INVESTIGATING THE COST OF MECHANIZED UNPAVED ROAD MAINTENANCE OPERATIONS IN UGANDA

BY

OBETI MOSES ANDREW
19/U/GMET/20960/WKD

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CONSTRUCTION TECHNOLOGY AND MANAGEMENT OF KYAMBOGO UNIVERSITY

JUNE, 2024

DECLARATION

I, Obeti Moses Andrew, hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Signed……………………………………….

Date………………………………………….

APPROVAL

The undersigned, certify that they have read and hereby recommend for submission to the Directorate of Research and Graduate Training, of Kyambogo University, a dissertation titled "INVESTIGATING THE COST OF MECHANIZED UNPAVED ROAD MAINTENANCE OPERATIONS IN UGANDA" in fulfilment of the requirements for the award of Master of Science in Construction Technology and Management Degree of Kyambogo University.

Signed ………………………. Date: …………………

Assoc. Prof. Lawrence Muhwezi

Signed ………………………. Date: …………………

Dr. John Muhumuza Kakitahi

DEDICATION

I dedicate this work to my wonderful late mum, Mrs Ray. A. M. Dramadri for her invaluable help and support. She was instrumental in shaping me into the man I have become. She was, and still is a great inspiration to me. I will never forget the dear sacrifices you made towards my development from childhood till this stage in my life. To my lovely and caring mum, the late Mrs Ray. A. M. Dramadri, I am most indebted!

ACKNOWLEDGEMENT

The development of this research involved a great number of individuals; I have tried briefly to list as many as possible, and I must apologize for any inadvertent omissions.

I wish to acknowledge my research supervisors Assoc. Prof. Lawrence Muhwezi, Dr. John Muhumuza Kakitahi and Dr. Chris Byaruhanga, for their advice, consideration, and sincere encouragement during the preparation of this research dissertation.

The researcher acknowledges and is grateful to the managers at KSL and Gulu DLG engineers, for considering and allowing this study to be conducted in their area of operation. The researcher is also thankful for the necessary information and data availed for this study from various listed and cited sources.

LIST OF ACRONYMS

BMAU	Budget Monitoring and Accountability Unit
CAR	Community Access Road
CAT	Caterpillar Company
CBM	Condition Based Maintenance
DLG	District Local Government
EIRS	Engine Idle Reduction Systems
FEL	Front End Loader
FY	Financial Year
GDP	Gross Domestic Product
km	kilometre
KSL	Kakira Sugar Limited
MoWT	Ministry of Works and Transport (Uganda)
MTTR	Mean Time To Repair
MTBF	Mean Time Between Failure
OEE	Overall Equipment Effectiveness
PMS	Performance Measurement System
PIARC	Permanent International Association of Road Congresses
TEEP	Total Equipment Effectiveness Performance
TPM	Total Productive Maintenance
UBOS	Uganda Bureau of Statistics
UNRA	Uganda National Roads Authority
URF	Uganda Road Fund

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Force Account Mechanism (FAM) is the predominant road maintenance system in Uganda's local government setting and also in some private sector plantation agriculture setups. With previous research citing challenges in cost management and efficiency of the FAM method, it becomes paramount to analyse how FAM is implemented in both the private sector and government led operations alongside proposing possible solutions to these challenges. This research offered to analyse unpaved road maintenance cost factors 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. Cost data from the Uganda National Roads Authority (UNRA) was chosen for cost comparison purposes. Two descriptive research methods were used: observations and case study approach. The selected case study areas were accessible and reachable in terms of data collection. Control parameters affecting unpaved mechanized road maintenance were identified as, machine repair costs, maintenance costs, machine depreciation costs, worker's salaries, machine insurance costs, and machine fuel costs. The study recommends the need for an effective electronic cost database system for unpaved road maintenance works with emphasis on mechanized road maintenance cost driver analytics and management, alongside improvement in aspects of maintenance processes. Further research can be conducted on equipment condition level prediction and analytics at the DLG.

Keywords; Mechanized unpaved road maintenance, Maintenance costs, Cost model

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

This chapter explains the background of this research, the problem being solved and the objectives of this study. Also expounded on are the research questions and hypotheses raised, the project scope, significance, and conceptual framework. This chapter gives the reader a glimpse into the necessity for this research and forms the basis for the research.

World over, road infrastructure is a crucial driving force for economic growth and sustained access to roads is essential to improve the living standards of a community (Benamghar, 2011). Production costs, employment creation, markets access, and investment depend on the quality of infrastructure, especially road transport (Wasike et al., 2001).

Globally, the need for infrastructure investment, is forecast to reach $94 trillion by 2040, and a further $3.5 trillion will be required to meet the United Nations' Sustainable Development Goals for electricity and water (Oxford Economics, 2017 p. 4&5). It is estimated that thirty-eight percent of infrastructure investment in Africa has been directed towards the electricity sector, with 20 percent going to water. The flip side of a strong focus on utilities infrastructure is that Africa dedicates a below average proportion of investment to the transport sector, which accounted for only 27 percent of the total investment between 2007 and 2015, compared to the world average of 45 percent (Oxford Economics, 2017 p.56).

In Africa, although use of roads dominates the transport sector, carrying 80% to 90% of passenger and freight traffic in most countries, the condition of these roads remains very poor by international standards (Bagaka et. al., 2010). Also reflected in the composition of development aid – in 2017, by far the largest share of World Bank lending to African countries was allocated to transport infrastructure projects (World Bank, 2017).

Lack of maintenance deteriorates overall quality of road networks and increases the amount that must be spent on rehabilitation, which usually cannot be adequately covered (World Bank, 2010). Through the Uganda Roads Fund (URF), the government has been able to finance routine and periodic maintenance of public roads in Uganda. Inadequate funding for road maintenance has fundamentally reduced periodic maintenance and driven backlog build-up. The approved road maintenance budget for FY 2019/20 (UGX 448.833bn) constituted 0.36% of Uganda's GDP (UGX 126,258bn), well below the minimum recommended of 0.85%. Only 2.9% of the annual maintenance budget was allocated to Community Access Roads (CARs), (MoWT, 2020 p.97, 111).

With the significant impact of rural roads on national development, they are no longer considered a feature of agricultural policy, but have become a critical headline indicator of development at global level (World Highways, 2015). Considering Community Access Roads account for approximately 50.2%

(79,947km) of the road network in Uganda (MoWT, 2020 p.4), and with Uganda's rural population standing at approximately 76%, this underscores the need to fix loopholes in road maintenance strategies in Uganda with emphasis on rural roads.

Agriculture has and continues to be one of Uganda's most crucial sectors of the economy employing over 72 percent of the population, majority of them women and youth and contributing over 23.5 percent of GDP over the years (MAAIF, 2018 p.1).

The public procurement law (the PPDA Act, 2003) was then amended in 2014 to provide for the Force Account Mechanism (FAM) as a means of execution of public works by the Procuring and Disposing Entity (PDE). Using the guidelines issued by the Ministry of Works and Transport (MoWT) and PPDA, Local governments are required to implement road maintenance works majorly by FAM. FAM is applicable under three interventions; 1- routine mechanized maintenance using light road equipment, 2- periodic maintenance using heavy equipment used to rehabilitate (re-gravel) the district roads and rehabilitation, and 3- resealing using heavy equipment used to construct and reseal the urban roads.

A survey of the equipment inventory 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 stations had at least one complete set of key equipment in good condition. Hence, the available equipment does 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).

According to Gongera & Petts (2003), FAM does not allow cost systems to reflect the full cost of maintenance; as other expenses such as salaries, unit infrastructure maintenance and initial cost of equipment are paid for by government. Government absorbs all related costs of finance, importation and taxes and other overheads hence the actual total cost over a period is difficult to ascertain, although this can be achieved.

In addition, unlike a private firm that must deliver before it is paid, allocations to force account units are often not tied to output. Although its efficiency can be increased through reform, it is unlikely to ever reach the efficiency achieved by contracting out to the private sector (Stock & Jan de Veen, 1996). In light of this, this 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.

1.2 Problem Statement

In June 2012, the Government of Uganda made a policy shift from contracting the road maintenance works in Local Governments (LGs) to implementing the Force Account Mechanism (FAM) following the acquisition of a fleet of 1,425 pieces of new equipment distributed to Local Governments (LGs) (Budget Monitoring and Accountability Unit (BMAU), 2015.

Muhwezi et al., (2020) identified material and machinery related factors as the most important factors affecting cost performance of unpaved road maintenance work in Uganda and concluded that critical attention be paid to the problems under each of these factors when planning and implementing road maintenance budgets.

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 facing road maintenance operations in Uganda (URF, 2022).

According to Gongera & Petts (2003), Force Account Mechanism (FAM) does not allow cost systems to reflect the full cost of maintenance; as other expenses such as salaries, unit infrastructure maintenance and initial cost of equipment are paid for by government. Uganda currently has a total road network of 21,200 km in total lane length, of which 6,133.km (29%) are paved roads and 15,067 km are unpaved roads (UNRA, 2023 p. 9). National roads host more than 80% of the average daily road traffic on the Ugandan road network and are a strong driver for social-economic development (BMAU, 2019 p.1). With roads being a critical driver of economic growth coupled with the fact that agriculture still employs approximately 72% of Uganda’s population and considering that 76% of Uganda’s population is rural based, the need to maintain community access and unpaved roads is therefore critical. It therefore becomes paramount to establish cost drivers affecting unpaved road maintenance and the overall costs involved.

A focus on both the private sector and government led initiatives creates an interesting study environment for a generating a cost model suitable for predicting the cost of unpaved road maintenance works. Considering this, this research sought to conduct a detailed cost analysis with a view to determining cost drivers for unpaved road maintenance works, it's as associated costs and how to predict them.

1.3 Objectives of the study

1.3.1 General objective

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

1.3.2 Specific objectives

The specific objectives of this research were:

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 model to predict the costs of mechanized unpaved road maintenance operations.

1.4 Research questions

i. What are the factors that affect the cost of mechanized unpaved road maintenance works.

ii. What are the fixed and variable costs of mechanized unpaved road maintenance operations.

iii. How can the costs of mechanized unpaved road maintenance operations be predicted?

1.5 Justification

When roads are in a poor condition, nearly all economic sectors are affected and suffer financial or time losses. The maintenance of roads thus becomes paramount as an all-year-round weather resistant road greatly serves to the benefit of various economic sectors. With Force Account Mechanism (FAM) as Uganda’s district local government’s main method of carrying out road maintenance costs and considering the associated challenges faced during the implementation of FAM, it is paramount to address these challenges and improve on the cost prediction of FAM as a maintenance approach. This research therefore sought to address the factors affecting unpaved road maintenance and come up with a cost model to attempt to predict these costs.

1.6 Project scope

1.6.1 Content scope

With the various challenges surrounding Uganda’s road maintenance sector and the various attempts at addressing these, this research sought to conduct a detailed cost analysis with a view to determining what the cost drivers for unpaved road maintenance are, how much do they cost, and how can they be predicted. To enable prediction of the unpaved road maintenance costs, the researcher aimed at developing a cost model solution based on certain identified parameters/cost drivers. Also, important to consider where the synergies and advantages that the private sector has and what the District Local Government (DLG) can emulate or improve on from the private sector regarding unpaved road maintenance.

The private sector case study chosen was Kakira Sugar Limited (KSL) and the government district local government (DLG) chosen was Gulu district. Another government agency, Uganda National Roads Authority (UNRA) were also selected for cost comparison purposes.

1.6.2 Geographical scope

The study was conducted in two case study locations. These included Kakira Sugar Limited (KSL) located in Jinja (Eastern Uganda) and Gulu 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) were also selected for cost comparison purposes.

1.6.3 Time scope

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 -November 2023 for Gulu DLG.

1.7 Significance of the research study

This research study will generally have the following significance:

- This research will help construction professionals involved in unpaved road maintenance projects to gain an in-depth knowledge of the cost drivers of unpaved road maintenance, their cost and how to relatively predict them.
- This research will offer new perspectives to academic persons with interest in unpaved road maintenance processes, associated costs of unpaved road maintenance, basic mechanical knowledge regarding construction equipment operations, and also provide a decision tool for future road maintenance overseers/managers to roughly determine unpaved road maintenance costs.

1.8 Conceptual framework

A conceptual framework is a structure which the researcher believes can best explain the natural progression of the phenomenon to be studied (Camp, 2001). It is linked with the concepts, empirical research and important theories used in promoting and systemizing the knowledge espoused by the researcher (Peshkin, 1993). It is the researcher's explanation of how the research problem would be explored. The conceptual framework presents an integrated way of looking at a problem under study (Liehr and Smith, 1999). In a statistical perspective, the conceptual framework describes the relationship between the main concepts of a study. It is arranged in a logical structure to aid provide a picture or visual display of how ideas in a study relate to one another (Grant and Osanloo, 2014). Interestingly, it shows the series of action the researcher intends carrying out in a research study (Dixon et. al., 2001). The framework makes it easier for the researcher to easily specify and define the concepts within the problem of the study (Luse et. al., 2012). Miles and Huberman (1994, p.18) opine that conceptual frameworks can be ‘graphical or in a narrative form showing the key variables or constructs to be studied and the presumed relationships between them.

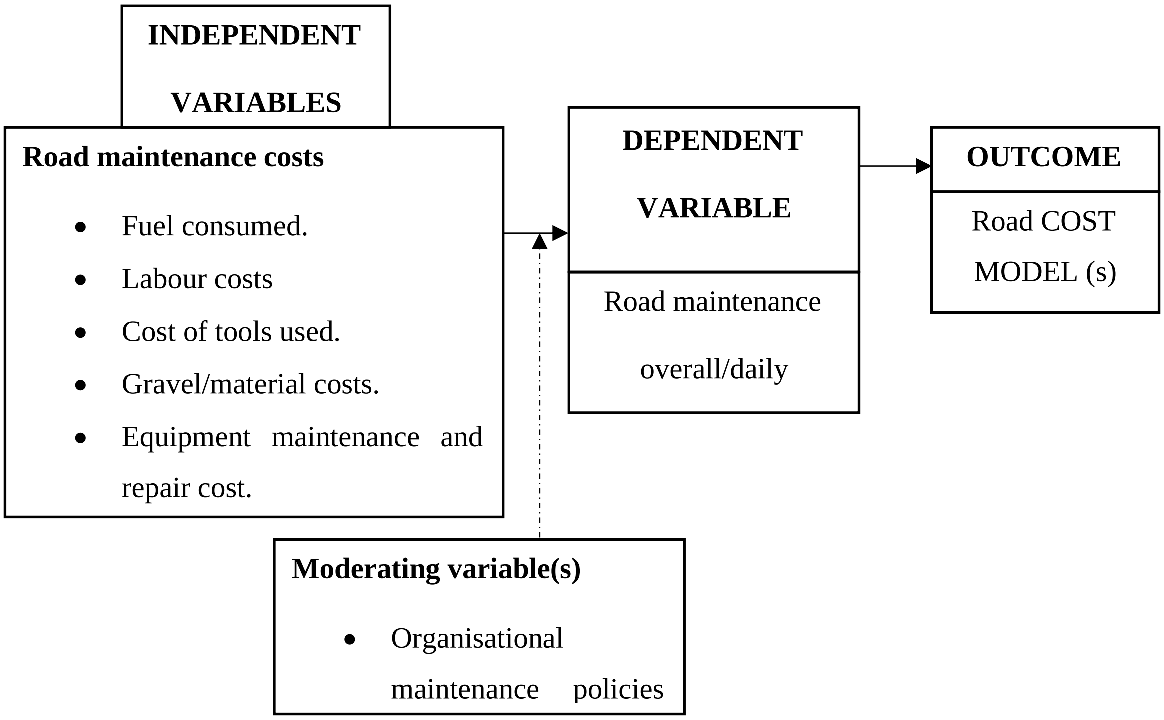


Figure 1. 1: Conceptual framework of the study

In the conceptual framework in Figure 1.1, and based on literature review, the independent variables (Causal factors) were identified as; fuel consumed, labour costs, cost of tools used, gravel/material costs, equipment maintenance and repair cost, equipment depreciation cost, and equipment insurance costs. The effect was on the overall road maintenance production cost which was expressed as a net cost ratioed against a unit measure, either of km worked or any identified output measure. The identified independent variables, selected through literature review and semi-structured interviews were deemed to be cost drivers that lead to a final output cost for the maintenance works.

With Force Account Mechanism (FAM) being a major method of handling road maintenance works at DLGs, and with the many challenges faced during its implementation (URF, 2022), it becomes increasingly paramount to address these challenges and submit a viable solution to equipment cost prediction, maintenance processes and their associated costs for a sub-Saharan African setting. The listed independent variables (causal factors) affect the dependent variable (effect) and in turn influence the intended project outcome which is the development of a road cost model. The moderating variables refers to a third variable that influences the relationship between the independent and dependent variables. In the case of this research, management policies and regulations were seen to influence decisions and approaches to road maintenance. Considering the case of FAM where the modality and means of execution is already predetermined, DLGs must implement the road maintenance policy as directed. In the case of KSL, pre-existing organisational policies determined how satellite stations executed road maintenance operations.

The moderating factors were identified as factors that influence the effect of the independent variables on the dependent variables. These were majorly identified as organisational maintenance policies/practices.

1.9 Chapter Summary

This chapter explained the background of this research, stated the research problem to be handled, indicated both general and specific research objectives, raised research questions to be answered in later chapters, provided a justification for this research, alongside a clear project scope. The significance of this research study alongside the conceptual framework to be used were also indicated.

The next chapter reviews both conceptual and empirical previously researched data related to this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter expounds on relevant data connected to unpaved road maintenance activities, equipment and cost aspects involved, researched by previous scholars and from relevant material sources.

2.2 Maintenance of Roads in Uganda

Maintenance can be classified into; routine, periodic and emergency depending on their interval of application, machinery, labour usage and type of defects to be maintained. Gravel loss, for example is maintained by resurfacing and this activity is periodic maintenance (ERA, 2002). The Rural Access Index (RAI) measures the proportion of the rural population who live 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 can be attributed to several interrelated reasons including but not limited to government preference for new construction over maintenance, insufficient road maintenance budgets, lack of a maintenance culture, institutional arrangements, lack of a suitable means of motivating a strong case for funds for maintenance and ineffective rural road asset management (Burrow, et al., 2016).

In June 2012, the Government of Uganda made a policy shift from contracting the road maintenance works in Local Governments (LGs) to implementing the

Force Account Mechanism (FAM) following the acquisition of a fleet of 1,425 pieces of new equipment distributed to Local Governments (LGs) (Budget Monitoring and Accountability Unit (BMAU), 2015. The public procurement law (the PPDA Act, 2003) was then amended in 2014 to provide for the FAM as a means of execution of public works by the Procuring and Disposing Entity (PDE). Specifically, section 95A of the Act provides for a PDE to undertake, in accordance with the regulations, works using the force account mechanism. The Uganda Government on average allocated approximately about UGX 172.154 billion in financial year 2020/21 towards district, urban and community (DUCAR) access roads which represented approximately 30% of the total road maintenance budget (URF, 2021).

Using the guidelines issued by the Ministry of Works and Transport (MoWT) and PPDA (Public Procurement and Disposal of Public Assets) authority, Local governments are required to implement road maintenance works majorly by Force Account Method (FAM). Under these same guidelines, FAM is applicable under three interventions, which include: routine mechanized maintenance using light road equipment, periodic maintenance using heavy equipment used to rehabilitate (re-gravel) the district roads and rehabilitation, and then resealing using heavy equipment used to construct and reseal the urban roads.

Contracting often is a lengthy and time-consuming process and can even be more costly depending on the nature of procurement (Valdovinos and Lorick, 2013). Existing literature suggests that FAM seeks to remedy such obstacles. However, the effectiveness of the FAM approach is largely dependent on the availability of equipment, materials, and adequate supervision within the procuring organization. According to Gongera and Petts (2003), FAM does not allow cost systems to reflect the full cost of maintenance; as other expenses such as salaries, unit infrastructure maintenance and initial cost of equipment are paid for by government. Government absorbs all related costs of finance, importation and taxes and other overheads hence the actual total cost over a period is difficult to ascertain, although this can be achieved.

The force account model exposes the government to the greatest degree of risk, since it cannot pass risk on to any other entity besides itself (Satyanarayana, 2012). FAM operations have fundamental inefficiencies including lack of financial discipline because they are not driven by profit motives, a procuring organization will often receive additional budget allocations when it generates cost overruns unlike a private firm that has a rigid budget constraint. In addition, unlike a private firm that must deliver before it is paid, allocations to force account units are often not tied to output. Although its efficiency can be increased through reform, it is unlikely to ever reach the efficiency achieved by contracting out to the private sector (Stock & Jan de Veen, 1996).

2.2.1 Routine maintenance of Roads

Routine maintenance comprises small-scale works, conducted regularly, aims “to ensure the daily passability and safety of existing roads in the short-run and to prevent premature deterioration of the roads” (PIARC, 1994). Frequency of activities varies but is generally once or more a week or month. Typical activities include roadside verge clearing and grass cutting, cleaning of silted ditches and culverts, patching, and pothole repair. For gravel roads it may include road re-grading every six months.

