305		
	Total	18861508.047	12			

a. Dependent Variable: maintenance_cost.
b. Predictors: (Constant), km.

Table 6
Sample Gulu DLG unpaved road maintenance cost data.

Sno.	Road	Planned road length (km)	Fuel consumed (ltrs)	Labour (USD)	Tools (USD)	Materials used (USD)	Cost with culvert (USD)	Maintenance cost/km with culvert (USD)
1	Nile Avenue	2.0	2,873.2	951.3	460.5	5,188.7	9,474	4,737
2	Bell-Panycwala	1.6	2,259.5	946.1	457.9	6,336.6	10,000	6,250
3	Pida-Techo	1.8	2,156.3	1,069.7	513.1	5,949.9	9,689	5,383
4	Laliya-Akonyibedo	1.9	2,922.0	975.0	521.1	7,743.8	12,162	6,401
5	Forgod-Paminano	3.6	5,578.9	1,371.1	348.4	6,912.1	14,211	3,947
6	Panyagira	2.1	3,166.1	959.2	528.9	7,187.9	11,842	5,639
7	Jubi	1.8	2,156.3	1,069.7	519.4	4,675.7	8,421	4,678
8	Yusuf Adek	1.8	2,156.3	1,069.7	506.9	6,003.9	9,737	5,409
9	Gulu-Gulu	1.0	2,043.3	643.4	444.2	2,395.4	5,526	5,526
10	Ochan Ben	1.5	2,064.2	776.3	457.9	4,333.2	7,632	5,088
11	Hassan lane	3.0	3,138.2	565.8	447.4	6,096.8	10,248	3,416
12	Dorothy laker	1.4	2,259.5	946.1	457.9	4,757.6	8,421	6,015
13	Patuda road	2.3	4,072.6	1,027.6	518.4	9,644.5	15,263	6,636
14	Obita Ludac	1.0	2,043.3	643.4	465.3	4,212.9	7,365	7,365
15	Bunyoro road	0.3	1,197.4	407.9	183.2	842.1	2,631	8,768

normality, and equality of variance) have been indicated, for both the Gulu DLG and KSL data.

Gulu DLG model testing

a) Correlation analysis.

Based on the correlation analysis carried out, the variables considered had a high positive linear relationship ($r = 0.824$, $p < 0.01$).

b) Normality.

A histogram of residuals for the dependant variable (road maintenance costs), was plotted to determine normality. The distribution appeared normal as shown in Fig. 4, and therefore, the model did not violate the assumption of normality.

c) Equality of variance.

The assumption of constant variance of Y (ZRESID-standardized residuals) for all values of X (ZPRED-predicted standardized variables) was checked for violation, by plotting the residuals against the predicted values. Residuals are the difference between the actual and predicted values. Apart from a few outliers, most residual observations remained

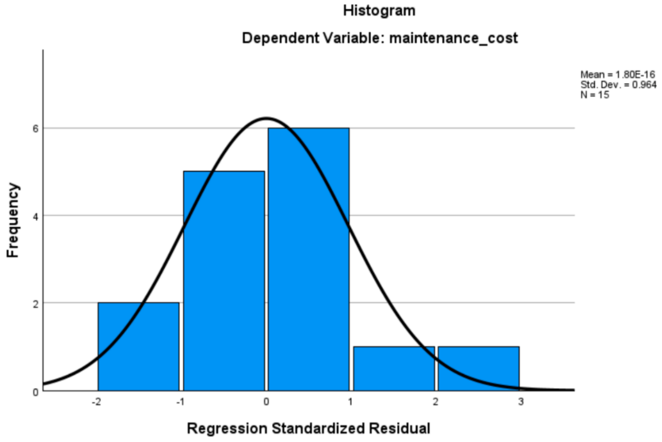

Fig. 4. Histogram of residuals for dependant variable (at Gulu DLG).

constant with the magnitude of the predicted values as shown in Fig. 5. Therefore, it is suggested that the equality of variance assumption has been proven.

KSL model testing

a) Correlation analysis.

Based on the correlation analysis carried out, the variables considered had a high positive linear relationship ($r = 0.829$, $p < 0.01$).

b) Normality.