2.2.2 Periodic maintenance of Roads

Periodic maintenance covers activities on a section of road at regular and relatively long intervals, aims "to preserve the structural integrity of the road" (PIARC, 1994). These operations tend to be large scale, requiring specialized equipment and skilled personnel. They cost more than routine maintenance works and require specific identification and planning for implementation and often even design. Activities can be classified as preventive, resurfacing, overlay, and pavement reconstruction. Resealing and overlay works are generally undertaken in response to measured deterioration in road conditions (MoWT, 2010). For a paved road repaving is needed about every eight years; for a gravel road re-graveling is needed about every three years.

2.2.3 Urgent maintenance of Roads

Urgent maintenance is undertaken for repairs that cannot be foreseen but require immediate attention, such as collapsed culverts or landslides that block a road (MoWT, 2010). Maintenance does not include rehabilitation, building shoulders, or widening roads. If the sections to be rebuilt constitute more than 25 percent of the road's length, the work is rehabilitation, not maintenance.

2.3 Division of roads into functional class

The rural roads in Uganda are divided into the following 5 classes according to their major function in the road networks as shown below.

Table 2. 1: Functional Road Classification System for National Roads in Uganda

	CLASS	DEFINITION
A	International Trunk Roads	Roads that link International Important Centres. Connection between the national road system and those of neighbouring countries. Major function is to provide mobility
B	National Trunk Roads	Roads that link provincial capitals, main centres of population and nationally important centres. Major function is to provide mobility
C	Primary Roads	Roads linking provincially important centres to each other or to a higher-class road (urban/rural centres). Linkage from districts, local centres of population and development areas to higher class roads. Major function is to provide both mobility and access
D	Secondary Roads	Roads linking locally important centres to each other, to more important centres, or to higher class roads (rural/market centres) and linkage between locally important traffic generators and their rural hinterland. Major function is to provide both mobility and access.
E	Minor Roads	Any road link to minor centre (market/local centre) and all other motorable roads. Major function is to provide access to land adjacent to the secondary road system.

Source: MoWT, (2010)

Table 2. 2: Functional Road Classification System & Route Numbering

Class	**Definition**
District Class I Roads	District Class I roads serve national interests in that they satisfy criteria established for secondary and/or tertiary road systems of MoWT's Trunk Road Network. District Class I roads will be candidates for eventual upgrading to the Trunk Road network after which they become the responsibility of UNRA for maintenance and further development. District I roads, to qualify for upgrading to MoWT jurisdiction, need to be engineered and constructed to Trunk Road standards
District Class II Roads	District Class II roads provide the basic internal transport needs of the district. District Class II roads connect to UNRA secondary or tertiary road systems, interconnect the district capital and county administrative centres, and provide direct access for district population centres to district health, educational, marketing, and administrative facilities. Such roads generally have a gravel surface and carry, on average, twenty or more motorized vehicles per day
District Class III Roads	District Class III roads (including cul-de-sacs) are typically low motorized traffic volume roads extending into the districts' lightly populated peripheral regions. District Class III roads may, at times, serve as connectors to and/or between district class II roads, but generally do not provide direct routing to major public activity centres. Such roads generally have an earth/gravel surface and carry, on average, less than twenty motorized vehicles per day
District Access Roads	In Uganda, the community access road (CARs) network comprises an extensive system of low motorized traffic volume, usually dry weather only, earth roads serving primarily pedestrians, bicycles, and animal drawn carts. Neither inventory/condition surveys detailing the actual extent and condition of this network, nor any clear definition of design class or appropriate design standard exist at present. During implementation by district local government staff of their district road inventory and condition surveys (ADRICS), local authorities at sub-county level are provided the opportunity to identify those CARs considered most important for the survival and continued development of their communities. This process will, over time, enable identification of the most important CARs and result in the development works. For complete details of the ADRICS procedure, refer to District Road Manuals Manual B.

Source: MoWT, (2010)

The National Road Network is continuously being updated to incorporate changes in the road length and other attributes. Currently, the National Network has increased by 80 km from 21,120 km to 21,200 km in total lane length. Of these 6,133.km (29%) are paved roads and 15,067 km are unpaved roads (UNRA, 2023 p. 9). Furthermore, according to functional classification, 12.3% of this network is Class A, 13.4% Class B, 73.6% is Class C and 0.7% is Class M.

Table 2.3 below shows the functional classification and surface type of the National Road Network as of June 2023.

Table 2. 3: Functional Classification, surface type and mileage of the national road network

Functional Classification	paved (km)	Unpaved (km)	Length (km)	% Total	Description
A	2,606.0	0	2,606.0	12.29%	International trunk roads
B	1,660.2	1,184.10	2,844.3	13.42%	National trunk roads
C	1,722.3	13,883	15,605.3	73.61%	Primary roads
M	144.6	0	144.60	0.68%	Expressways
Total	**6,133.10**	**15,067.10**	**21,200.2**	**100.00%**	

Source: UNRA, (2023 p. 10)

2.4 Gravel roads and cross-sectional elements

The cross-sectional elements of a highway design pertain to those features which deal with its width, such as road reserve width, carriageway width, central reservation (median), shoulders, camber, side slopes, horizontal and vertical clearances.

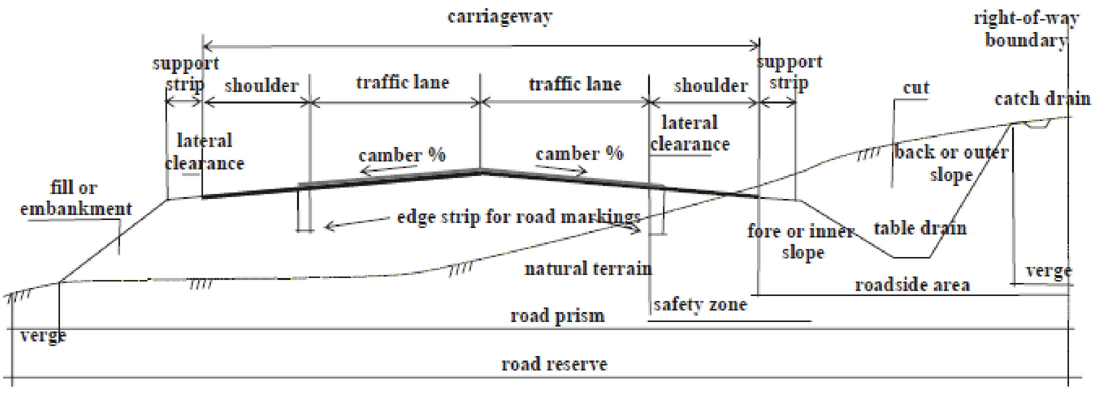


Figure 2. 1: Single carriage way cross-sectional elements.

Source: MoWT, Uganda Road Design Manual Vol 1, (2010)

Henning (2007) defines unsealed roads as a road that has no permanent surface proofing of water in contrast of sealed roads. Gravel roads are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage, and structures (bridges, culverts). Due to their nature of construction, gravel roads are prone to deterioration by different factors. These factors include traffic (speed, volume, and axle loads), environmental factors especially climate (temperature and precipitation), surfacing material (type and nature) and geometrical design of gravel roads (Alzubaidi, 1999).

2.5 Sample Road maintenance machinery

At KSL, the equipment used included the dumper truck (TATA 2516C), backhoe excavator (JCB 3CX), motor grader (CAT 120H), earthmover (CAT D6H), front-end wheel loader (CAT 950H), and roller compactor (Ingersoll Rand). The indicated brands are models are for offering a better perspective regarding the kind of operation being run and associated equipment specifications for calculation purposes. Gulu DLG, mostly used Japanese make KOMATSU machines.

Figure 2. 2: Excavator at works.

Figure 2. 3: Motor grader

Figure 2. 4: Bulldozer

Figure 2. 5: Dumper truck

Figure 2. 6: Wheel loader loading the truck.

Figure 2. 7: Lime application by casual labourers.

Figure 2. 8: Water bowser

Figure 2. 9: Roller compactor

2.6 Review of criteria for the selection of construction equipment

The primary agenda of equipment selection process is to achieve higher productivity, more operational flexibility, and viable economic considerations. Past research shows that the appropriate selection of equipment has always been considered as a strategic decision during the construction phase of any project (Tatari and Skibniewski, 2006). With the growing industrialization and mechanization, this is getting even more important and complex for companies to assess and make the best decision from the pool of many alternatives (Schaufelberger, 2019). Anchoring on this reason, many research articles and several academic studies have been carried out to improve the mechanized construction practices (Shapira and Goldenberg, 2005).

Selection of equipment is typically made by matching equipment in a fleet with tasks. Such matching accounts for equipment productivity, equipment capacity, and cost (Gransberg et al., 2006). It usually involves the selection of the best option among many alternatives based on criteria and method that can be used for the decision-making process. Gates and Scarpa (1980) stated that when a contractor selects earth moving equipment, he should investigate these four categories: spatial relationships, soil characteristics, contract provision and (logistical considerations. According to them, spatial relationships were further classified into seven factors mainly belonging to geographic information of the construction site. Whereas soil characteristics cover the ability of soil to support earthmoving operations.

Gates and Scarpa (1980) put quantities of excavation, moving and fill; construction duration; mode of payment; legal limitations; weight and size of equipment; working constraints such as hours, dust, noise, and traffic in contract provisions. Logistical considerations were also included which primarily cover cost, availability of equipment and experience of operator.

Another research undertaken by Chan and Harris (1989) established a data base application for the equipment selection. In their spread sheet, they used technical criteria for the selection of best backhoes and loaders during earth moving operations. Chan et al. (2001) developed evaluation criteria for the selection of material handling equipment. Their research work identified performance measure, technical, economic, and strategic aspects as the evaluation criteria.

Haidar et al. (1999) split the equipment selection process into knowledge based and optimization genetic algorithms. The former part involved procedures that screen the desired equipment from the list based on subject knowledge whereas the later one refined the selection based on criteria. These criteria included production rate, ownership cost, operating cost, equipment characteristics along with manufacturer, model, number, and operating life. Bascetin (2003) established a decision support system by using qualitative and quantitative factors for the selection of open pit mining equipment. He classified the selection criteria into cost and operational technical requirements.

In a study that was undertaken by Shapira and Goldenberg (2005), a list of tangible and intangible factors was identified. The tangible factors included technical specifications, site conditions and cost consideration. The intangible factors were qualitative and include safety considerations, company policies regarding equipment acquisition, market conditions and environmental constraints.

Chamzini and Yakhchali (2012) identified the nine-point criteria and classified them into two broad categories i.e., benefit criteria based on technical performance and cost criteria.

Marzouk and Moselhi (2004) developed a fuzzy clustering model for estimating haulers' travel time capable of being integrated with diverse simulation and estimation models. The proposed model exploited regression analysis and subtractive clustering. Feifei et al. (2010) presented a flexible and common Petri net model for equipment allocation optimization for a given construction duration, cost, and labour. A case study was conducted on a real construction project involving earthmoving operations.

Lucko (2011) applied a statistical model to forecast the residual value of used heavy construction equipment in the United States. The objective was to evaluate the performance of model in radically changed economy in the second half decade. This model was a comprehensive multiple linear regression analysis for various categories of common types and sizes of equipment. Anjaneyappa et al. (2014) mentioned that various types of light compacting equipment like rammers, vibratory plate compactors, single-drum walk-behind rollers, and double-drum walk-behind rollers are being used for compaction of the materials in constrained areas. Locally available loamy soil was compacted to different layer thicknesses of 50, 100, 150, and 200 mm using selected plate compactors, single-drum walk-behind rollers, and double-drum walk-behind rollers. Field moisture-density relationships for this equipment were established in their studies.

Marks et al. (2013) demonstrated how the design of construction equipment impacts the visibility of its operator. The contribution of this research was that it could precisely evaluate and compare different equipment models and design characteristics. The blind spot measurement data for several similar pieces of equipment provided design suggestions that increased operator visibility. Xu et al. (2013) presented a resource sharing-based construction equipment allocation problem with multiple stages under a fuzzy environment. A multi-objective multistage decision-making model was established in which the equipment failure rate was regarded as a fuzzy variable. Kim et al. (2012) presented a comparative analysis of the generation of greenhouse gases by various equipment types used in different construction activities. Twenty-four cases involving a typical road construction project in Korea were selected for comparison.

Professionals in the construction industry must be able to accurately forecast costs. Forecasting of equipment repair costs is one element of the larger problem of predicting overall costs according to Mitchell et al. (2011). The cumulative cost model developed by Mitchell et al. (2011), can provide construction engineers with a valuable tool for better understanding the nature of repair costs as they relate to production fleets. Data that are being collected (or that could be collected) can assist in the determination of the rate of accumulation of repair costs for a machine for a given period of use or the estimation of fleet repair budgets for a job or period. There are two different methodologies for constructing the repair cost portion of the cumulative cost model: life-to-date (LTD) repair costs and the period-cost-based (PCB) model. Kannan (2011) related some of the recent academic research to industry practices. In doing so, it validates some parts of the research and makes new observations in three areas: repair costs, residual values, and total cost of ownership (TCO) and productivity. It also provides a few pointers for future research.

ElMisalami (2010) presented new methodology to quantify the value of Sell/Hold decision of construction equipment at any period of its useful time. Ng et al. (2009) explored the critical success factors (CSFs) for equipment-intensive subcontractors Seventeen CSFs were identified, and the results indicated that majority of them were internal factors. A one-way ANOVA test was carried out and confirmed the consistency in perceptions of different construction stakeholders surveyed. Through a factor analysis the CSFs were grouped into six major components namely: (a) market position; (b) equipment-related factors; (c) human resources; (d) earnings; (e) managerial ability to adapt to changes; and (f) project success related factors. Hammad et al. (2007) aimed to extend previous equipment research of large infrastructure projects.

Tatum et al. (2006) used five systems that make up earthmoving equipment implement, traction, structure, power train, and control and information to analyse this technical advancement. The analysis of each system includes its purpose and operation, technical limitations and key technologies, and a chronology of major advancements. The findings are the benefits of using the five systems for analysis of technical change, the sequence and timing of key technical advances in each system, the fundamental technologies that fostered these advances, and the integration of systems into balanced equipment designs. The findings from this research resulted in significant implications and relevance for civil designers working on integrated teams, contractors selecting methods and planning operations, equipment suppliers developing new machines, construction educators teaching the technical basics of equipment, and researchers developing advanced modelling and simulation tools.

2.7 Factors affecting efficiency of road construction and maintenance projects

Literature reviews show that numerous works has been carried out to analyse factors that affect the efficiency of construction projects. Shobana & Ambika, (2016) identified that factors affect the operation and maintenance cost budget of construction projects in India were poor coordination among workers, labour shortage, late supply of materials, labours work more than 8 hours per day, lack of proper inspection, lack of skilled labour, financial problems arise during construction, and changes in design.

A survey was carried out by Oke et al., (2017) to highlight the factors affecting operation and maintenance cost budget in construction projects in Swaziland. The survey showed that the main factors affecting operation and maintenance cost budget in construction projects were unexperienced subcontractors, poor supervision on site, unskilled labours, poor planning, lack of communication, project manager's ignorance, poor material management, poor plant management, and design changes.

According to Enshassi et al., (2009), many construction stakeholders interviewed stated that handling many projects at the same time, material shortage, and unavailability of competent staff, equipment operation and maintenance, and the cost budget of construction projects affected the efficiency of road construction and maintenance projects. A questionnaire survey was conducted by Jha & Iyer, (2006) to identify the factors affecting operation and maintenance cost budget of construction projects. Analysis of the survey showed that factors affecting operation and maintenance cost budget in construction projects are conflicts among parties involved in the project, harsh weather conditions, lack of knowledge with the project manager, and unfair award of contract. The main factors affecting operation and maintenance cost budget in the Malaysian construction industry are lack of quality awareness in project participants, lack of support from the top management, improper planning, and unskilled workers (Sohu et al., 2018).

Oyedele et al., (2015) investigated factors affecting operation and maintenance cost budget of construction projects in Nigeria by conducting a questionnaire survey in construction professionals. The results of the survey presented that significant factor affecting operation and maintenance cost budget are poor quality of construction materials, low skill workers, lack of quality assurance, poor technical knowledge of contractors, unrealistic project cost, making slow decisions, and inadequate site supervision. Other factors affecting operation and maintenance cost budget of construction projects include unclear client's requirements for design, improper material selection, lack of coordination between designer and owners, use of improper equipment (Ahmed & Yusuff, 2016).

Al-Agele and Al-Hassan, (2016) assessed factors responsible for cost deviations in construction work in Iraq after a study of eight different completed projects as accepting lowest offers, inadequate planning, and delayed cash flows by owners.

This was similar to the findings by Ahmed et. al., (2014). Oguya and Muturi, (2016) that established contractor's competency, construction parties' financial management, timely availability of construction resources and conflicts, as the major factors affecting performances of road projects in arid and semi-arid areas of Kenya. Whereas Alinaitwe et. al., (2013) investigated and established that, changes to the scope of work, delayed payments, poor monitoring and control, high cost of capital and political instability were the major factors contributing to construction delays and cost overruns in Uganda. In addition, Otim et. al., (2011) established that the following difficulties exist in controlling cost in construction projects: delays in paying contractors, delays in decision making and lack of materials and equipment among others.

2.8 Road maintenance works at the District Local Government in Uganda

Gulu DLG, like other local governments are required to implement road maintenance works majorly by FAM using the guidelines issued by the MoWT and PPDA (URF, 2021). Under these same guidelines, FAM is applicable under three interventions, which include: routine mechanized maintenance using light road equipment, periodic maintenance using heavy equipment used to rehabilitate (re-gravel) the district roads and rehabilitation, and then resealing using heavy equipment used to construct and reseal the urban roads (MoWT, 2013).

FAM relies on an organisation's internal resources (equipment, staffing and finances) to drive productivity. LGs in Uganda would require at least: a motor grader, two (2) dump trucks (tippers), a wheel loader, a backhoe excavator, a compactor (roller) and a water bowser (BMAU, 2015). The PPDA law stipulates that Accounting Officers are by obligation required to appoint a public officer to take responsibility for managing the works executed, preparing work plans for approval and a supervisor responsible for supervising the public officer - the force account manager. The required technical personnel as highlighted in the MoWT guideline (MoWT, 2013) are the headmen, road overseers, civil and mechanical foremen. Road gangs are the nontechnical staff employed on the roads.

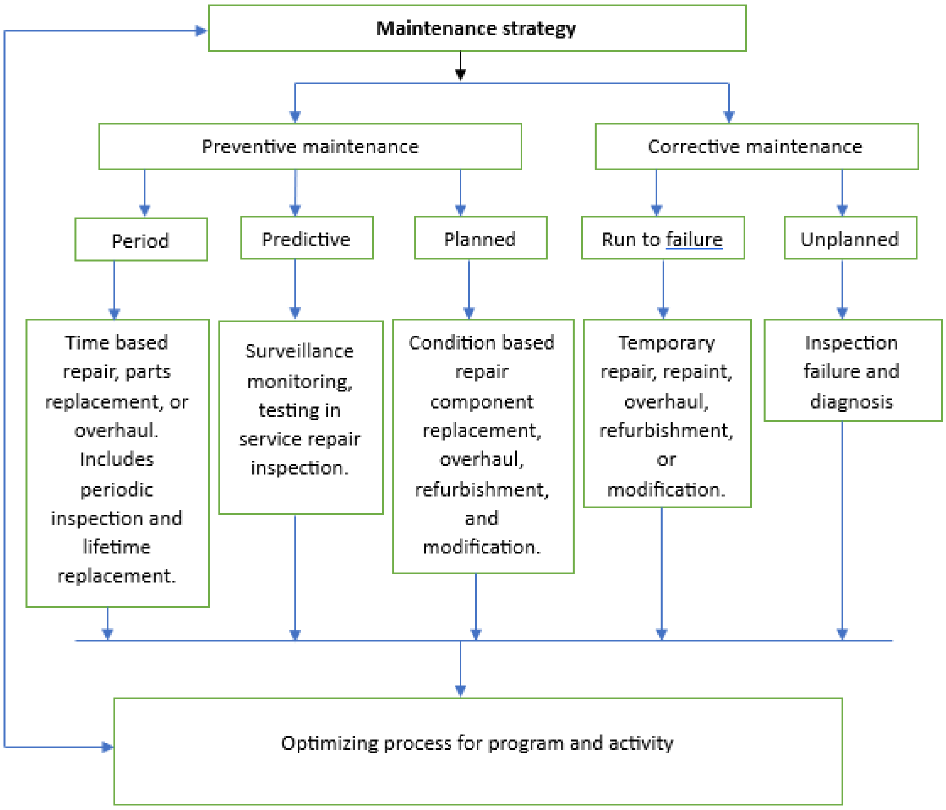


Figure 2. 10: Gulu DLG 2023 maintenance strategy

Source: Courtesy of Gulu DLG

2.9 Road maintenance challenges in Uganda

Petts (2013) argued that maintenance for road networks 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. The condition of gravel roads is known to undergo very quick deterioration 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 releases, 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).

The Uganda Road Fund (URF) was established by an Act of Parliament in 2008 to finance routine and periodic maintenance of public roads in Uganda principally from road user charges. The objective is to ensure that public roads are always maintained through provision of adequate and stable financing for routine and periodic road maintenance undertaken by Designated Agencies (DAs). It became operational in January 2010. According to the URF 2021/22 annual performance report, public roads network was managed by 177 Designated Agencies (Das). The DA’s and sub-agencies collectively looked after a total of 107,020km of public roads made up of 21,020km of national roads under UNRA management; 2,103km of Kampala Capital City Authority (KCCA) roads; 30,000km of district roads; 8,500km of urban roads managed by town councils; 4,500km of urban roads managed by Cities and Municipal Councils; and 42,250km 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. Also highlighted were the grey areas in implementation of the force account policy which is the main method of road maintenance delivery in local governments, indicating that the entrenchment of the road gang system, especially under the DUCAR (District Urban and Community Access Roads) network is still poor.

The report also identified the following challenges compiled in Table 2.4, facing road maintenance in Uganda and proposed some remedies.

Table 2. 4: Road maintenance challenges in Uganda

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
Sno.	**Findings**	**Risk/effect**	**Agency's location**	**Recommendations/strategies for improvement**
1.	Lack of a road unit to undertake works by force account. Time sharing of equipment with other agencies remained a challenge as funding was received at the same time.	Expensive hire of 8equipment	Ibanda MC, Sheema MC, Busia MC	MoWT should prioritize municipalities in the next consignment of equipment to be procured. URF to coordinate with MoWT to fast-track establishment of the proposed zonal equipment centers.
2.	Lack of a low bed for transportation of equipment like grader, roller, wheel loader etc. yet there was difficulty in accessing zonal equipment	Slow progression of works; poor quality works; and higher unit rates for maintenance activities	Kayunga DLG, Mpigi DLG	MoWT should review and provide a strategy to address the issue. E.g., Clustering 3 DLGs and providing them with a low bed.
3.	Obsolete equipment with high breakdown rate/high maintenance costs and insufficient for the network size	Failure to implement planned works within the FY	Mpigi UNRA	UNRA should plan and improve the equipment capacity of stations in order to improve efficiency

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
				and effectiveness
4.	Lack of reliable supervision transport The LGs lacked sound supervision cars and motorcycles.	Value loss through unsupervised shoddy work	Tororo UNRA, Sheema MC, Mpigi DLG, Kayunga DLG, Ibanda MC, Tororo DLG, Namisindwa DLG	URF to support DAs in requesting MoFPED to lift the ban on procurement of vehicles.
5.	Understaffing of works and technical services department	Failure to effectively manage the road network	DLGs: Tororo, Namisindwa MCs: Busia, Ibanda TCs: Lwakhakha, Malaba, Nagongera	DAs should fill the key positions in the works department to enable effective supervision of works and reporting. URF to prioritize rollout of regional Technical Support Units (TSUs) for the LGs to augment their capacity to implement the road maintenance programme.
6.	Encroachment on road reserves by locals, thence encumbering restoration of roads to their standard widths.	A risk of running into compensation costs.	Ibanda MC, Sheema MC	MoWT should issue guidelines on demarcation of road reserves for urban roads to avert road encroachers.
7.	Non-mainstreaming of crosscutting issues.	Non-compliance with Government policy	DLGs: Tororo, Namisindwa MCs: Busia TCs: Lwakhakha, Malaba, Nagongera	DAs should seek guidance from Equal Opportunities Commission and MoWT
8.	Difficulty in receipt of supplementary funding on IFMIS TSA requiring an onerous application process to the PS/ST In Q2, Mpigi DLG failed to do a timely transfer of UGX 25 million emergency funds for Mpigi TC. The funds were eventually transferred in the last month of Q3 after an onerous process that led	Late implementation of projects under special funding by URF	Mpigi DLG, Mpigi TC	URF to engage MoFPED to cause a seamless disbursement of special funds (supplementary funds) to URF DAs

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
	to the creation of a separate code on IFMIS TSA for supplementary funding (funding above IPF).			
9.	Premature damage of roads by overloaded trucks (carrying sand, hardcore, etc.) which were circumventing both fixed and mobile weighbridges	Increased unit cost of road maintenance	Mpigi UNRA	UNRA should step up measures deterrent to overloading like procurement of more mobile weighbridges and intensifying stakeholder sensitization.
10.	Damage of recently maintained roads by overloaded trucks transporting sand, hard core, bricks, sugarcanes, timber, etc.	High unit cost of road maintenance	Mpigi DLG, Kayunga DLG	DAs should: - Come up with bylaws barring overloaded trucks from traversing their road network; and - Work with the Police to curb this vice.
11.	Growing scarcity of gravel with increasing haulage distances	Use of poor-quality gravel on the roads	Kayunga DLG, Mpigi DLG, Mpigi UNRA	URF to fund rolling out of low-cost seals previously researched on UNRA should fully embrace use of low-cost sealing technology in areas where gravel has been depleted
12.	Drainage challenges arising from run-off from Kenya, which damaged road networks	Fast deterioration of condition of roads	MCs: Busia TCs: Malaba	DAs should request MoLG in coordination with other Government institutions and the relevant authorities in Kenya for area-wide design and construction of drainage systems in the urban centers.

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
13.	Delays in receipt of funds	Failure to implement planned works	DLGs: Tororo, Namisindwa MCs: Busia TCs: Lwakhakha, Malaba, Nagongera	URF to improve timeliness of release of funds to DAs, and DAs should improve timeliness of releases to their Sub-agencies
14.	Low quarterly releases, which constrain completion of planned works under the equipment sharing arrangement	Failure to implement works as per the work plan	TCs: Lwakhakha, Malaba, Nagongera	URF to issue guidelines to DAs on harmonizing funding with access to equipment
15.	Difficulty in transportation of fuel to the field using drums loaded on pickups. The Station did not have even one 4 m3 fuel tank truck to conveniently transport and distribute fuel to equipment in the field.	Fuel losses while transporting and distributing fuel to field equipment	Mpigi UNRA	UNRA should procure fuel tank trucks for each Station as opposed to the current arrangement where each region is allocated one fuel tank truck that only services the needs of one Station per region.
16.	Long procurement lead times for various station requirements due to centralization of all procurements within the value of UGX 100 million (supplies and services) and UGX 200 million (works) to regions	A risk of delayed implementation of planned works and loss of funds to Treasury at the end of FY.	Mpigi UNRA	UNRA should review and improve efficiency of procurement at Stations
17.	Insufficient training for equipment operators The one-month duration of training was inadequate.	Premature failure of equipment; safety hazard; and higher unit costs for road maintenance	Kayunga DLG	MoWT should review the duration and content of the training given to operators to improve its usefulness.
18.	Huge portion of the road network in poor condition and requiring rehabilitation	Increased cost of maintenance	DLGs: Tororo, Namisindwa TCs: Lwakhakha, Malaba	MoWT should prioritize the DAs in the road's rehabilitation programmes
19.	Project billboards not conforming to the standard design issued by URF in terms of colours and structure of content displayed. The URF logo was also missing	Diminished visibility of URF	Ibanda MC, Kayunga DLG, Mpigi DLG, Sheema MC	DAs should adhere to the standard billboard design that was circulated to all DAs clearly indicating URF as the funding agency for road maintenance works.

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
				[*Standard billboard design for road maintenance was communicated to all DAs in Circular ref URF/DA/COR/001/17 dated 22 Feb. 2017]*
20.	Late downstream disbursement of funds leading to delays in implementation of works (Av. 48.0 days from start of each quarter)	Failure to implement works as per the work plan	Tororo UNRA	UNRA should improve internal systems to address the persistent delays
21.	Over commitment on works implemented using Framework Contracts – call off orders outstrip available funds in the budget	Accumulation of unpaid certificates / arrears	Tororo UNRA	UNRA should going forward ensure that call-off orders under framework contracts are in sync with funds available in the annual work plans submitted to URF
22.	Mismatch in quarterly release of funds for fuel, maintenance of equipment, and roadworks	Failure to implement planned works within the FY	Tororo UNRA,	UNRA should rationalize and match fuel allocations and releases for mechanical repairs to funds released to stations for roadworks
23.	Discrepancy between the works in the funded work plan and the works under implementation	Difficulty in accountability and oversight	Tororo UNRA, Namisindwa DLG, Lwakhakha TC, Nagongera TC	DAs should going forward ensure prompt submission of revised work plans to URF as and when changes are made. This is in line with the annual budget guidelines issued to DAs.
24.	Lack of records on management of resources and daily outputs in the force account operations (fuel utilisation, daily production, equipment utilisation, stores etc)	Failure to provide accountability for funds and resources	DLGs: Tororo, Namisindwa MCs: Busia TCs: Lwakhakha, Malaba, Nagongera	URF to coordinate with MoWT to develop a force account manual to guide agencies and harmonize approach. URF to develop standard forms and disseminate them to all LG DAs to guide them in required

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
				record keeping under force account.
25.	Blockage of roadside drains by garbage dumped in by locals who found gazetted rubbish disposal points quite distant	Failure to contain stormwater during floods	Ibanda MC	DA should gradually transform its open side drains into covered drains to forestall dumping of garbage in its drainage system
26.	Inadequate implementation of routine manual maintenance works specifically vegetation control, cleaning of culverts including their inlet and outlet drains in favor of more routine mechanized maintenance works	Quick deterioration of road network due to drainage blockage by silt, debris, and vegetation	Ibanda MC, Kayunga DLG, Mpigi DLG, Sheema MC	DAs should give routine manual maintenance highest priority in accordance with the annual budget guidelines issued by URF
27.	Comingling of funds with water and rehabilitation works	Difficulty in tracking expenditure	DLGs: Namisindwa	DA should use expenditure codes to enable easy isolation of expenditures under URF funding
28.	Huge advances to technical staff for payment of road gangs/ other construction inputs	Risk of abuse of funds	DLGs: Namisindwa MCs: Busia TCs: Lwakhakha,	DAs should pay road gangs through their respective bank accounts or to service providers
29.	Non remittance of funds to some town councils and sub-counties	Risk of loss of funds	DLGs: Namisindwa	DA should explain the irregularity and provide correction measures
30.	Difficulty in time sharing of district equipment given the huge number of town councils and sub-counties	Delayed implementation of planned works/ use of expensive hired equipment	MCs: Busia TCs: Malaba, Nagongera	MoWT should streamline accessibility to equipment by sub-agencies.
31.	Poor construction of culvert end structures The stream culverts inspected had headwalls but no wingwalls to provide complete retention of backfill at culvert end points.	A risk of premature failure of culvert crossings	Sheema MC, Ibanda MC	DAs should make reference to the Uganda Technical Manual for District Road Works (TMDRW) Volume 4 Manual A for guidance on construction of culvert end structures

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
32.	Poor culvert installation: creation of humps instead of smooth ramps at culvert crossings due to flat terrain challenges	Diminished safety and riding comfort of vehicular traffic using the roads	Mpigi DLG	DA should make reference to the Uganda Technical Manual for District Road Works (TMDRW) Volume 4 Manual A for guidance on culvert installation in flat terrain
33.	Outrageous delays in equipment repairs at the regional mechanical workshops. Equipment takes years in the regional mechanical workshops while purportedly undergoing major repairs.	A risk of discouraging LGs from using the regional mechanical workshops for major repairs.	Kayunga DLG	MoWT should provide a strategy for improving turnaround time for mechanical repairs at the regional mechanical workshops in order to improve the effectiveness of the force account policy.
34.	Inadequate cap on budget line for operational expenses i.e., 4.5% of IPF This cap had remained persistently inadequate to cover all operational costs including DRC operations.	A risk of encroaching on funds available for actual road maintenance operations	Sheema MC	DA should migrate operational expenses for actual roadworks like supervision costs from the budget line of operational costs and instead tag them onto road schemes as part of their maintenance cost. Once this is observed, the 4.5% cap should suffice.
35.	Failure to undertake roadworks within standard widths and to exploit gravel sources in road reserves due to encroachments on road reserves	Narrow roads and safety hazard to neighbouring developments	Mpigi UNRA	UNRA should undertake road reserve demarcation on the entire national roads network; sensitize roadside communities to steer clear of the road reserves; and conduct forceful evictions where amicable vacation of road reserves cannot be reached.
36.	Mix-up in the categorization of scope of works	Disproportionate unit rates	MC: Busia	DA should going forward ensure proper categorization of works. URF to fast-track establishment of the unit cost framework

Generic findings of road maintenance challenges in Uganda (Table 2.4)				
				to guide agencies in planning.
37.	Lack of records for equipment utilisation and maintenance	Misuse of equipment	DLGs: Namisindwa MCs: Busia TCs: Lwakhakha, Malaba, Nagongera	MoWT should re-issue guidelines for equipment operation and maintenance as well as required record keeping
38.	Inclement weather leading to damaging of road networks and flooding	Loss of accessibility of sections of the road networks	DLGs: Namisindwa MCs: Busia TCs: Lwakhakha, Malaba, Nagongera Mbale DLG, Mbale MC	DAs should apply for programme reviews to enable timely restoration of accessibility in areas ravaged by rain.
39.	Major works on roads that were earmarked for upgrading under USMID	Loss of value on works soon to be demolished	MC: Busia	DAs should harmonize planning for major maintenance interventions with development projects like USMID
40.	Lack of measurements records to support payment of road gangs.	Inadequate accountability for funds spent on road gangs	DLGs: Tororo, Namisindwa MCs: Busia TCs: Lwakhakha, Malaba, Nagongera	DAs should maintain a record of measurement of works as well as daily attendance of road gangs
41.	Communities resisting restoration of gravel borrow pits on their land in anticipation of making quicker sales of their residual gravel.	Environmental hazard	Mpigi UNRA	UNRA should sensitize landowners on the environmental hazards associated with failure to restore borrow pits after exploitation for gravel.

Source: URF, (2022)

From Table 2.4, 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.

2.10 Road maintenance equipment costs

Besides the one-time initial capital cost of machine purchase, ownership costs are fixed costs that are incurred annually, regardless of whether the equipment is operated or idle. Operating costs refers to the costs incurred only when the equipment is used (Peurifoy et al., 2018).

Cost associated with plant, equipment, and tools normally used in construction operations are categorised as follows.

i. Small hand tools and consumables.
ii. Equipment usually engaged in multiple work activities.
iii. Equipment used for specific jobs/assignments: These are capital items used in operations such as trench excavation or material hoisting. The equipment is shipped onsite, used for the required operation, and thereafter returned to its original location.

This research's focus is on the third category of equipment with emphasis on estimating the cost of equipment ownership and operation.

2.10.1 Equipment ownership cost

Ownership costs are fixed costs which usually include initial capital cost, depreciation, investment (or interest) cost, insurance cost, taxes, and storage cost.

a) Initial cost

This cost is incurred for getting equipment into the contractor's yard, or construction site, and having the equipment ready for operation (Gransberg et al., 2006).

b) Depreciation

Depreciation refers to the amount of value your equipment loses every year, due to age, wear, deterioration, and obsolescence, until the point where it no longer holds any residual value. Common depreciation methods include the straight-line method, double-declining balance (DDB) method, Modified Accelerated Cost Recovery System (MACRS) and sum-of-years'-digits method. MACRS has been the U.S. required tax depreciation method for all depreciable assets since the 1980's. It defines statutory depreciation rates that take advantage of the accelerated DB and DDB methods (Blank et al, 2018).

c) Investment (or interest) cost

Investment (or interest) cost refers to the annual cost (expressed as an hourly cost) of capital invested in a machine. Investment cost is calculated as the product of interest rate multiplied by the value of the equipment, which is then converted into operational cost per hour (Gransberg et al., 2006).

d) Insurance, tax, and storage costs

Insurance cost refers to the cost incurred due to fire, theft, accident, and liability insurance for the equipment. Tax cost refers to the cost of property tax and licenses for equipment. The cost of insurance and tax for each item of equipment may be known on an annual basis. In this case, this cost is simply divided by the hours of operation during the year to yield the cost per hour for these items.

Storage cost refers to the cost of rent and maintenance for equipment storage yards, security guard wages and employee salaries for personnel involved in moving equipment in and out of storage areas and associated direct overheads (Gransberg et al., 2006).

e) Total ownership cost

Total equipment ownership cost is cyphered as the sum of depreciation, insurance cost, tax, investment cost, and storage cost.

2.10.2 Cost of Operating Construction Equipment

These are the costs relating to equipment operations. The best basis for estimating the cost of operating construction equipment is the use of historical data from the experience of similar equipment under similar conditions. If such data is not available, recommendations from the equipment manufacturer could be used in the form of equipment catalogues (Peurifoy, 2018).

a) Maintenance and Repair Cost

Due to the intensive nature of construction operations, equipment is subjected to considerable wear and tear, which varies greatly between the different types of equipment used and prevailing job conditions. Equipment owners usually set up maintenance facilities and engage qualified workers to perform the maintenance operations (Gransberg et al., 2006).

b) Tyre Cost

The tyre cost represents costs incurred in tyre repair and replacement. One of the most accurate sources of information while estimating tyre life, is the equipment field historical data obtained under similar field operating conditions. Dyson

(2018) observed that tyre failures significantly contribute to machine downtime. Failure modes ranged from belt edge separation to tyre cuts and normal wear.

c) Consumable Costs

Consumables refers to items needed for the operation of a field equipment and get consumed during its operation. These include, but are not limited to, fuel, lubricants, and other petroleum products besides filters, hoses, strainers, and other small parts/items that are used during the equipment operations (Gransberg et al., 2006).

d) Mobilization and Demobilization Cost

This refers to the cost of moving/shipping equipment from one work site to another. This cost is sometimes neglected because of the assumption that the previous work contracts cater for it (Gransberg et al., 2006).

e) Equipment Operator Cost

Operator's salaries/wages are often computed as a separate item to other calculated operating costs. It should, however, include overtime/premium charges, labourer's compensation insurance, social security taxes, savings, bonus, and other fringe benefits in the hourly wage payments (Gransberg et al., 2006).

2.11 Equipment downtime (DT)

Downtime (DT) is the time when an equipment is not operational due to repairs or mechanical adjustments (Nwanya et al., 2017). Downtime tends to increase with equipment usage. Availability refers to the period when equipment is in actual production or is available for production, which is the opposite of downtime. For instance, if the equipment's downtime is 30%, then its availability is 70%. The downtime cost includes the ownership cost, operating cost, operator cost, and productivity loss caused by the loss of equipment availability.

Santo et al, (2019) identified equipment misuse for heavier duties than their intended design, inadequate staffing, poorly trained operators and mechanics, failure to adhere to equipment Standard Operating Procedures (SOPs), as some of the factors for premature failures of road construction equipment in Uganda. Marinelli et al., (2014) applied an Artificial Neural Network (ANN) based model, with a 94% accuracy, for predicting condition levels of earthmoving trucks. The model identified an almost exclusive connection of the condition level with the kilometres travelled and the maintenance level. The impact of machine age and capacity was found to be negligible.

Edwards et al., (2002) applied a regression model to predict downtime costs of tracked hydraulic excavators operating in the United Kingdom (UK) opencast mining industry. Machine weight was used as a predictor for both cycle time and hire cost. The type of work under execution was seen to have significant impact on costs and production. Two research gaps were identified; the first one, being the need to incorporate cost per hour of consumables to perfect the model. The second being the incorporation of a broader range of equipment types operating in different work environments to create multiple downtime cost functions.

Downtime data analysed by Nepal and Park (2004) were found to represent an average of 6 per cent of planned working time for equipment. They went on to point out that, “Research on construction equipment downtime is limited” and that the downtime data they observed were, “chaotic”. Edwards et al., (2000) found that downtime is chaotic and not necessarily a function of machine size. The study conducted, concluded that downtime does not increase with machine weight. Percentage direct maintenance cost on parts was also found to increase with machine weight. The research also found that, approximately four days and nine hours per annum were lost to machine downtime in the quarrying and mining industry accounting for about 1.8% of total production time.

Yang et al., (2003) meanwhile, employed a fuzzy model to derive an “acceptable” result that might be improved given more independent variables while Seung and Sinha (2006), used an artificial neural network in attempting to account for modelling the complexity and changeable nature of excavating environments in the construction sector. Downtime data for heavy mining dump trucks in Eritrea, was analysed by Dyson (2018) and he found that the total downtime from body and frame breakdowns approximated 50.83hours of downtime per machine per month. This accounted for about 25% of the production time per machine. Factoring in other component breakdowns indicated fleet availability of 64% and downtime of 36%. Downtime could also be exasperated by inadequate labour placing many damaged machines on a waiting mode since most of the labour will be committed to planned maintenance and other breakdowns. Non-availability of an effective component replacement plan and equipment mid-life refurbishment, also increases the risk of machine failure and downtime.

The Caterpillar performance handbook indicates that the total number of actual operation hours on a machine along with the ownership period is a key factor in determining operating and owning costs (CAT, 2017). With recent advances in engine idle reduction systems (EIRS), idle time, for even short periods, can be reduced up to 60 percent. Caterpillar, CAT (2020) cites excessive idle time as jeopardizing component life, accelerating wear of Tier 4 technologies (emissions treatment components), requiring unnecessary fluid and filter changes, burning through warranty hours, and sacrificing resale value.