A histogram of residuals for the dependant variable (road maintenance costs), was plotted to determine normality. The distribution appeared normal as shown in Fig. 6, and therefore, the model did not violate the assumption of normality.

c) Equality of variance.

The assumption of constant variance of Y (ZRESID-standardized residuals) for all values of X (ZPRED-predicted standardized variables) was checked for violation by plotting the residuals against the predicted values. Apart from a few outliers, most residual observations remained constant with the magnitude of the predicted values as shown in Fig. 7. Therefore, it is suggested that the equality of variance assumption has been proven.

Cost model applicability

Regarding R^2 values in regression analysis, various scholarly opinions exist on what constitutes a good R^2 variance. Falk and Miller (1992) recommended that R^2 values should be ≥ 0.10 of the variance explained, of a particular endogenous construct, to be deemed adequate. While Cohen (1988) suggested R^2 values for endogenous latent variables are assessed as follows: 0.26 (substantial), 0.13 (moderate), 0.02 (weak). On the other hand, Chin (1998) recommended R^2 values for endogenous latent variables based on: 0.67 (substantial), 0.33 (moderate), 0.19 (weak). Hair et al., (2011) and Hair et al., (2013) suggested in scholarly research that focused on marketing issues, that R^2 values of 0.75, 0.50, or 0.25 for endogenous latent variables can, as a rough rule of thumb, be respectively described as substantial, moderate, or weak.

All data sets analysed had an R^2 value ranging from 0.679 to 0.687. Since R^2 shows how well a regression model (independent variable) predicts the outcome of observed data (dependent variable), this shows that km of unpaved road maintained, was a great predictor of the road maintenance cost. Considering the earlier stated objective of predicting unpaved road maintenance costs, the developed Gulu DLG and KSL models can be used by road maintenance planners and supervisors in preliminary cost prediction, considering that they predict between 67.9–68.7 % of the maintenance costs observed. This will further improve general budget planning at the DLGs and in the private sector environment. With approximately 32 % of the outcome not explained by the independent variable (km maintained), the research advocates for future research works to accommodate more data sets, spread across multiple case study areas, thus further refining the model accuracy.

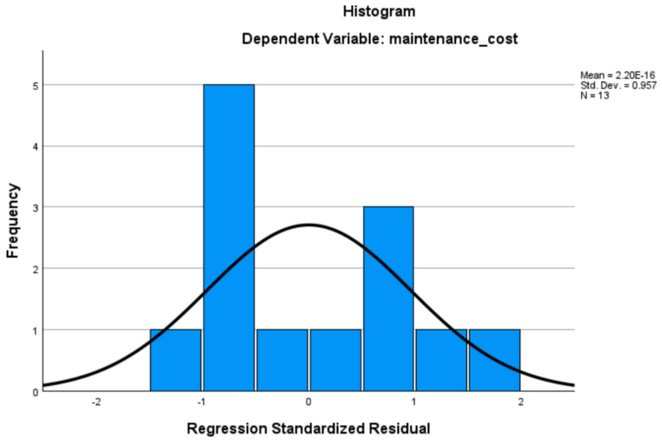

Fig. 6. Histogram of residuals for dependant variable (at KSL).

Discussion and comparison with previous finding by other researchers

Regarding objective 1 which was to establish factors affecting the cost of mechanized unpaved road maintenance works. The following factors were identified during the research study, as key factors affecting the cost of unpaved road maintenance. These were grouped into site related, equipment related, crew level, company processes/policies, site management, project related, and force majeure factors.

Site-related factors included uncertainties during equipment operation, and remoteness of the sites. This agrees with the findings from research carried out in other countries by Arditi et al., 1997; and Edwards et al., 1998. Also, site location was noted to affect the MTTR of the equipment at KSL, in agreement with Day and Benjamin, (1991). But since all field equipment breakdowns were first handled from the KSL Karongo satellite station, similar MTTR data was noted for equipment under this area ranging from 1 to 2 h.