2.11.1 Downtime Factor Analysis

The following are identified downtime factors as per the research literature review. Previous research has reported that factors related to plant and equipment breakdown, particularly from a management perspective, must be considered in assessing the impact of DT (Edwards et al., 1998). Therefore, the researcher first identified the generic factors and processes related to DT through literature review and structured interviews (see Figure 2.11), some of which are incorporated into causal loop diagrams.

a) Site-related factors

As shown in Figure 2.11, examples of site-related factors include poor working conditions, uncertainties during equipment operation, and location of the site. The first two factors may affect the performance of equipment. For example, difficult and rugged terrain may cause equipment to deteriorate rapidly, thereby causing sudden failure. Proactive action on the part of a contractor can have significant effects in dealing with such factors. Contractors may not aware, however, of the site conditions they may encounter, either because of a lack of data or proper site investigation. Meanwhile, the uncertainty of operation, operating in different environmental conditions, causes a greater risk of equipment breakdown (Arditi et al., 1997; Edwards et al., 1998). The location of the site, for instance, may limit the type and size of equipment that can be transported to the site (Day & Benjamin, 1991). Moreover, the remoteness of a construction site may affect the repair time of equipment by affecting communication and the prompt procurement of parts.

b) Equipment-related factors

Factors that are related to equipment are its age, type, quality, complexity of operation, and degree of usage. A company's procedures and policies and site management actions can have significant influence on the selection, use and operation of equipment. It has been reported that the risk of equipment breakdown is related to the complexity and sophistication of the mechanical and hydraulic system of a piece of equipment (Elazouni & Basha, 1996; Arditi et al., 1997). It is, therefore, important for site management to have proper knowledge about equipment in terms of its capacity, complexity, and technical suitability for use under the given conditions.

c) Crew-level factors

These factors are related with human aspects of crews who are involved in the equipment maintenance, operation, and production process. The factors in this category would include skill level of operators and mechanics, fatigue, morale, and motivation. An operator's skill is one of the most important factors and it affects that operator's performance and the direct cost of DT through job efficiency (Arditi et al., 1997; Elazouni & Basha, 1996; Edwards et al., 2000). In addition, misuse of equipment, induced by the negligence of the operator and lack of proper training and know-how on the part of equipment supervisor, may result in increased frequency and cost of DT (Pathmanathan, 1980).

Another important aspect that may have impact on DT is through morale, motivation, and fatigue of the crews. These conditions may occur when site management attempts to increase the work rate by extensive use of overtime and placing pressure on crews to avoid the impact of DT. Above a certain threshold level, both factors can have negative effects on productivity by affecting fatigue and morale (Cooper, 1994; Roberts & Alfred, 1974). Furthermore, when the job context such as supervision, resource availability, worker compensation and the work environment is degraded, workers' motivations can result in loss of productivity (Maloney & McFillen, 1985).

d) Force majeure

This category includes the events that are unanticipated by project participants, particularly those related to natural calamities and events. Examples include floods, landslides, vandalism, and accidents. Such events may result in delays in equipment maintenance and effect on project performance. Contractors should anticipate some events, such as a heavy rainfall season, and take the necessary precautions to reduce their likely impact on DT. Additionally, adopting proper safety practices and increasing security measures can control events such as vandalism and accidents (Pathmanathan, 1980).

e) Company's procedures and policies

This category includes company's standard procedures and policies towards equipment management decisions and may include factors such as maintenance policies, replacement decisions, inventory management and control, standby repair and maintenance facilities, and procurement systems.

The equipment policies of a construction firm reflect the priorities set by top management and carry significance in terms of resource allocation and strategic planning (Sözen & Giritli, 1987). Not all the companies can justify, for example, the costs of carrying an inventory of spare parts, which might also be influenced by several available jobs on hand. A company's policies may also reflect the corporate-level strategy and existing market conditions. Furthermore, maintaining a proper fleet of equipment can be of strategic importance to a company in cases where the award of a contract is based also upon the condition and availability of equipment. Equipment management procedures and policies vary companywide. Thus, they can have different implications on downtime.

f) Project-level factors

Project-level factors such as the availability of spare parts, resources, and rental facilities, substitute equipment on hand, the location and sophistication of a workshop, and other project-specific requirements vary considerably and are related to DT. Site management can have a certain degree of influence on some of these factors, but mostly they are influenced by other causes, such as a company's action plan and procedures, the local and national market conditions, requirements of the project owner and, to some extent, site-related factors. Site management, for instance, may have difficulty in getting spare parts and materials to repair the equipment. In addition, any delay in the time required for skilled mechanics to arrive on the site may paralyze the work. Furthermore, receiving substitute equipment on time is another major challenge to projects that are in remote parts of a country. There are instances in which the specifications and contract documents may specify the types and sizes of equipment to be used. For instance, to avoid undesirable end results, the types and sizes of compacting equipment are sometimes specified, as are the travel speeds and the number of passes over embankments (Day & Benjamin, 1991). Additionally, the availability, location and sophistication of a workshop can have considerable influence on DT.

g) Site management actions

Site management may influence DT in several ways, such as substituting broken equipment, waiting for broken equipment to be repaired, adding, or changing resources, accelerating activities, transferring crews to other operations or sites, and changing the sequence of work. Each of these actions, when implemented properly, may reduce the impact of DT; if the selected course of action is not appropriate or is implemented in an improper way, however, it may exacerbate the situation. For example, extended use of overtime to accelerate work without improving the work environment may erode the motivation level of crews; it may also increase fatigue and, thus, induce more errors and rework (Thomas & Raynar, 1997; Eden et al., 2000). Consequently, a project may suffer loss of productivity. In addition, the selection of interdependent equipment is also important to ensure economical construction operations and to minimize costly idle time (Day & Benjamin, 1991).

h) Downtime and its consequences

Some of the important consequences of DT include idleness of equipment and crews, work disruption, activity delays and loss of productivity. Each of these consequences may, in turn, interact with site management actions, company's procedure and policies, project-level factors, and crew-level factors, as indicated by the two-way arrows in Figure 2.11. It is known that the nature of construction projects is that they are primarily "solution driven" and mostly focus on minimizing costs and limiting immediate consequences (Mitropoulos & Tatum, 1999). Thus, it is possible that site management may underestimate the actual impact of DT that may evolve from their action in due course. Site management, therefore, should understand the underlying phenomenon of DT and its possible impact on project performance in a systematic way, which we discuss further in the following section.

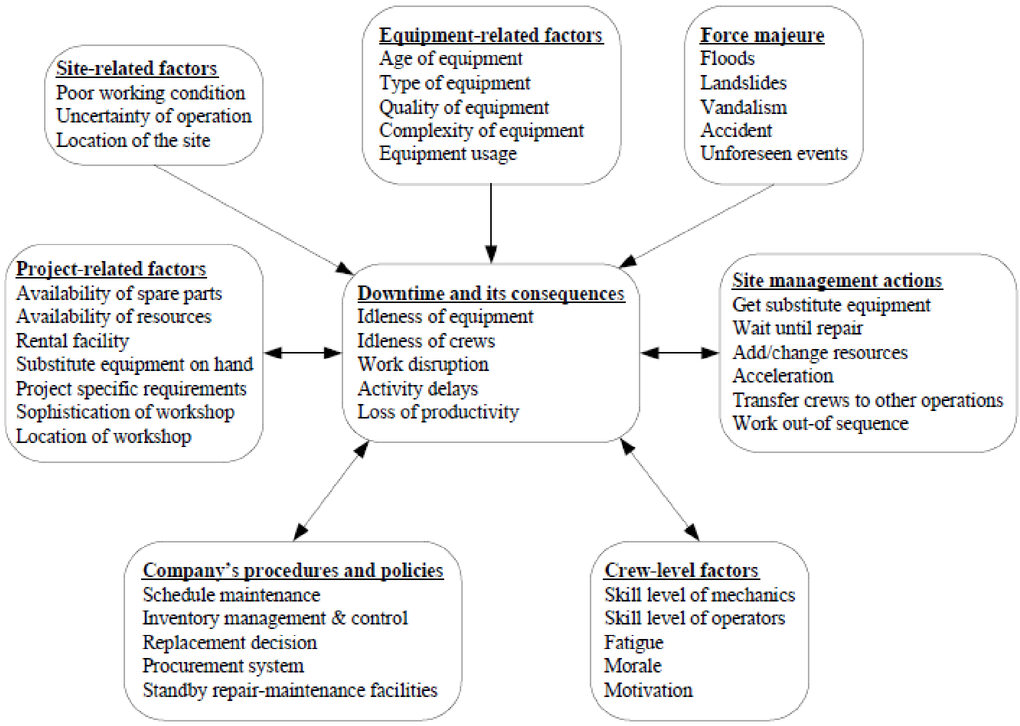


Figure 2. 11: DT factor analysis

Source: Adapted from Nepal, (2004)

2.11.2 Dynamics of Downtime

The identified DT factors related with crews and site management actions have been incorporated into causal loop diagrams to analyse various consequences of DT. The first and most noticeable effect of DT is resource idleness, which, if it lasts for extended periods, would slow down the progress of a project. Slow project progress increases schedule pressure (Neil, 1989). Many personnel under schedule pressures, become distracted from proper supervision and resort to hasty maintenance. This distraction tends to produce a low quality of maintenance, which then increases DT, which again increases schedule pressure, generating the vicious reinforcing loop denoted as R1 in Figure 2.12. On the other hand, DT of vital equipment and/or on critical activities brings an increase in DT costs. As DT cost increases, there is an increased emphasis on cost, which shows up as cost pressure. Personnel under high-cost pressure (due to unexpected DT costs) might pay less attention to maintenance work. As a result, another vicious feedback loop is triggered, represented as R2 in Figure 2.12. These feedback loops cause further cost pressures and can slow down project progress until, or unless, the root causes are identified, and proper action is taken.

Extended and frequent DT also can disrupt the original flow of work. Disruption of work may occur in several ways. For example, personnel may decide to change the sequence of work, which may introduce new methods or procedures, or they may decide to divert the resources affected by DT to other site operations. If personnel are not fully aware of the indirect consequences of their decisions, the diverted resources could distract the original production plan by diluting the experience level of existing crews and increasing site congestions and work interference (Piper & Vachon, 2001). The frequent disruption of work also can erode crew morale (Eden et al., 2000). This effect can also lead to frequent stoppages and the imposition of additional learning requirements for crews, which slows down project progress (Piper & Vachon, 2001). As a result, the feedback effects caused by two additional reinforcing loops, indicated as R3 and R4 in Figure 2.12, affect the construction process.

Schedule pressure can be reduced by timely maintenance of equipment by project staff, as indicated by balancing loop B1. The other common managerial actions that are often taken to avoid the impact of DT on project progress are the use of overtime and the placing of pressure on staff to increase the work completion rate. Overtime can facilitate the progress of construction by increasing working hours, as conceptualized with balancing loop B2 in Figure 2.12, but as it continues it also can lower productivity through causing fatigue in workers (Cooper, 1994; Thomas and Raynar, 1997). As a result, an additional vicious reinforcing loop, R5 in Figure 2.12, is generated.

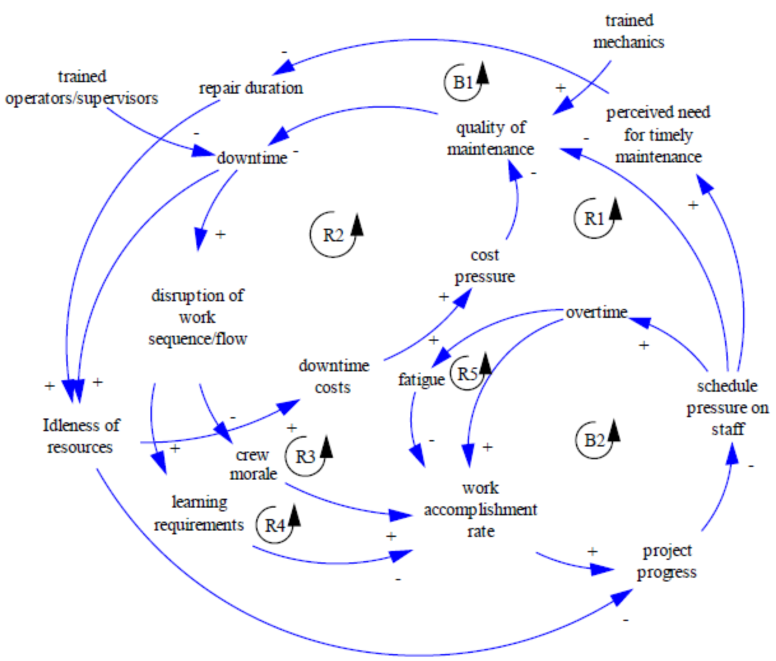


Figure 2. 12: Dynamics of equipment DT

Source: Adapted from Nepal, (2004)

2.12 Mean Time To Repair (MTTR)

Equipment availability refers to the period a piece of equipment is in an operable condition and readily available for use when needed, excluding all recorded repair durations. The measurement units are usually expressed in hours. Dhillon

(2008) expresses availability as the probability that a piece of equipment is functioning to the user's satisfaction at a specified time, when used according to specified conditions, where the total time includes operating time, logistical time, active repair time, and administrative time. Pinto et al., (2002) on the other hand, describe availability as the ratio of possible working hours to calendar hours and that it is a key indicator for reliability analysis.

$Availability\ Time\ \% = AAT/TT \times 100$………………...……..… **(Equation 2.1)**

Where: AAT = Actual Available Time; and TT = Total Time.

The Actual Available Time was derived from the computation:

Actual Availability Time (AAT) = $TT - (P + R + D + L + S + O) \times$ *Number of days* ……………………………………………………………………….….

(Equation 2.2)

Where: Pre-start Inspections is represented by (P); Refuelling of the Machine by (R); Daily Inspections (D); Breaks -Tea and Lunch (L); Shift Change-Over (S); Other work Activities (O); Hours per Shift (H); and Total Time (TT) = H x Number of days.

MTTR was calculated using the formula: $MTTR = TDT/NF$

Where: MTTR = Meantime to Repair TDT = Total Downtime NF = Number of failures.

2.13 Mean Time Between Failure (MTBF)

Meantime Between Failure is the predicted elapsed time period between inherent failures of equipment or systems during normal operations. Esmaeili (2016) expresses Mean Time Between Failures (MTBF) as the mean time of the failure distribution of a machine/component, for a constant failure rate. It is expressed as the total operating time as a ratio of the total number of repairs. Esmaeili (2016) found that MTBF took an almost linear trend during the study period under review, and it was calculated using the following formula:

$MTBF = TOH/NF$ ………………………………………………..……… **(Equation 2.3)**

Where: MTBF = Meantime Between Failure; TOH = Total Operated Hours and NF = Number of failures

It is therefore important to corroborate the Key Performance Indicators (KPIs) as it is common practice in certain operations, to calculate equipment availability and thereafter make up MTTR and MTBF figures from no background information.

$A = MTBF/(MTBF + MTTR)$ …………………………………………… **(Equation 2.4)**

Where: A = Availability, MTBF = Meantime Between Failure, MTTR = Meantime To Repair.

2.14 Machine Utilisation

Machine utilisation refers to the percentage of available production time during a selected time period that a machine operates to process materials (Sessions et al, 2021). Machine production depends upon job efficiency, which can be defined as machine utilisation on a time usage basis (CAT, 2017). CAT specifies that an 83% job efficiency is fairly robust.

2.15 Major soil types in Uganda

According to Langlands classifications (1974), and NEMA (2009) the soil of Gulu consists of ferruginous soil (Acric Ferralsols) with a high percentage of sandy soils, making it susceptible to erosion. Due to its sandy nature, the soil has a low water retention capacity and a high rate of water infiltration. The natural soils in Jinja are mostly Nitisols. Nitisols are normally deeper than 150cm 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.

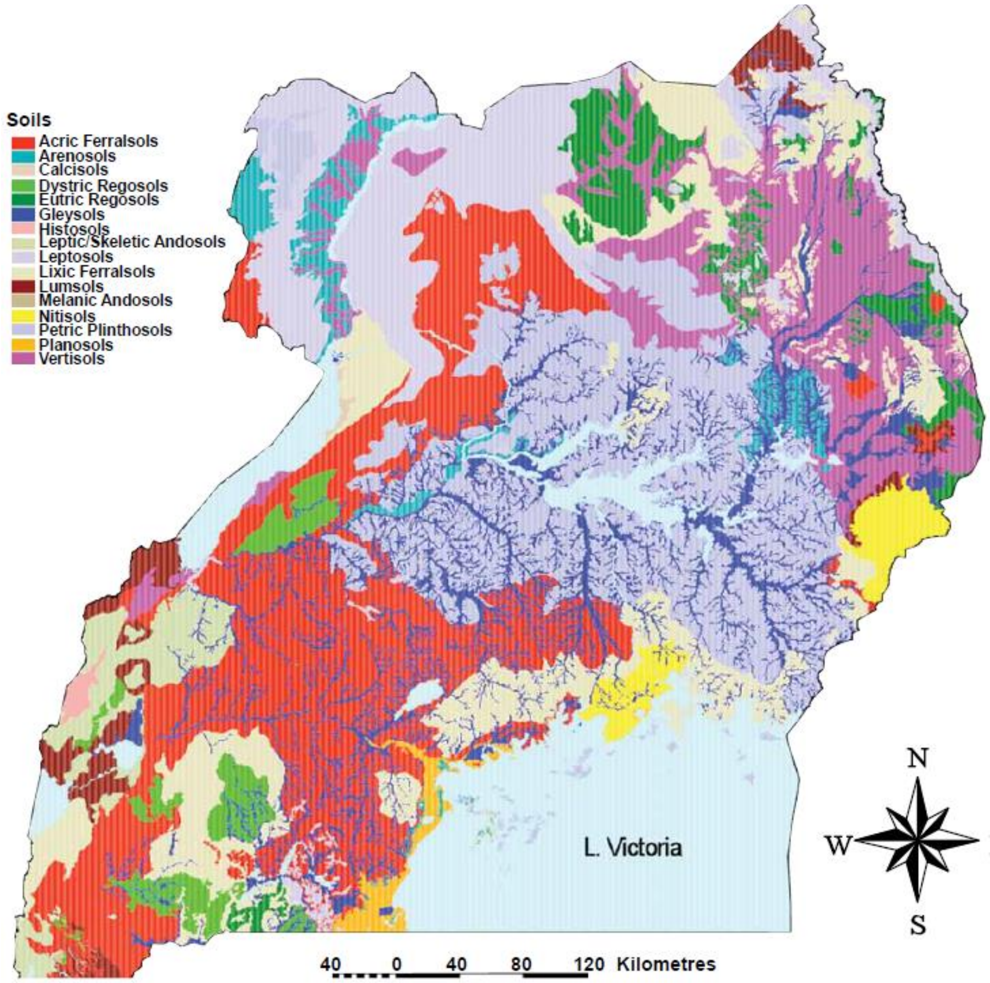


Figure 2. 13: The major soils of Uganda
Source: (NEMA, 2009)

2.16 Chapter Summary

This chapter expounded on key definitions of road maintenance aspects, challenges related to road maintenance, road maintenance equipment costs, equipment downtime and reliability factors, key equipment maintenance policies, equipment performance measurement, equipment reliability factors, key indicators of downtime during machine maintenance, equipment utilisation among others. Previous research regarding equipment failure and downtime were also highlighted including areas that offered opportunities for further research.

The research gaps were mainly in road maintenance costing, and forecasting. Regarding road maintenance/construction equipment selection and associated works, various methods and models had been discussed previously in literature. However, most studies did not consider economical operation analysis. Instead, the studies focused on developing systems, algorithms, or a framework to assist the user for selection of equipment. Other research was focussed on associated factors affecting construction/road maintenance operations and associated challenges faced. Some of these studies included time and cost estimation at the conceptual stage of the project; however, this study includes operation cost analysis during work execution.

The next chapter expounds on methods and steps used by the researcher to meet the research objectives and address the gaps raised.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter contains the research design, case study plan and protocols, data collection tools, data sources and data analysis methods used by the researcher.

3.2 Schematic diagram for methodological approach

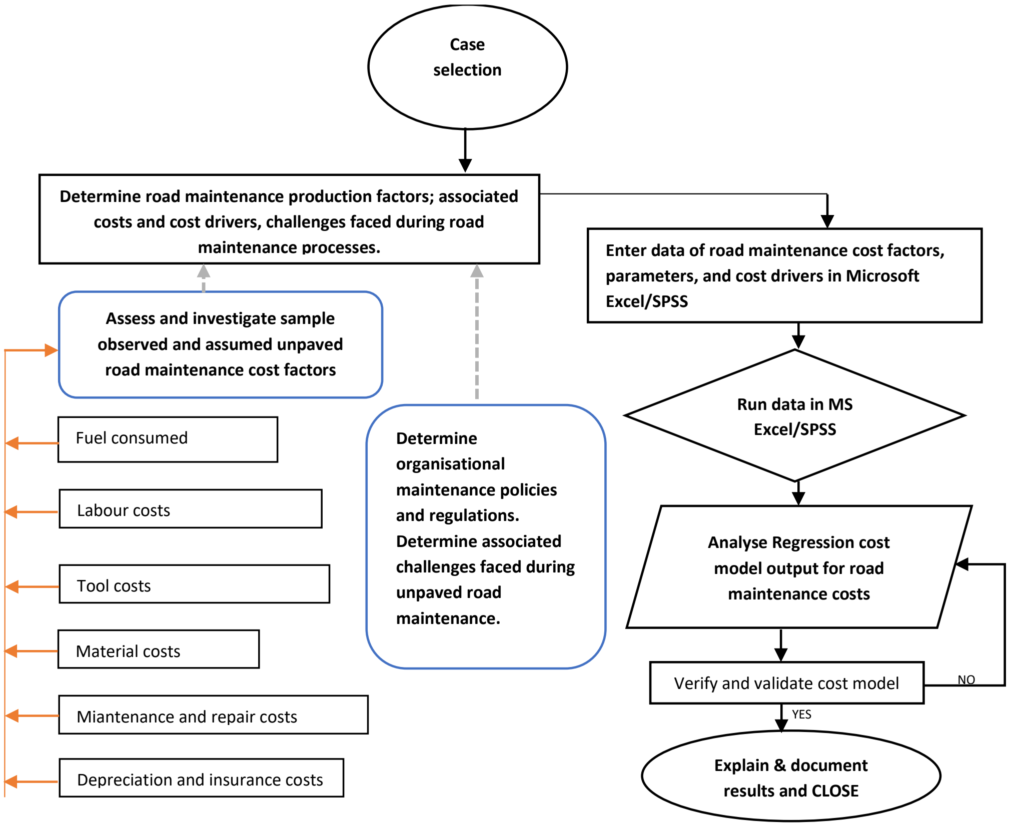


Figure 3. 1: Schematic diagram for methodological approach

From the above schematic diagram, the case study area was selected basing on location, timeliness, and data availability, road maintenance equipment, and cycle times. Their cost drivers were determined; then the data was entered in MS Excel spreadsheet /SPSS statistical software while incorporating all the necessary cost parameters and factors; a cost per km output was then generated from the Excel spreadsheet. The equipment production cost was a composition of the machine repair and maintenance cost, lubricant cost, fuel costs, insurance costs, operator salary costs, and depreciation costs. These production costs were obtained from KSL and Gulu District Local Government machine daily logs, maintenance & repair records, project priced bills of quantities. All data obtained was analysed in SPSS and MS Excel Software, then compared with previous research findings. Explanations for all findings obtained were given and the findings were then documented.

3.3 Research design

The research used descriptive research design to describe the phenomenon as it exists. This is because descriptive research is an appropriate choice when the research aim is to identify characteristics, frequencies, trends, and categories (Siedlecki, 2020). Two descriptive research methods were used: observations and case study approach. A case study is an appropriate research design when you want to gain concrete, contextual, in-depth knowledge about a specific real-world subject. It allows you to explore the key characteristics, meanings, and implications of the case (Yin, 2018). Case studies can be single or multiple case if one has to compare and illuminate different aspects of a research problem. The case study approach allows the use of both quantitative and qualitative data analysis (Zainal, 2007).

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. This research adopted multiple-case design research within the quantitative and qualitative research paradigm, with the aim to corroborate and interpret information management for unpaved road maintenance practices. Multiple-case design has its own benefits and limitations. The benefits highlighted by Gustafsson (2017) are that a multiple-case design allows a wider discovery of theoretical evolution and research questions. Furthermore, it allows the researcher to have a deeper understanding of the explorative subject, the evidence generated from a multiple case study is strong and reliable, and the writer can clarify if the findings from the results are valuable or not. According to Gustafsson (2017) there are more benefits than limitations to multiple-case designs. The one major limitation noted by Gustafsson (2017) is that a multiple-case design can be expensive and time consuming to implement.

The quantitative approach was thought to be best suited for this study because it allows for collecting numeric data on observable individual behaviour of samples, then subjecting this data to statistical analysis (Amin, 2005). 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.

All the information gathered during the interviews was transcribed and analysed using inductive content analysis. Marshall and Rossman (2011) describe the notion of content analysis as an "objective and neutral way" to secure qualitative descriptive data, where specific words are counted. 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 v29 for analysis and processing.

Also, to ensure a chain of evidence was followed, all data collected was in line with 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.

3.3.1 Data coding

In line with Rabinovich and Kacen, (2010), categories were developed independently at first and only later, during axial, or second-order coding, related in some way. Coding helped to reduce the data into themes or categories that emerged from the analysed data in line with Clark and Creswell, (2010). The purpose of creating categories is to provide a means of describing the phenomenon, to increase understanding and to generate knowledge (Elo and Kyngas, 2008). The material, revisited and recoded, created data from which links were made to interpret and analyse concepts and issues relating to unpaved road maintenance.

The links in the data help develop ideas from the data interpretation and analysis. Through this process the essence of the terms of the available data are captured in a written word or in short phrases (Saldana, 2011). As categories and themes were developed integrative interpretations were offered of what was learned. As Marshall and Rossman (2011) suggest, a "story could be told" bringing meaning and coherence to the themes, patterns, and categories, developing linkages that make sense and is engaging to read.

3.3.2 Case study plan

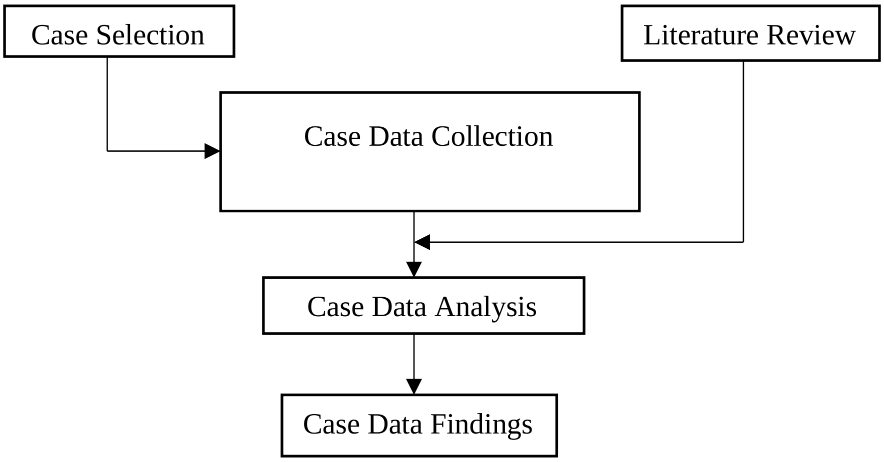


Figure 3. 2: Case study plan

In this multiple case study research, the researcher identified case study areas/location, collected, and analysed data to produce results and the analysed data were discussed in the context of the earlier raised research questions and reviewed literature before drawing conclusions. The selected case study areas were Kakira Sugar Limited (KSL) based in Jinja, Gulu City Council Engineering department which also doubles as the Gulu District Engineering Department. Both case study locations are based in Uganda.

The case study areas were selected primarily due to their convenience, access to information, and geographic proximity. 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 City Council and 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 as a comparison to the private sector setup at Kakira Sugar Limited (KSL). Mechanized unpaved maintenance road cost data from UNRA was used for comparison purposes when discussing the road maintenance costs.

Participants involved in the study were recruited from heads of departments, managers and workers who carry out road maintenance execution at KSL and at Gulu DLG. The participants were not unnecessarily classified in terms of race, age, or gender. Participants were presented with a letter (attached in appendix) explaining all facets of what is expected and what the purpose of the study was. The participants were further allowed to decide on their involvement and participation and could withdraw at any time without any consequence. Participants were assured of confidentiality and anonymity. Viewing of the findings by participants was used to validate data, for ethical reasons. Written approval was obtained from the Kyambogo University and endorsed at KSL. Data from UNRA was obtained by secondary data collection by means of annual UNRA reports and computing the data presented into an acceptable format.

The selected case study design was a multiple case (holistic) design with quantitative techniques used in data collection and analysis. Care was also taken to ensure case study design quality tests of internal validity, construct validity, external validity and reliability were adhered to. Since the key issue in internal validity is the causal relationship between variables, the solution lay in establishing key conditions/parameters to be met prior to establishing these causal effects. the explanations developed where built on previous literature covered in the literature review. Regression models and graphical data was presented to clearly explain complex phenomena in an easily understandable 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). The draft case study report was reviewed by key experienced technical persons and my research supervisors. 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 pilot. The UNRA cost data was used for comparison purposes.

The credibility of the findings of this research is founded on triangulation principles which are supported by semi-structured interview and participant observation. Data triangulation consists of gathering the data from different sources. According to Farquhar (2012) triangulation is a key concept in case study research especially with reference to triangulating data sources or data methods. Marshall and Rossman (2011) argue that triangulation is the act of bringing more than one type/source of data to bear on a single point. The multiple case study design enabled the phenomenon of the participants involved in unpaved road maintenance to be examined in different contexts. Through triangulation a more accurate, comprehensive, and objective representation of the data was achieved.

The case study protocol used, helped in ensuring the chain of evidence was maintained. All collected data were stored in the form of field notes, videos, sketches, and statistical records obtained. This ensured reliability of the collected data. Field data input in SPSS software was tested using; 1-correlation analysis to determine the relationship between different variables, 2-Normality analysis where a histogram of residuals was plotted for the dependent variable, 3-Equality of variance where a plot of residuals against the predicted values was generated.

To achieve the objectives of the research study and adequately answer the research questions, information was gathered through a review of the literature, site observation, and reviewing the project's archival documents of projects in general.

The study attended through the following phases of research approach:

(a) In phase one: Literature review was carried out mainly to examine and understand the concept, the problem associated, and the methodologies used from previous studies on comparative studies of unpaved road maintenance approaches, equipment maintenance and productivity computations, and road maintenance policies. The second and third phase included the collection of data based on both desk review and field work.

(b) Desk review: Data collection started by collecting data on completed unpaved road maintenance works in Jinja and Gulu. Jinja was selected for a private sector perspective while Gulu was selected for a government local government perspective on unpaved road maintenance works. In this phase of research, relevant published data from periodicals, journals, conference proceedings, web-based knowledge and other research reports were analysed. The thorough literature survey on the secondary data helped to develop a framework for the intended research.

The data collected was perused several times before starting the process of analysis to become familiar with the dataset. This was done according to the guidelines provided by Clark and Creswell (2010), Henning, Van Rensburg and Smit (2004), and Thomas (2006). Taylor and Lindlof (2010, p. 247) further indicate that through the inductive process of data analysis the analyst must explore and do close reading, to interpret results.

3.4 Case study protocol

A Case Study Protocol (CSP) refers to a set of guidelines that can be used to structure and govern a case research project (Yin, 2018). It can be particularly useful in research projects involving multiple researchers as it ensures uniformity in data collection and analysis (Yin, 2018). CSPs also ensure uniformity in research projects where data is to be collected in multiple locations over an extended period. In addition to procedures, a CSP also contains the research instrument(s) that will be used to collect data during the research project. Depending on the research design and the problem(s) under consideration, the research instrument may either be quantitative, qualitative, or a combination of both, if the research design allows for a pluralist approach (Mingers, 2001). This research adopted the quantitative research method as earlier explained.

Table 3. 1: Case Study Protocol

Stage	Activity	Participants	Purpose
Stage 1: General overview	Provide overview of research project. Case research method to be used.	Researcher	Provides a brief overview of the research project and the case research method.
Stage 2: Procedures	Initial approach to organisations • Selection of cases • Number of cases • Establishing contact Scheduling of field visits Length of sessions Equipment and stationery	Researcher Research supervisor	Detailed description of the procedures for conducting each case. These procedures should be utilised to ensure uniformity in the data collection process and consequently facilitate both within case and cross case analyses
Stage 3: Research instruments	Semi-structured interview with the primary contacts. Identify and collect secondary data documents and artefacts; Review company organizational structure; Identify stakeholders for the data collection stages.	Researcher, case study area departmental heads/Lead maintenance engineers; Mechanics, machine operators,	Research instruments developed utilising guidelines by Neuman (2000) and Sekaran (2000). It is recommended that these research instruments be highly structured to facilitate the data collection process and uniformity in the collection of said data.
Stage 4: Data Analysis guidelines	Overview of data analysis processes <u>Details regarding:</u> a) How convergence of data from multiple sources will be achieved b) How triangulation of perspectives from multiple participants will be achieved • Description of 'Within case' analysis process: a) Descriptive Data b) Explanatory Data c) Individual case report • Description of "Cross case" analysis process • Description of 'Cross sectoral' analysis process (where necessary) • Data schema a) Summary of primary data types, sources, and purpose b) Summary of secondary data types, sources, and purpose. • Description of data displays that will be used in analysis.	Researcher	Guidelines for data analysis based on guidelines such as those provided by Miles and Huberman (1994), Yin (2018) and Neuman (2000).
Appendix	Data collection/participation/researcher introduction letter Identify and collect secondary data documents and artefacts; Review company organizational structure; Identify stakeholders. for the data collection stages.	Researcher, University department	Template letter provided by university to student as introduction letter. It is recommended that these research instruments be highly structured to facilitate the data collection process and uniformity in the collection of said data.

Table 3. 2: Research instruments

<table>
<tr><th colspan="2">Research Instruments (Table 3.2)</th></tr>
<tr><th>Stage</th><th>Data Collection/Analysis Instruments</th></tr>
<tr><td>Preparation:

stage 1</td><td>Overview of research project:
My major interest was in understanding the DLG’s Force Account Mechanism of mechanized unpaved road maintenance and its associated costs in relation to similar private sector led initiatives in Uganda.
Preliminary research questions and associated literature review:
Preliminary research questions:
What are the factors that affect the cost of mechanized unpaved road maintenance works.
What are the fixed and variable costs of mechanized unpaved road maintenance operations.
How can the costs of mechanized unpaved road maintenance operations be predicted?
Associated literature review: Reading material on the following: -
State of road infrastructure in Africa and particularly uganda.
Challenges facing Uganda’s road construction and maintenance sector.
How have these challenges been addressed?
What literature exists on this subject?
What are the gaps in addressing the challenges cited?
What areas have not been addressed in existing research literature?</td></tr>
<tr><td>Data collection: stage 2&3</td><td>Select case study locations to be considered.
Locations selected should be as many as possible for reliability purposes and must be aligned to the case study research objectives.
Establish preliminary contact with key persons in selected case study areas.
Write emails, letters to the focal points/admins at the selected case study area. Obtain permission (preferably written permission) before obtaining data.
Schedule field visit to case study area.
Identify key stakeholders.
Plant managers
Maintenance staff
Operational staff
Use semi-structured interview questions to interview key personnel onsite.
<u>Sample for district engineering team:</u>
Brief overview of how Force Account Mechanized system for unpaved road maintenance works is carried out at DLG (District Local Government) level.
What equipment is used for mechanized road maintenance?
What are the operational costs of these equipment (fuel, operator labour, repair and maintenance costs...etc).
What sample unpaved road maintenance projects have been carried out indicating km covered and total cost involved?
Have there been any machine breakdown records and what are their associated repair costs?
How long do the machine repairs usually take?
Are there any tools used in the computation of Force Account System costs (Excel sheet</td></tr>
</table>

<table>
<tr><th colspan="2">Research Instruments (Table 3.2)</th></tr>
<tr><td></td><td>

calculators, formulas, ...etc)?.
Are there any challenges faced by the DLG/your office during the implementation of Force Account System or any other maintenance strategy?
How where the challenges addressed?
What is the predominant soil type in the area under unpaved road maintenance.
Is there any other useful information regarding mechanized unpaved road maintenance operations?

<u>Sample for private sector engineering team:</u>

Brief overview of the method used for unpaved road maintenance works?
What equipment is used for mechanized road maintenance?
What are the operational costs of these equipment (fuel, operator labour, repair and maintenance costs...etc).
What sample unpaved road maintenance projects have been carried out indicating km covered and total cost involved?
Have there been any machine breakdown records and what are their associated repair costs?
How long do the machine repairs usually take?
Are there any tools used in the computation of the road maintenance costs (Excel sheet calculators, formulas, ...etc)?
Are there any challenges faced by the engineering team during the implementation of the road maintenance works?
What is the predominant soil type in the area under unpaved road maintenance.
Is there any other useful information regarding mechanized unpaved road maintenance operations?

Identify and collect primary data documents.

Semi-structured interviews
Participant observation
Non-participant observation
Videos and pictorial records of onsite works

Identify and collect secondary data documents.

Machine catalogues
Existing research literature.
Company records and data on maintenance operations.

Review company/organisational data, literature, and records.

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.

</td></tr>
<tr><td>Data Analysis and presentation: Stage 4</td><td>

Use IBM SPSS v26, MS Excel for data analysis.
Use of tables and graphical data for data presentation.

</td></tr>
</table>

3.5 Eisenhardt framework

The case research design proposed by Eisenhardt (1989) provides the context in which the guidelines for the development of the CSP (Case Study Protocol) will be discussed. 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 Maimbo and Graham Pervan, 2005).

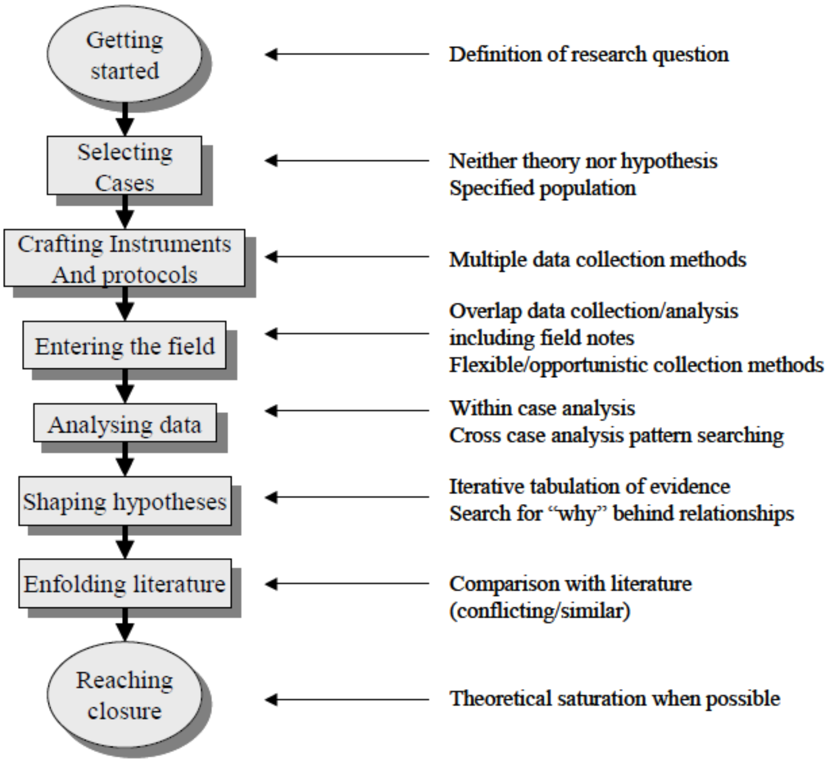


Figure 3. 3: Research framework

Source: Adopted from Eisenhardt, (1989).

Table 3. 3: Framework for Case Research

Phase	Stage	Activity	Reason
Phase One	Getting started	• Define of research question(s) • Possible a priori constructs	• Focuses efforts • Provides better grounding of measures
	Selecting cases	• Neither theory nor hypothesis • Specified population • Theoretical sampling	• Retains theoretical flexibility • Constrains extraneous variation and sharpens external validity
	Crafting instruments and protocols	• Multiple data collection method • Qualitative and quantitative	• Triangulation strengthens grounding of theory
Phase Two	Entering the field	• Iterative data collection and analysis • Flexible opportunistic data collection	• Speeds analysis • Facilitates emergent themes
	Analysing the data	• Within-case • Cross case analysis	• Gains familiarity with data and preliminary theory generation • Looks beyond initial impressions
	Shaping hypothesis	• Iterative tabulation of evidence for each construct • Replication logic across cases • Search for the cause, i.e. the 'why' behind relationships	• Sharpens construct definition, validity, and measurability • Confirms, extends, and sharpens theory • Builds internal validity
Phase Three	Enfolding the literature	• Comparison with conflicting literature • Comparison with similar literature	• Builds internal validity, raises theoretical level and sharpens construct definition • Improves generalisability, raises theoretical level and sharpens construct definition
	Reaching closure	Theoretical saturation	Ends process when marginal improvement becomes small.

Source: Adapted from Eisenhardt, (1989)

3.6 Sources of data collection

The researcher used both primary and secondary sources of data collection as stated below.

3.6.1 Primary Sources

This included data collection by use of semi-structured interviews, field observation (participant and non-participant) of ongoing road maintenance works. These resulted in a collection of field notes, videos, sketches, photographs, field statistical and survey data.

3.6.2 Secondary Sources

Secondary sources of data reviewed by the researcher included: Scholarly journal articles, unpublished manuscripts, Period newspaper and magazine articles, Machine catalogues, official government documents and reports, company records and data on maintenance operations. The reviewed company/organisational data included 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.