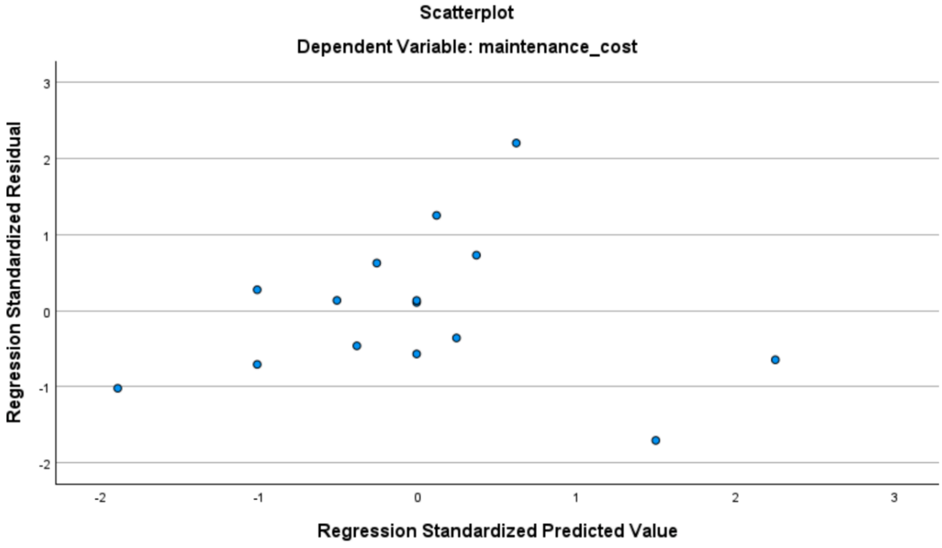

Fig. 5. Test for constant variance (at Gulu DLG).

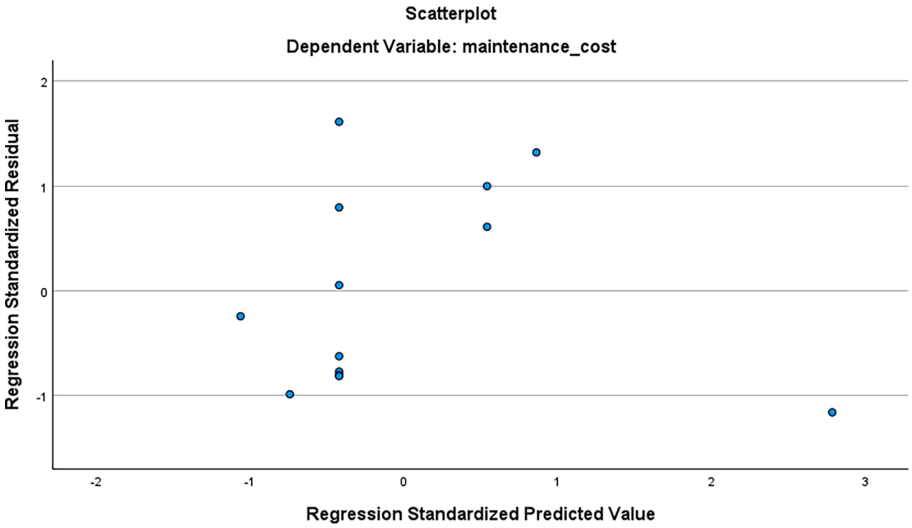

Fig. 7. Test for constant variance (at KSL).

Equipment-related factors included age, type, quality, complexity of operation, and degree of usage. The company equipment at KSL was used on all KSL roads regardless of soil conditions. The station had a limited number of equipment assigned to it and they had to work with what they had. The same was noted at Gulu DLG. Constant breakdowns were noted on the older equipment, which aligns with Nwanya et al., (2017) who found that downtime increased with machine age but differs with Marinelli et al., (2014), whose model found machine age as having a neglible impact on equipment condition levels.

Crew-level factors were mostly concerned with the human aspects of crews who are involved in the equipment maintenance, operation, and production process. The factors in this category included operator/mechanics' skill levels, work fatigue, staff morale and motivation. Most operators and mechanics at KSL and Gulu DLG were earning less than 400,000Ugx (approximately 108USD) per month. This is a low salary rate and greatly affects staff morale. Many of the workers interviewed anonymously hinted on the low salary scales and the demotivation it brought. This agrees with Cooper, (1994); Roberts and Alfred, (1974); Maloney and McFillen, (1985), who all cited proper supervision, resource availability, worker compensation and the work environment as being key in staff motivation and productivity. The government should explore ways to further motivate DLG road maintenance staff, besides offering road allowances.