3.7 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 for additional information. The field data collection log is indicated in Table 3.4

Table 3. 4: Data collection tools and data type collected

SNo.	Data collection tool	Data collected
1	Semi-structured interview	Organisational process of road maintenance, equipment involved, and challenges faced. Equipment breakdown records, repair and maintenance process and costs.
2	Participant observation. (Data collected using field notes, photographs, videos).	Unpaved road maintenance projects. km covered, aspects/factors of road maintenance operation costs, and total costs involved.
3	Non-participant observation (Data collected using field notes, photographs, videos).	unpaved road maintenance projects. km covered and total costs involved. Equipment breakdown records, aspects/factors of road maintenance operation costs, and total costs involved. Repair and maintenance process and costs.

The data collected for the road maintenance processes, cost drivers and other associated processes took place by way of semi-structured interviews. The reason for using this method is best described by De Vos et. al., (2005, p. 297), namely "to gain a detailed picture of a participant's beliefs about, or perceptions or accounts of, a particular topic". Semi-structured interviews are the most appropriate when the interviewer has to dig deeper in search of critical comments, design requirements, and other insights (Lazar et. al., 2010; Wilson, 2010). The semi-structured approach allowed respondents some latitude and freedom to talk about what is of interest or importance to them allowing flexibility in the interview process (Hesse-Biber & Leavy, 2011). During the sharing of information new concepts and information may emerge relevant to the study. The interviewer is to be then able to ask the interviewee to clarify or expand on these aspects in more detail. The interview process may be considered a conversation with a specific purpose. It is important for the interviewer to project an attitude that whatever the participant was saying is of value and useful (Berg, 2009; Marshall & Rossman, 2011; Merriam, 2009).

3.8 Achievement of specific objectives

Specific Objective 1 was achieved using data collected through field observation, literature review of organisational equipment logs and existing researched material. This helped to identify the cost factors that are affecting equipment production and downtime.

Specific Objective 2 was achieved using data collected through field observation, road maintenance bills of quantities, equipment usage data logs and literature review of organisational equipment logs. These were then computed to determine the unpaved road maintenance costs.

Unpaved road maintenance cost = direct production Costs + indirect production costs………………………………………………………………. **(Equation 3.1)**

Indirect production cost items included equipment depreciation, interest on investment, taxes, storage, and insurance. Direct (operating costs) included cost of fuel, lubricants, tires, equipment maintenance/ repairs, material purchase costs, tool purchase costs, and labour costs. The researcher's observations were then converted to numerical data and then analysed using SPSS. Existing company archives and file records related to unpaved road maintenance, equipment maintenance and repair were also used.

Specific Objective 3 was achieved using a regression cost model development process, involving the steps of model estimation, model calibration, model validation and model application. Model estimation refers to the application of statistical analysis techniques and observed data to determine model parameters. These parameters were determined in Specific Objective 1. Calibration is the activity of verifying that a model, of a defined problem in a specified domain, correctly describes the phenomena that occurs in that domain. During model calibration, values of various relevant coefficients were adjusted to minimize the deviations between model predictions and actual observed measurements in the field.

Verification was performed to ensure that the model performs as intended. Validation refers to the process of demonstrating that the model is a reasonable representation of the actual system so that it reproduces system behaviour with enough fidelity to satisfy the initial objectives (Giancristofaro, 2003).

The research employed a deterministic model method because its outcomes are precisely determined through known relationships among states and events, without any room for random variations. The regression cost model was selected due to its proven reliability in cost analysis operations. Regression models developed have been highlighted in chapter four of this research work.

3.9 Framework for Conceptual Modelling

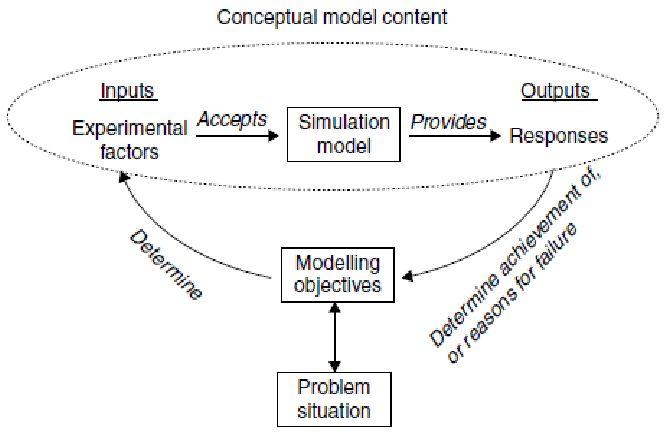


Figure 3. 4: Adopted framework for conceptual modelling.
Source: Adapted from Stewart, (2004)

Commencing with an understanding of the problem, a set of modelling objectives were determined. These objectives were then used to drive the derivation of the conceptual model, first by defining the inputs and outputs, and thereafter by defining the model content as listed below.

- Develop an understanding of the problem.
- Determine the modelling objectives.
- Design the conceptual model inputs and outputs and.
- Design the conceptual model (model content).

3.10 Ethical implications and how they were addressed.

Ethical considerations in research are a set of principles that guide your research designs and practices. This includes neither plagiarizing nor falsifying information, as well as being honest, avoiding deception, and accepting responsibility for your own work. 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).

Table 3. 5: Ethical issues faced and how they were addressed.

SNo.	Ethical issue	Action taken
1	Voluntary participation	The researcher informed all inform all potential participants that they were free to choose whether to participate or not, and they could withdraw at any time, from contributing to the research study without fear of any negative repercussion.
2	Informed consent	The researcher obtained an introduction letter from Kyambogo University clearly explaining the purpose of the research and what would be studied. KSL provided a consent letter. The researcher also ensured that all data used was strictly for academic purposes.
3	Anonymity/confidentiality	The researcher guaranteed anonymity/confidentiality by not collecting any personally identifying information—for example, names, phone numbers, email addresses, IP addresses, physical characteristics, or incriminating photos/videos.
4	Potential for harm	Harm can be psychological, social, physical, or legal. The researcher ensured that all participants were notified about the research and what it entails including any potential for harm. The researcher ensured no one was hurt in any way by the contents of this research. The case study focal points were all sent a copy of this research study, and none has filed a complaint regarding its contents.
5	Results communication and plagiarism mitigation	The researcher ensured the contents in this research were honest, reliable, transparent, and credible by following best practices in carrying out research as outlined by Yin, 2018. This research was reviewed by the researcher's university supervisor before submission. Plagiarism was mitigated by ensuring all quoted or referenced material was clearly cited. Also, the contents of this research were subjected to the Turnitin plagiarism checker returning a similarity index of 18%. Also, all the methodological approaches used, and raw data has been provided in this research to ensure it can be replicated.

3.11 Research limitations

Every research has limitations. This can be theoretical, methodological, empirical, analytical, or even ethical (https://www.aje.com/arc/How-To-Write-Limitations-Of-The-Study/. Retrieved November 18, 2023, from https://www.aje.com/arc/how-to-write-limitations-of-the-study/.) The findings of this study have to be seen in light of some of these limitations. The theoretical scope of this study was limited to understanding cost drivers that affect unpaved road maintenance works and how these can be predicted using a linear regression cost model system.

By comparing different cases, the researcher was able to gain a deeper and broader understanding of the phenomenon, and uncover its underlying mechanisms, causes, and effects since multiple cases can enhance the credibility and reliability of the research, by providing more evidence and data to support the findings, and by allowing the researcher to test and refine the hypotheses or theories that guide the study (Yin, 2018). Furthermore, multiple cases can increase the transferability and applicability of the research, by showing how the findings can be relevant and useful for different audiences, contexts, or scenarios. The downside to the multiple case study approach was that it required more time, resources, and effort from the researcher, as well as from the participants and stakeholders involved in the research. Compared to a single-case study, a multi-case study involves more data collection, analysis, and synthesis, which can be challenging and demanding for the researcher, especially if the cases are complex, diverse, or distant (Gulu and Jinja districts are distant from each other also considering the different government and private sector settings). Additionally, obtaining the consent and cooperation of the managers and other staff, and trying to manage the logistics and coordination of the fieldwork was very challenging. UNRA cost data obtained also had no breakdown and was mainly composed of contract cost sums and km of road maintained.

There was also the issue of selecting the appropriate number and type of cases, balancing the depth and breadth of the analysis, and integrating and presenting the findings in a clear and coherent way.

The ethical limitations were mainly concerning limited access to data that was viewed as confidential at both the DLGs and at KSL. This raw data could mostly be accessed through semi-structured interviews and participation in the road maintenance activities. A few hard copy and soft copy documentations were provided at KSL and Gulu DLG. The researcher ensured that written/verbal permission was obtained prior to accessing any data, premises, or information. Some of the access letters have been attached in the appendix.

Regarding the linear regression method used for analysis, one of the limitations is that it only considers variables with linear relationships. This implies that data sets without linear relationships are most likely to be excluded. There may be variables other than those considered which do influence the response variable. Also factoring in that a strong correlation does not necessarily imply cause and effect relationship. In terms of content depth/scope, the research mainly focussed on cost factors and their quantitative value with regard to unpaved road maintenance and how to model these. The research did not delve into equipment breakdown analysis, forecasts, and modelling, alongside equipment 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.

3.12 Research assumptions

The rationale of this section is to explain and justify the selection of a multiple-case design using a qualitative research paradigm to address the research question "What are the cost drivers for unpaved road maintenance and how can these be predicted?". Since the multiple case study approach helps create theoretical constructs, propositions and/or midrange theory from case-based, empirical evidence, this enabled the researcher to understand the differences and similarities of unpaved road maintenance processes between the three multiple cases studied (Eisenhardt and Graebner, 2007).

a) Ontological assumptions

Regarding this study an interpretivist approach was used, to make sense of the cost drivers influencing unpaved road maintenance works. The problem being researched regarding the cost drivers were influenced by the perspective of the participants, (viz those experiencing the phenomenon); thus, the interpretation and reporting thereof, required an interpretivist approach to the research.

According to Perri and Bellamy (2012) the accuracy of secondary interpretation is based on the standard of interviewer, to fully interpret and capture the essential structure and details of the interviewees' experiences, as shared in an interview.

b) Assumptions made during the analysis during data analysis

The following were the assumptions made during the data analysis process.

A workday is 8hours. Soil types, though varying created neglible impact since all DLGs have similar equipment and no choice in what equipment they will be supplied. At KSL, there was also no choice in equipment to be used since the satellite station used what they were provided with.

c) Cost model assumptions

Assumption #1: The dependent variable had to be measured at the continuous level (i.e., it is either an interval or ratio variable). Examples of continuous variables include machine hours worked (measured in hours).

Assumption #2: The independent variable had to be measured at the continuous level.

Assumption #3: There needed to be a linear relationship between the two variables (dependent and independent).

Assumption #4: There had to be no significant outliers. An outlier is an observed data point that has a dependent variable value that is very different to the value predicted by the regression equation. As such, an outlier will be a point on a scatterplot that is (vertically) far away from the regression line indicating that it has a large residual value.

Assumption #5: There had to be independence of observations seen.

Assumption #6: All data sets used needed to show homoscedasticity, which is where the variances along the line of best fit remain similar as you move along the line.

Assumption #7: All data sets had to be checked to ensure the residuals (errors) of the regression line were approximately normally distributed.

3.13 Chapter Summary

This chapter expounded on the research design used, the case study plan, case study protocol, the Eisenhardt framework, the primary and secondary data sources, the data collection instruments used, methodology used to achieve the specific research objectives, including the methods used for data analysis and presentation. Ethical issues and how they were addressed have also been highlighted alongside expounding on the cost model design framework. This article provided insights on how multiple-case design research was conducted, within the quantitative and qualitative research paradigm, with the aim to corroborate and interpret information management for unpaved road maintenance practices.

The next chapter offers a detailed presentation, analysis of data and discussion of results obtained from field data collected. It will further explain with the use of examples, how the results link to the different facets of the multiple-case design adopted.

CHAPTER FOUR

PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

This chapter explains how data collected from the field was analysed, presented, and discussed as guided by the objectives and research questions of the research study. It greatly includes the presentation of the collected data in form of tables, charts, comments, and conclusions about the research findings.

4.2 Determination of control parameters for the cost model

This phase of the research involved analysing the general layout of unpaved road maintenance operations and what factors primarily affect those operations.

4.2.1 Road maintenance process at KSL

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 road maintenance fleet and is also the office location for the KSL road maintenance engineer.

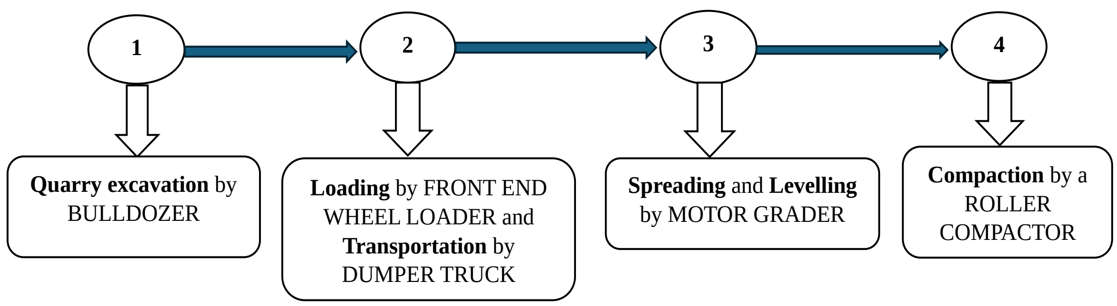


Figure 4. 1: Road maintenance process at KSL.

The unpaved road maintenance process at Kakira Sugar Limited (KSL) is mostly mechanized 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 Agriculture engineering has a vehicle fleet consisting of a TATA lorry(s), road compactor, motor grader, front end loader, bulldozer, and an excavator. These are assigned equipment for 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 for agricultural and engineering equipment operation.

Every morning, the TATA 2516C lorry trucks, the Ingersol Rand vibrator, the JCB 3CX excavator, the CAT 950H front end wheel loader, the CAT 120H motor grader, and the CAT D6H earthmover/bulldozer leave their satellite station at Karongo and head to their respective assignments. (*The equipment topologies had been earlier stated for reference reasons but will be mentioned using industry names going forward*). The dumper trucks, front end loaders, and the bulldozer head to the assigned quarry site, closest to the road under maintenance. The earth mover excavates the marram soils (laterite), and then the Front-end loader of bucket capacity 2.7m^3, lifts the excavated soil material into the lorry’

$14m^3$ dump box. Depending on the bucket fill, four to five bucket loads are enough to fill the dumper truck, before it transports the soils for dumping at the allocated road maintenance site. All machines are strictly driven by one person and are authorized not to carry any passengers. At the dumping site, the dumper truck is guided by the field road maintenance overseer who directs the trucks to the right point of deposition. Soils are dumped in heaps spaced at about 5m intervals or less, depending on the nature of fill required.

In case of onsite breakdown of the road maintenance machinery, the machine breakdown and repair unit at the satellite station would be dispatched to the road maintenance site for immediate repair works. This team usually consisted of four mechanics: two to three Class I mechanics and one Class II mechanic.

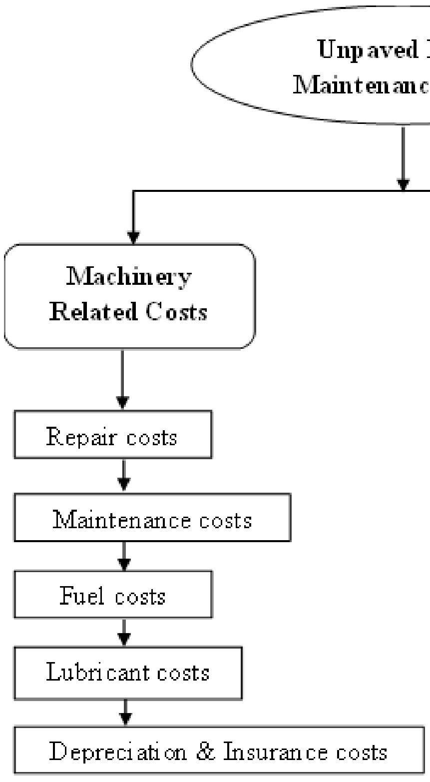


Figure 4. 2: Simple work-structure of research parameters

The road process in Figure 4.2, helped determine the road maintenance cost parameters mentioned later in the text. At the end of the days' work, the machines are transported back to the satellite station storage area. Here, they are inspected for any parts requiring repair or maintenance; fuel readings are checked and compared with the fuel tank reading taken at the days' start. The vehicle odometer readings/hour metres readings taken at the days' end are also compared with that taken at the days' start in order to determine vehicle distance travelled. All the data are recorded and later compiled in the road maintenance monthly report including machine/vehicle hours worked. One of the challenges identified at KSL during the road maintenance operations was mentioned by employees as low salary remunerations. Workers cited this as a key issue in the semi-structured interviews.

4.2.2 Road maintenance process at Gulu DLG

Gulu is a district in the Northern Region of Uganda. The regional headquarters are still in the city of Gulu, which is also the administrative capital of Northern Uganda. the district consists of two main divisions, Gulu West and Gulu East.

Gulu District 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 kilometres, by road, north of Uganda's capital city, Kampala (Wikipedia, accessed 2023). 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. The FAM method of road maintenance has already been addressed in the literature review (Chapter 2). The 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. These are a fixed number of equipment and therefore the DLG works with what it has in in its fleet.

4.2.3 Equipment repair procedure at KSL

Machine repair costs at the satellite station, mostly consisted of unplanned breakdowns of machines that affected its regular operations, ranging from minor repairs like tyre punctures to major repair works like engine overhaul. At the satellite station workshop and at the main heavy plant garage, mostly major repairs such as engine breakdowns or transmission system failures were handled. Minor repairs such as tyre puncture fixes or bolt replacements were done at the road maintenance site by the mobile vehicle repair and maintenance unit. Other more serious repairs would be attempted at the satellite workshops if there was availability of spare parts. Whenever, there was a breakdown, the following process was usually followed.

- Breakdown of road maintenance equipment occurs. The machine operator communicates to the road's maintenance supervisor regarding the breakdown, who in turn communicates to the machine repair workshop supervisor. The machine repair workshop supervisor assesses for availability of the required spare parts at the satellite station.
- If spare parts are available, a mobile equipment maintenance team is dispatched to the breakdown site to assess and repair the equipment, thus reducing on the Mean Time To Repair (MTTR). Distance however played

a key role in the response time as sites that were further away from the satellite station at Karongo, had high MTTR compared to sites that were closer to the satellite station. This mostly affected the dumper trucks that were periodically operating further away from the satellite station.

While assessing requesting for spares meant for the satellite station from the main garage, the following procedure was usually followed:

- Note down the field complaint and the recommend action to be taken.
- A field job card is the generated, which identifies the spare part to be sourced from the main garage stores. The field job card is then taken to the main garage and logged in with the “Time office clerk”, who notes down the complaint and assigns the field job card a reference number.
- The Field job card is then taken to the garage superintendent/supervisor to request for the required item by opening an Internal Material Request (IMR). The garage storekeeper will then base on the IMR to check for availability of the spare before issuing it out.
- A gate pass is then issued to the staff in need of the spare to allow safe exit from the garage. The staff will then leave the IMR with the garage office clerk for safekeeping and filing. The spare can then be transported to the required satellite station.

The satellite machine workshop was staffed with a superintendent, a supervisor, Mechanics (Class I & II).

4.2.4 Machine Utilization

The Ingersoll rand compactor had the highest utilisation at 85.7%, next in line is the excavator and earthmover at 85.4%; the wheel loader and Motor grader averaged about 84%, with the dumper truck coming in last at 83.1%. Average Machine Utilisation was 84.7%.

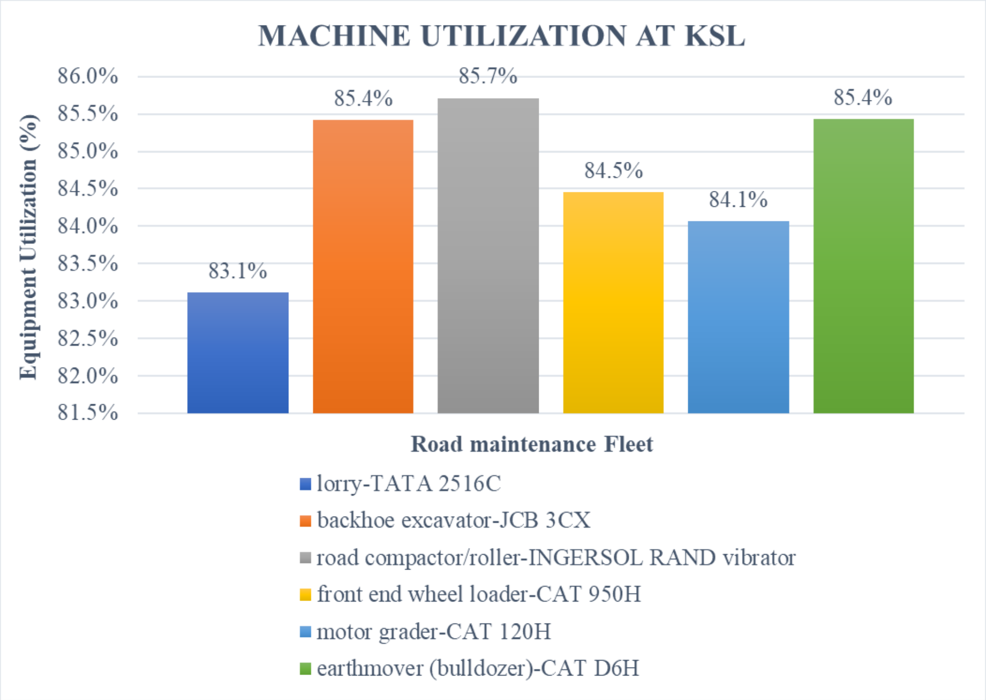


Figure 4. 3: Machine utilisation at KSL

4.2.5 Machine Availability

Machine Availability, also known as uptime, refers to the percentage of time a machine is in operation. The roller compactor had the highest utilisation at 98.2%, next in line is the excavator and earthmover at 98%; the wheel loader at 97%, the Motor grader averaged about 96.7%, with the dumper truck coming in last at 95.8%. Average Machine Availability was 97.3%.

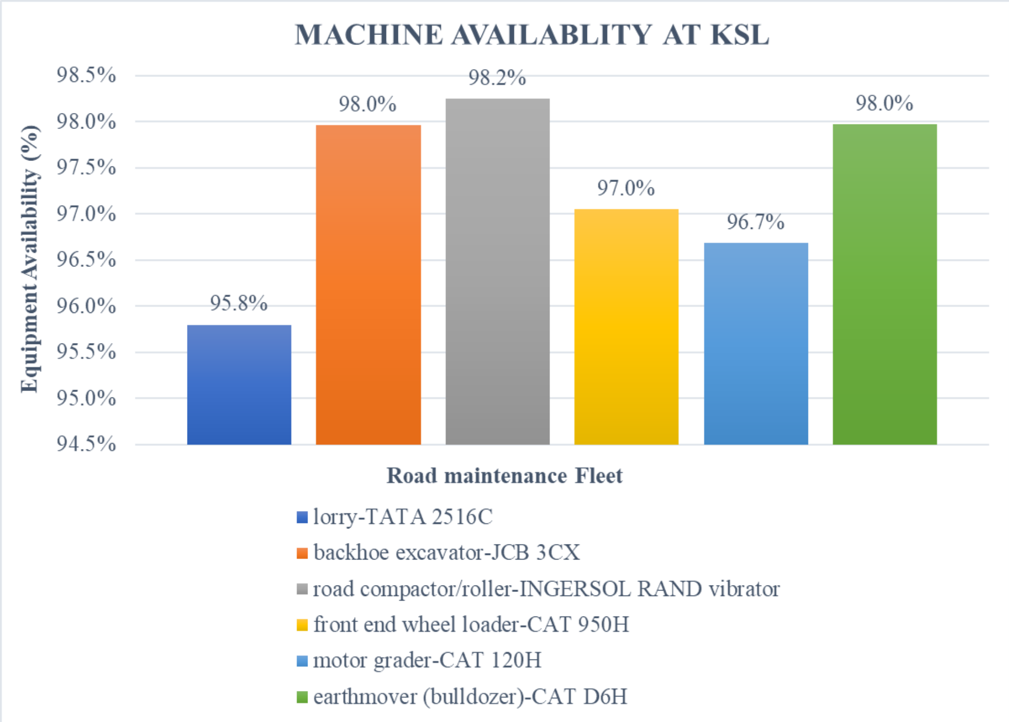


Figure 4. 4: Machine Availability at KSL

For the case of Gulu DLG, with no real data on particular equipment availability, the researcher relied on the MoWT, (2020) annual sector performance report for FY 2019/20 which 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 old Chinese equipment fleet, against a target of 60%. Gulu DLG had the newly acquired Japanese road equipment fleet, mainly KOMATSU equipment.

4.3 Development of a cost per km rate for mechanized unpaved road maintenance

This phase of the research involved analysing different facets of unpaved road maintenance operations and their associated costs.

4.3.1 KSL Common machine repairs, maintenance, and servicing operations

Common machine repairs included items such as Tyre punctures, starting failures, bolt terminal replacements, tilt cylinder hose/hydraulic hose replacements; segment bolt, ripper mounting bolts, under carriage cop bolts, and discharged bolt replacements, clutch rod replacements. Leakages were also a common feature. Minor field repairs such as broken bolts, hoses and terminals were usually solved on site since spares for these were mostly available at the satellite station. Therefore, the researcher sourced for reported and recorded incidences of machine breakdown in the field, and their associated spares for repairs, whose costs were known in the market. This therefore helped to plot a rough cost estimate for the minor repairs per machine, per month. This was later converted into a cost per hour rate by ratioing the monthly rate with an 8hour workday, 25 days a month. The selected work time is however ideal since work times greatly vary and are not necessarily 8hours a day and 25days a month.

However, there were instances of major repairs where equipment totally failed and required to be hauled to the main garage workshop for repair works. These mostly involved major engine repairs or repairs to major movable equipment parts. Based on information provided by the main garage manager, major repair costs were heavily determined by the damaged part, the associated costs of sourcing and delivering spares (whether nationally from local dealers or internationally) and the installation costs (sometimes done by expatriate machine repair specialists). These major repairs were highly unpredictable and random.

They were also varying even on machines of the same type. With recorded data, highly unavailable, the researcher was not able to acquire insightful data on these major repairs besides getting a view of the ongoing major repairs. Machine servicing data was, however, readily available with various equipment being serviced after different hours of operations or km covered.

The backhoe excavator, road compactor/roller compactor, front end wheel loader, motor grader, and the earthmover (bulldozer) were serviced at the Heavy Plant section of the main garage. The main observed challenge at the main garage was the long lead time it took to obtain major machine components. Many of the heavy equipment (especially CAT machines), were on breakdown awaiting importation of critical spares which had delayed. There was therefore, a gap in KSL's major component replacement plan.

Repair labour costs were calculated as constants with or without a machine failure, since the mechanics were paid monthly salaries which were not necessarily tied to equipment failures. The mechanics were grouped into Class I and II mechanics with Class I mechanics earning about 350,000 Ugx while Class II mechanics earn about 450,000 Ugx monthly. This can be converted into approximately 1,750Ugx and 2,250 Ugx per hour, for the Class I and II mechanics respectively, taking into consideration a daily 8hour working schedule and a 25days working month.

4.3.2 KSL Machine lubricant costs

Machine maintenance costs consisted of the vehicle servicing costs and scheduled component replacement costs carried out according to the vehicle specification logs. Vehicle servicing costs mostly included scheduled maintenance operations like; scheduled engine oil, oil and fuel filter, water separator replacement after 250 km distance reading of the total distance covered for the hour-meter machines and other subsequent changes at 500, 750 and 1000 km distances. Basing on observed field values, lubricants accounted for approximately 33% of the total machine maintenance cost per hour. Lubricant consumption per hour values were obtained by use of monthly lubricant consumption data and also other available equipment information in standard machine operations handbooks for example the Caterpillar Performance Handbook (Caterpillar, 2015).

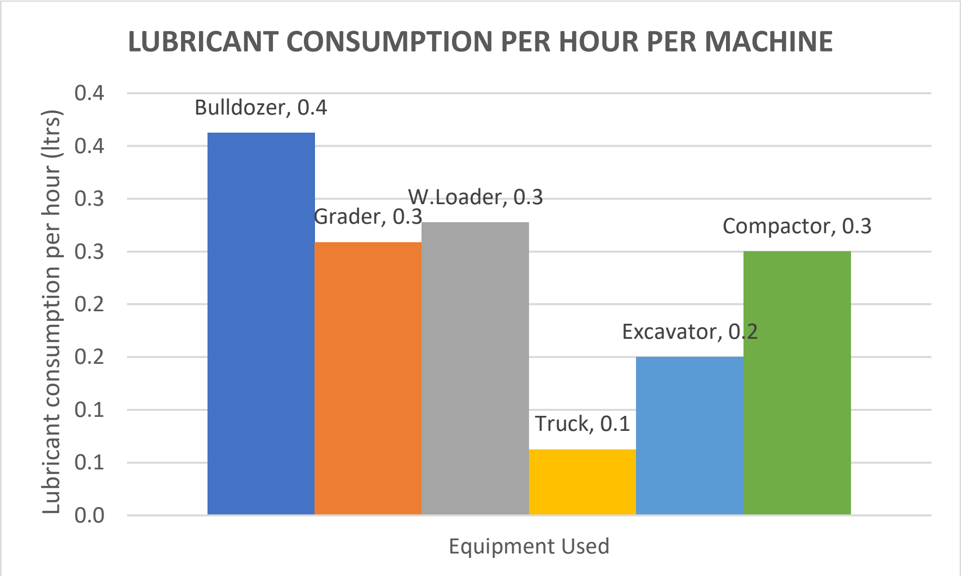


Figure 4. 5: Average lubricant consumption per hour by different machines

The bulldozer had the highest consumption of lubricants per hour at 0.4litres/hour, next in line is the front-end loader, motor grader, roller compactor, excavator and lastly the dumper truck.

4.3.3 KSL Machine fuel expenses/costs

Machine fuel consumption depends on the engine fuel consumption rates and the task under execution. At KSL, fuel depots are located at each agriculture satellite station with enough capacity to fuel all the machines in that station for approximately a week. Machine fuel tank capacities were recorded for each machine and fuel volume left in the tank was also noted. The amount of fuel added in the morning was noted, and the amount remaining in the tank was noted in the evening. Basing on the machine's hour-metres or fuel consumption rate (litres/hr or litres/km), the machine's fuel consumption rate was then calculated and compared with the machine's known hour-metre readings.

Any abnormally high deviations in the hour metre readings of the machine were then recorded and an explanation required from the driver of that machine and the supervisor of the maintenance works. Figure 4.6 shows the average monthly fuel consumptions of the various machines used as a percentage of the total monthly fuel consumed. From Figure 4.7, the earthmover had the highest fuel consumption per hour at 21.3 followed by the motor grader at 16.0, then the front-end loader at 12.9, the roller compactor at 7.1 and the excavator at 4.4litres per hour. In terms of hours worked, the dumper truck was excluded since its work done is measured in terms of vehicle trips (km) unlike the other machines in the fleet. The machines' fuel consumption is compared with the machines' hours worked in Figure 4.8.

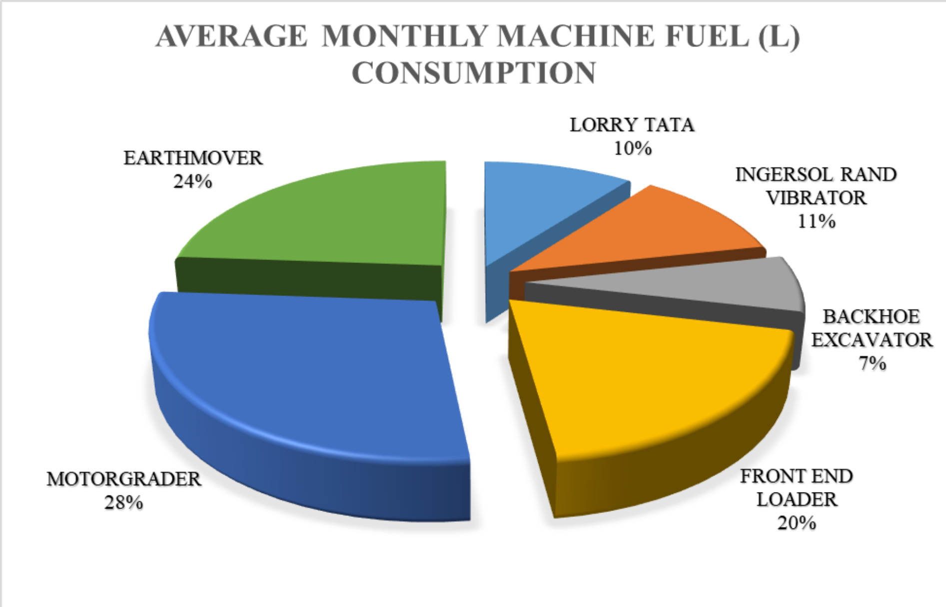


Figure 4. 6: Average monthly fuel consumption at KSL

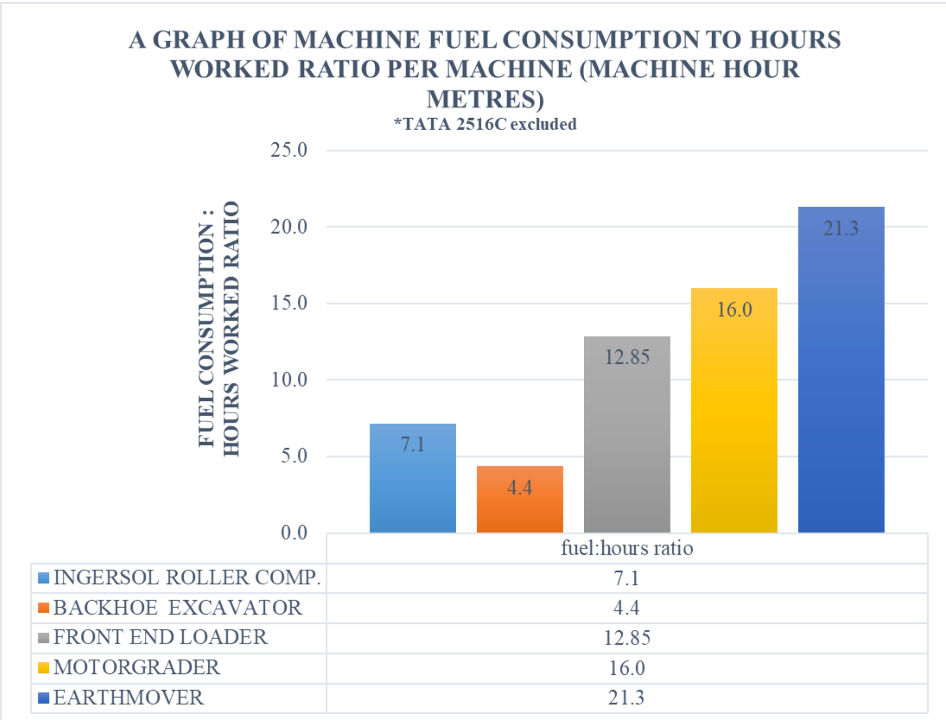


Figure 4. 7: Comparison of hours worked to machine fuel consumption

Basing on the field data collected, a trend analysis was conducted, and the general trend of the fuel consumption shows an R^2 value of 0.7024; while this is relatively high (accounting for 70% of the variation in the target variable), it also indicates that the different monthly fuel consumption of the various equipment is not uniform. This is in line with the earlier observed machine fuel consumptions per hour values indicated in Table 4.1 (p.94). On the other hand, the machine hours worked had an R^2 value of 0.256 which is relatively low and indicates a little correlation between the machine hours worked by different equipment. This disparity in machine hours, could be attributed to different machine travel speeds, tasks, and general equipment make.

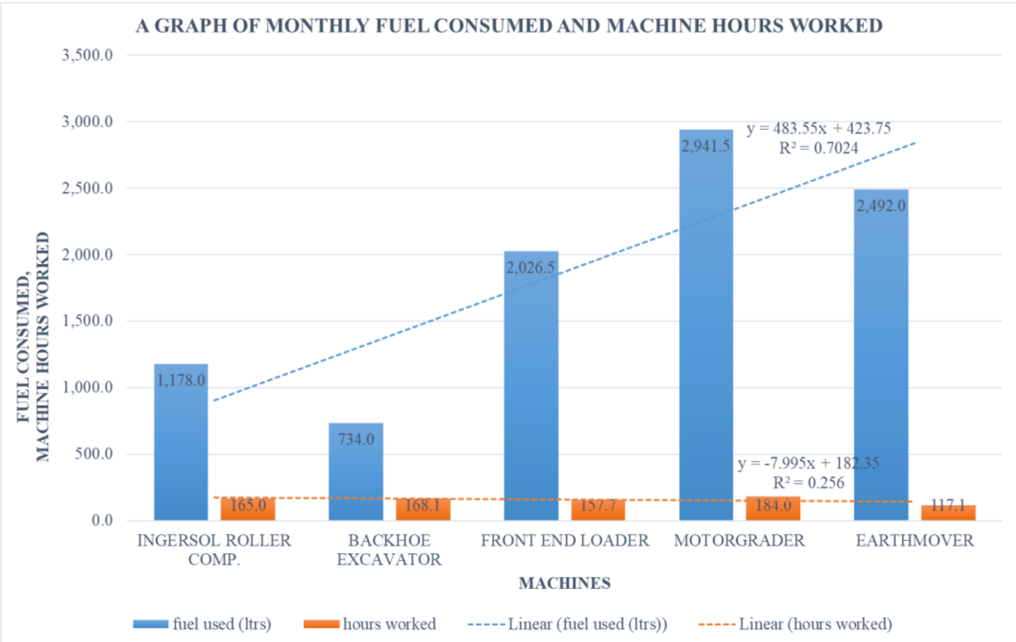


Figure 4. 8: General trend of machine fuel consumption and machine hours worked

Figure 4.8 indicates the average monthly fuel consumption of each piece of machinery in the fleet at KSL alongside machine hours worked. The motor grader had the highest monthly fuel consumption at 2,941.50litres, followed by the earthmover/bulldozer at 2,492.00litres. The front-end loader, the roller vibrator, the dumper truck, and the backhoe excavator had fuel consumptions of 2,026.50litres, 1,178.00litres, 1,079.00litres and 734.00litres respectively.

Table 4. 1: Observed and expected machine fuel to hours worked ratios alongside their discrepancies

S/No.	Machine Type Details	KSL Established Fuel litres: hour	Observed litres: hour	Discrepancy
1	Roller vibrator	7.1	7	-0.1
2	Backhoe excavator	4.4	4	-0.4
3	Earthmover	21.3	21	-0.3
4	Front end wheel loader	12.9	13	0.1

Table 4.1 shows machine fuel to hours worked ratios alongside their discrepancies. This can be attributed to many reasons such as fuel theft, inaccurate work hours, and inaccurate fuel readings.

a) <u>DUMPER TRUCK</u>

The graph in Figure 4.9 indicates a strong positive correlation of 0.8181 between the distance covered and fuel consumed for the dumper truck, as indicated by the R^2 value, $y = 0.3355x + 15.235$; $R^2 = 0.8181$.