All operators at KSL had minimum driving permit grade G and F for agricultural and engineering equipment operation. KSL also had a strong work compliance culture and no cases of operators working with lower permit levels were observed. This resulted in less machine breakdowns and high machine availability of 95–98 %. For the case of Gulu DLG, with no real data on equipment availability, the researcher relied on the MoWT, (2020) annual sector performance report for financial year FY 2019/20 which indicated an 88.5 % average availability, for the newly acquired Japanese road equipment fleet, attained against a target of 90 %. This could be attributed to several factors including poor salary scales, which demotivate workers, besides the lack of proper equipment operation, maintenance and management training as also cited in the URF (2021/22) annual report. These findings agree with research done by Arditi et al., (1997); Elazouni and Basha, (1996); Edwards et al., (2000); Cooper, (1994); Roberts and Alfred, (1974); Maloney and McFillen, (1985) and Pathmanathan, (1980) on job efficiency, associated equipment breakdowns and downtime.

The Force majeure category included unforeseen occurrences, mostly natural calamities, vandalism, and accidents. The researcher was unable to obtain or access KSL's and the DLG's accident reports. However inclement weather was cited in the URF 2022 annual report as leading to destruction of road networks by flooding and causing further loss of accessibility of road sections. Affected districts were mostly in the eastern uganda region/areas and included Namisindwa, Busia, Lwakhakha, Malaba, Nagongera and Mbale. Such events increase the cost of road rehabilitation or maintenance. This agrees with Pathmanathan, (1980).

Regarding company procedures and policies, KSL being a corporate business entity had clear processes regarding its road maintenance operations. Being a profit-making entity, delays were not tolerated, and managers were keen to rectify any bottlenecks in time. However, long repair and maintenance durations were cited during the interviews with KSL road maintenance staff as key bottlenecks to road maintenance works. At Gulu DLG, long repair and maintenance durations were also mentioned by road maintenance staff as a key bottlenecks. A case in point was the unpaved road maintenance works on Bunyoro road were the grader used was borrowed from Moyo DLG. The URF 2021/22 annual report also cited outrageous delays in equipment repairs at the regional mechanical workshops, which hampered road maintenance works. This agrees with the findings of Sözen and Giritli, (1987) who explained that organisational policies reflect the corporate-level strategy and have an implication on productivity.

Project-level factors such as the availability of spare parts, equipment resources, compatible substitute machines, maintenance workshop capabilities, location of site and maintenance workshops, were also identified as key factors in determining the cost of road maintenance operations. KSL has an equipment maintenance workshop for both agricultural (tractors, sprayers) and road maintenance equipment, at the Karongo satellite station alongside having a robust major maintenance workshop where all major equipment overhauls and repairs were done. Pictorial evidence is attached in supplementary research documents. These repair stations were all well equipped with spare parts and trained workers. At Gulu DLG, many idle and damaged equipment were seen lying in the MoWT yard. These were all awaiting repairs. The DLG road maintenance technical team explained that maintenance had been outsourced to a third-party company. In tandem with URF's 2021/22 annual report citing delayed maintenance affecting delivery of maintenance operations, this agrees with the findings of Day and Benjamin, (1991) who identified organisational policy, prevailing market conditions, changing end user requirements and partly site-related factors as key in affecting equipment productivity costs.

From literature review carried out, Muhwezi et al., (2021), Mbabazi et al., (2020), Byaruhanga et al., (2017), Booth et al., (2015), URF., (2022), alongside onsite observations and interviews; low number of equipment, high machine failure and subsequent downtime, low staffing/labour alongside low staff capabilities, funding challenges, poor record keeping, and funding challenges were identified as key challenges faced during road maintenance operations in Uganda.

The average cost per km of roads maintained at the Karongo satellite station was computed as 26,442,032Ugx/km (6,958.4USD/km) with KSL's Karongo satellite station maintaining an average of 2.33 km of unpaved roads per month. This cost is lower than Gulu DLG's maintenance cost per km of 32,674,895Ugx/km (8,598.65USD/km). This could be attributed to the fact that the company KSL, owns its quarry sites and thus does not purchase gravel. Also, KSL owns garages and thus does not need to outsource any repair/maintenance works. The District Local Government (DLG) also incurs an extra cost of road maintenance labour allowances which KSL does not incur, since its workers are only paid monthly salaries and offered meals onsite. The KSL 6,958.4USD/km and Gulu DLG 8,598.65USD/km mechanised unpaved road maintenance costs also compares well with the UNRA's average cost of 34,987,122.9Ugx/km (9,165USD/km), for all national mechanized unpaved road maintenance projects carried out in 2022.

The developed regression models for KSL and Gulu DLG factored in a single regression model that focussed on road maintenance cost and km of road maintained for uniformity purposes.

Conclusions and recommendations

Conclusions

The following are the research conclusions drawn.

The research successfully identified the factors that affect the cost of mechanized unpaved road maintenance works as: fuel costs, labour costs, machine repair costs, tool costs, length of road to be maintained, and the cost of material to be used.

The fixed and variable costs for KSL and Gulu DLG mechanized unpaved road maintenance operations was computed and provided as a cost/km ratio of 26,442,032Ugx/km (6,958.4USD/km) and 32,674,895Ugx/km (8,598.65USD/km) respectively. The UNRA unpaved road maintenance costs were calculated as an average cost of 34,987,122.9Ugx/km (9,165USD/km). The cost difference between the KSL and Gulu DLG costs is approximately 19 %, while the Gulu and UNRA costs are within 6 % cost range. This proves that inhouse systems and processes significantly reduce road maintenance costs as evidenced at KSL and Gulu DLG.

The cost driving factors identified were for equipment working in ferruginous soils (Gulu) and nitisol environments (Jinja). Considering that different KSL satellite stations were offered similar set of equipment for their entire operations, there was no choice in equipment to be used for different road maintenance operations. Both KSL and Gulu DLG had regression cost models factoring in km of road maintained, and overall road maintenance cost as key variables in order to have harmonized cost models.

The cost model generated at KSL and Gulu DLG can be used for preliminary cost forecasting but changes in equipment typologies will create variations in the accuracy of the model. To policy makers, this research hints on the need for more inhouse equipment maintenance, as a cost and time reduction feature. Also, fair staff salary renumerations are key in staff confidence and morale boosting. The cost models offer a preliminary cost prediction mechanism for personnel involved in unpaved road maintenance works in Sub-Saharan Africa. To the research community, the research offers possible gaps for future research on unpaved road maintenance operations. Future research can incorporate more equipment specific cost models (for equipment categories commonly used at DLGs) so as to further improve on the model accuracy.

The research focus and interest did not delve deep into equipment breakdown analysis, forecasts, modelling, condition level prediction and analytics. This can be room for further research and exploration especially at DLG level and in the private sector, with regard to unpaved road maintenance.

Recommendations

The research recommendations are:

Creation of a proper centralised road asset management database, where road maintenance data is collected, analysed, and recorded, with more emphasis on equipment usage analytics and management. Most data accessed were physical copies, which are at high risk of damage or loss. The central digitised database would also act as a more reliable reference for reliable road maintenance cost forecasting.

DLGs should strive to ensure more inhouse maintenance of equipment takes place and thus help reduce on the number of redundant equipment.

Considering the identified factors affecting road maintenance costs, a key factor was low salary remuneration among operators that led to demotivation and low morale. The government and the private sector should consider ways to motivate workers involved in road maintenance works.

Considering that the research did not delve deep into equipment breakdown analysis, downtime forecasts, downtime modelling, condition level prediction and analytics; this can be room for further research and exploration especially at DLG level and in the private sector.

With the research regression cost models accounting for approximately 67 %–68 % of the calculated unpaved road maintenance costs, more cost data from various road maintenance operations will have to be factored in future cost models.

The data collected and analysed focussed on road maintenance operations, equipment usage and equipment repairs/ maintenance. The overall research is intended for field operation and mid-level staff actively engaged in unpaved road maintenance operations to get an overview of road maintenance challenges faced, and how to address them. Also, the cost model solution is an attempt at predicting overall unpaved road maintenance costs to ensure proper planning, while also leaving room for further refinement of road maintenance cost prediction models.

CRediT authorship contribution statement

Andrew Moses Obeti: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Lawrence Muhwezi:** Writing – review & editing, Validation, Supervision. **John Muhumuza Kakitahi:** Writing – review & editing, Supervision. **Chris Bic Byaruhanga:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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