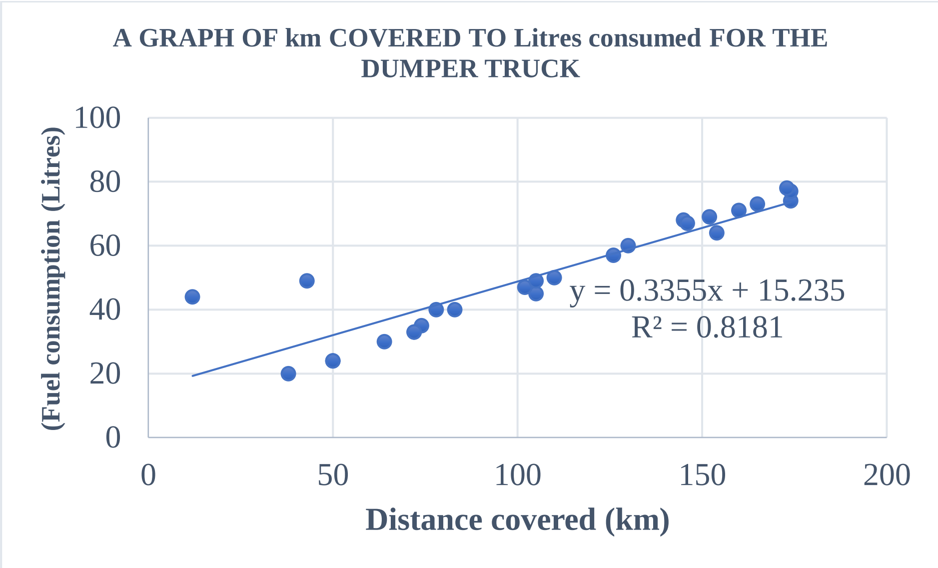


Figure 4. 9: A graph of distance (km) covered to litres of fuel consumed for the dumper truck

b) Backhoe excavator

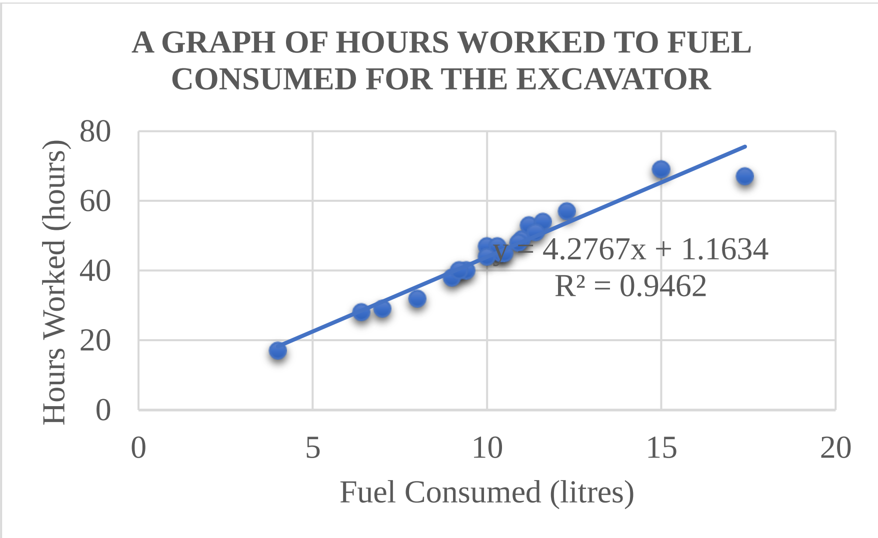


Figure 4. 10: A graph of hours worked to litres consumed for the backhoe excavator

The graph in Figure 4.10 indicates a strong positive correlation of 0.9462 between the km covered and fuel consumed for the backhoe excavator, as indicated by the R^2 value, y= 4.2767x + 1.1634; $R^2 = 0.9462$.

c) Front End Wheel Loader

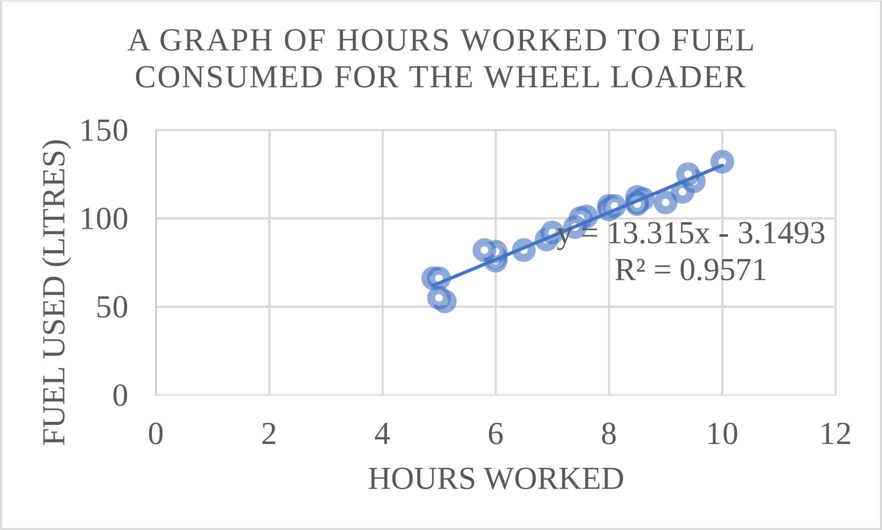


Figure 4. 11: A graph of hours worked to litres consumed for the backhoe excavator

The graph in Figure 4.11 indicates a strong positive correlation of 0.9571 between the km covered and fuel consumed for the front-end loader, as indicated by the R^2 value, $y = 13.315x - 3.1493$; $R^2 = 0.9571$

d) Motor Grader

The graph in Figure 4.12 shows a strong positive correlation of 0.8735 between the km covered and fuel consumed for the motor grader, as indicated by the R^2 value, $y = 14.127x + 14.974$; $R^2 = 0.8735$

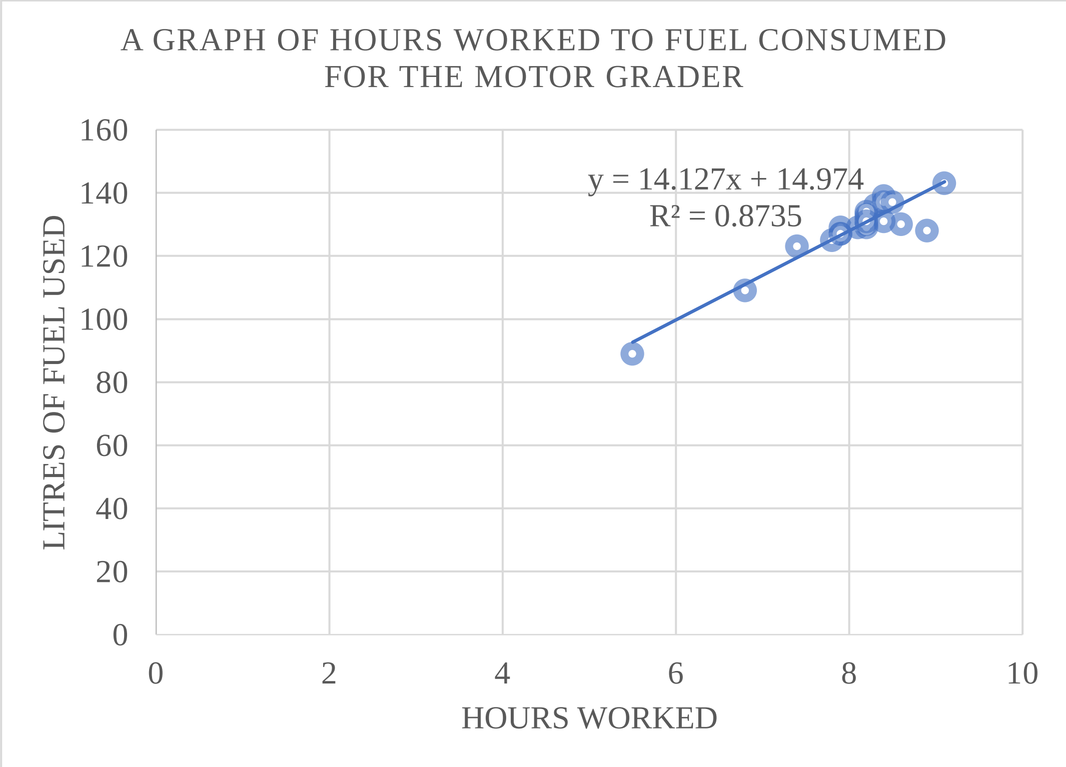


Figure 4. 12: Fuel (litres) consumed against ours worked for the Motor Grader

4.3.4 KSL Machine insurance costs

The road maintenance monthly machinery insurance costs at KSL were as below.

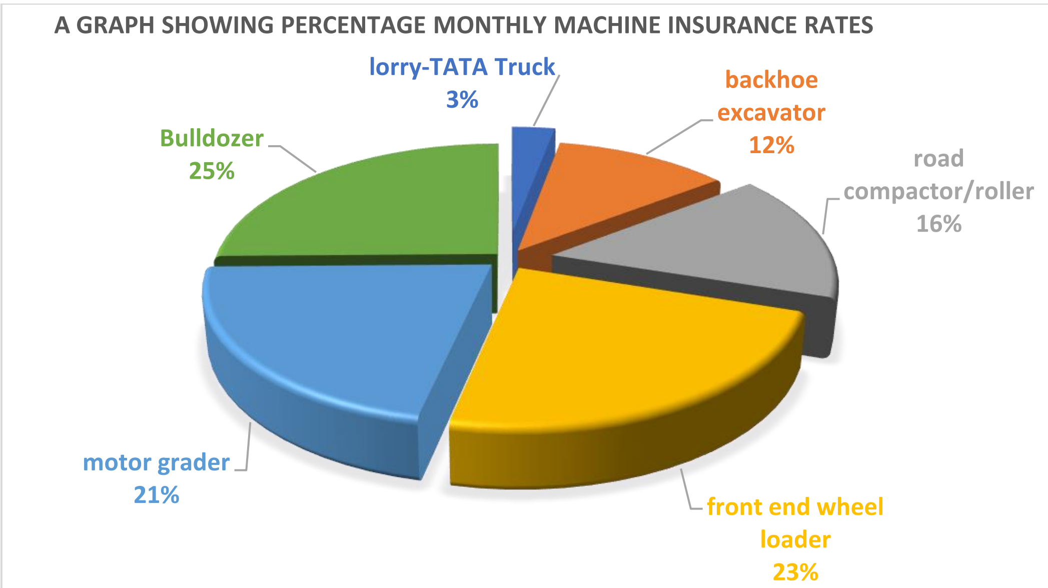


Figure 4. 13: Monthly machine insurance costs

The Earthmover had the highest percentage of the front-end wheel loader had the highest percentage of the total insurance costs, 25%. It was followed by the motor grader and earthmover both at 24%. The road compactor, backhoe excavator and TATA lorry had 14%, 10% and 3% of the total insurance costs respectively. The insurance cost calculations were done as follows.

Step 1: 0.9 × machine purchase cost = Cost1, C1

(C1 is 90% purchase cost)

Step 2: C1 + 0.5 = Cost2, C2, where 0.5 is the training levy.

Step 3: C2 × 18% = Cost3, C3 (VAT Exclusive)

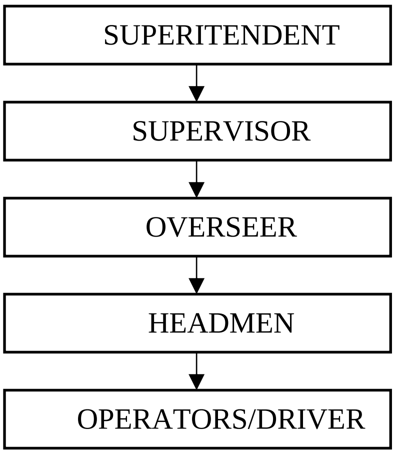
Step 4: C3 + stamp duty (about 35,000Ugx) + sticker fees (about 6,000Ugx) = C4; Annual insurance cost = C4

Step 5: Monthly insurance costs = (C4/12) = Cost5, C5

This was computed as an indirect cost to get a wholistic picture of both direct and indirect costs. However, comparing with the Gulu DLG road maintenance costs, where insurance wasn’t factored, this was later dropped from the overall production costs.

4.3.5 Machine operator salaries at KSL and Gulu DLG

Labour is key in any engineering operation and in the unpaved road maintenance sector, the labour helps run the machinery. The KSL agriculture engineering department is structured as shown below alongside its salary structure.



SALARY STRUCTURE

Occupation		Salary (Ugx)
1	Superintendent	3,500,000
2	Supervisor	1,500,000
3	Overseer	900,000
4	Headmen	700,000
5	Operators/drivers	500,000
6	Mechanic Class II	450,000
7	Mechanic Class I	350,000

Figure 4. 14: KSL Agriculture engineering work structure and salary structure

Source: Courtesy of KSL

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. Although the rates at KSL were slightly better than the government salary rates at Gulu DLG, still many of the workers interviewed anonymously hinted on the low salary scales and the demotivation it brings. Also, both rates were fairly comparable considering that the DLG employees earned an allowance for every road maintained while the KSL employees did not.

The Gulu DLG road maintenance department supervision cost per road project is as indicated in Table 4.2. Thes are mainly allowances allocated per project.

Table 4. 2: Allowances allocated to DLG road maintenance teams

Item	Personnels		Allowances		Rate		Amount (Ugx)
			Units	*No of Days*	*Qty*	*Rates (Ugx)*	
1	Project Engineer		Man days	1	1	60,000	60,000
2	Skilled labourers, surveyor, physical planner		Man days	1	1	300,000	300,000
3	Unskilled/casual Labourers		Man days	1	1	15,000	15,000
4	Operators						
		Grader	Man days	1	1	55,000	55,000
		Roller	Man days	1	1	55,000	55,000
		Bulldozer	Man days	1	1	55,000	55,000
		Wheel Loader	Man days	1	1	55,000	55,000
5	Turn men						
		Grader	Man days	1	1	30,000	30,000
		Bulldozer	Man days	1	1	30,000	30,000
		Roller	Man days	1	1	30,000	30,000
		Low Bed	Man days	1	1	30,000	30,000
		Water Bowzer	Man days	1	1	30,000	30,000
		Wheel Loader	Man days	1	1	30,000	30,000
6	Truck Drivers		Man days	1	1	30,000	30,000
		Water Bowzer	Man days	1	1	30,000	30,000
		Low Bed	Man days	1	1	30,000	30,000
7		Truck's turn men	Man days	1	1	30,000	30,000
						Total	**895,000**

Source: (Extract from Gulu DLG road maintenance department 2022 cost sheets. Attached in appendix)

As per the Ministry of Public service circular standing instruction (CSI) No. 1of 2022, salary structure for financial year 2022/2023, the salary grading and structure for staff involved in engineering works is indicated in Table 4.3

Table 4. 3: Salary structure at DLGs

	SALARY STRUCTURE	
	Occupation and grading	**Salary (Ugx)**
1	District engineer (U1E)	1,700,000
2	Assistant engineer (U4)	940,000
3	Road's inspector (U6)	430,000
4	Land surveyor (U5)	600,000
5	Mechanical assistants/mechanics (U7)	377,000
6	Drivers (U7)	377,000

Source: Adapted from Ministry of Public Service, (2022)

4.3.6 KSL Machine depreciation costs

Depreciation refers to a systematic and rational process of spreading the cost of tangible assets over the life of those assets. Depreciation is therefore a process of cost allocation.

Cost to be allocated = acquisition cost - salvage value.............**(Equation 4.1)**

This cost is allocated over the estimated useful life of the asset, that is to say,

$$\textit{Depreciation cost} = \frac{(acquisition\ cost - salvage\ value)}{(n\ number\ of\ years)} \ldots\ldots\ldots \quad \textbf{(Equation 4.2)}$$

Time-based depreciation methods include Straight line method, Declining balance method and Sum-of-the-years'-digits method. Declining balance method was adopted in this research due to its advantages over the other methods of calculating depreciation. The expected useful life of a Caterpillar steel-tracked tractor in an agricultural setting can range up to and possibly exceed 20,000 machine hours (about 18-20years), (CAT, 2015).

Since machines at KSL are auctioned at the end of their useful life, it is assumed that a minimum of 10% of the machines overall cost will be recovered at the auctioning with certain profit allowances made. The uncertainty of the auctioning process can also be incorporated into the 10% of machine purchase cost (from now on referred to as salvage value). The machine salvage values are shown in Table 4.4 with machine useful life estimated at a maximum of 25 years.

Table 4. 4: KSL Machine purchase, salvage, and depreciation costs

SNo.	EQUIPMENT	MACHINE PURCHASE COST		SALVAGE VALUE	MACHINE DEPRECIATION RATE (ANNUALLY)	MACHINE DEPRECIATION RATE (MONTHLY)
		UGX	USD			
1	Lorry-TATA truck	150,000,000	41,667	15,000,000	5,400,000	450,000
2	Backhoe excavator	600,000,000	166,667	60,000,000	21,600,000	1,800,000
3	Road compactor/roller	800,000,000	222,222	80,000,000	28,800,000	2,400,000
4	Front end wheel loader	1,200,000,000	333,333	120,000,000	43,200,000	3,600,000
5	Motor grader	1,100,000,000	305,556	110,000,000	39,600,000	3,300,000
6	Earthmover (bulldozer)	1,300,000,000	361,111	130,000,000	46,800,000	3,900,000

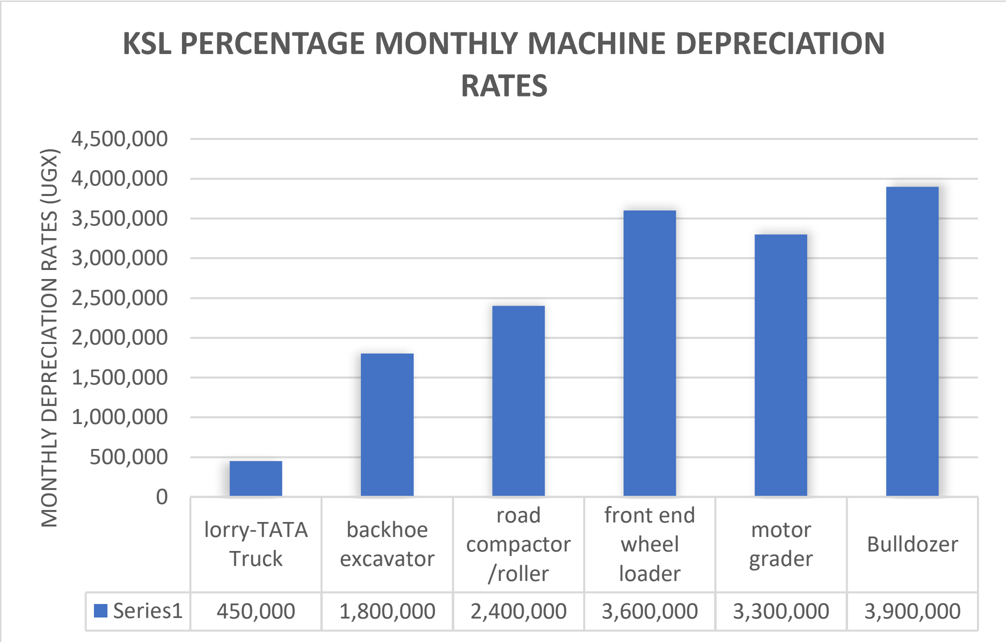


Figure 4. 15: KSL Percentage monthly machine depreciation rates

The earthmover that had the highest depreciation at 25% (3,900,000Ugx) of the total monthly depreciation, followed by the front-end wheel loader at 23% (3,600,000Ugx), the motor grader at 21% (3,300,000Ugx), the roller compactor at 16% (2,400,000Ugx), the backhoe excavator at 12% (1,800,000Ugx), the dumper truck at 3% (450,000Ugx) of the total depreciation respectively.

4.3.7 KSL Total Machine Production costs

Basing on the different cost parameters that were identified, the following table was generated with the various cost aspects assigned to each machine. The raw data has been attached in the appendix.

Table 4. 5: Daily Fleet operation cost at KSL

Equipment	Daily Production cost (Ugx)
Earthmover	2,069,921
Roller compactor	1,156,818
Front end wheel loader	1,468,586
Motor grader	1,678,444
Dumper truck	1,079,215
Backhoe excavator	1,160,936
TOTAL (Ugx)	**8,613,920**

4.3.8 Summary cost/km road maintenance costs at Gulu DLG

Basing on fleet records and road project bills of quantities (BOQs) provided by the Gulu District Loal Government (DLG), the following data in Table 4.6 was compiled. All Gulu DLG BOQs used indicated a maximum of 13-14days for unpaved road maintenance works. The KSL cost/km of road maintained amounted to 26,442,032Ugx/km. This is lower than the government average cost of 32,674,895Ugx/km since KSL has its own material deposits and therefore does not purchase any murrum materials. Also, KSL carries out its own inhouse machine maintenance costs and this accounts for a reduced maintenance cost. There is also the issue of labour costs where the DLG pays workers an allowance for FAM road maintenance whereas KSL does not do so, and only pays a monthly salary.

Table 4. 6: Unpaved roads in Gulu DLG and associated costs

Sno.	**Road**	**Planned road length (km)**	**cost with culvert (Ugx)**	**cost without culvert (Ugx)**	**Maintenance cost/km with culvert (Ugx)**	**Maintenance cost/km without culvert (Ugx)**
1	Mechanized maintenance of Nile Avenue Road	2.0	36,000,000	29,114,000	18,000,000	14,557,000
2	Bell-Panycwala Road.	1.6	38,000,000	31,939,000	23,750,000	19,961,875
3	Unyama A triple cell box culvert.	3.0	180,000,000		60,000,000	0
4	Pida-Techo road.	1.8	36,818,000	29,943,000	20,454,444	16,635,000
5	Laliya-Akonyibedo road	1.9	46,215,000	40,188,500	24,323,684	21,151,842
6	Forgod-Paminano road	3.6	54,000,000	45,128,000	15,000,000	12,535,556
7	Panyagira road	2.1	45,000,000	38,707,000	21,428,571	18,431,905
8	Jubi road.	1.8	32,000,000	25,755,000	17,777,778	14,308,333
9	Yusuf Adek road	1.8	37,000,000	29,900,000	20,555,556	16,611,111
10	Gulu-Gulu road	1.0	21,000,000	17,455,000	21,000,000	17,455,000
11	Ochan Ben road	1.5	29,000,000	23,122,500	19,333,333	15,415,000
12	Hassan lane & Onono Onweng road	3.0	32,980,500	25,685,500	10,993,500	8,561,833
13	Patuda road	2.3	58,000,000	48,183,000	25,217,391	20,949,130
14	Unyama B double cell box culvert	1.0	120,000,000		120,000,000	0
15	Dorothy laker road	1.4	32,000,000	25,894,000	22,857,143	18,495,714
16	Gulu-Gulu double cell box culvert	1.0	120,000,000		120,000,000	0
17	Obita Ludac road	1.0	27,986,500	22,702,500	27,986,500	22,702,500
18	Administration	4.0	30,000,000	30,000,000	7,500,000	7,500,000
19	ADRICS	1.0	24,000,000	24,000,000	24,000,000	24,000,000
20	Bunyoro road	0.3	9,996,000	9,996,000	33,320,000	33,320,000
MEAN	**COST/km (without depreciation and insurance)**				**32,674,895**	**15,129,590**
ADD	**Depreciation (Ugx/km)**				**691,212.9**	**691,212.9**
ADD	**Insurance (Ugx/km)**				**607,115.4**	**607,115.4**
TOTAL (Ugx)	**TOTAL COST/km**				**33,973,223**	**16,427,918**

Considering the case of the URF 2015 Monitoring and Evaluation of Road Maintenance Programmes for DAs (Designated Agencies) in the Northern / Northwestern Region covering Amuru, Moyo, Yumbe and Arua District Local Governments; Arua Municipality, and Moyo UNRA station, for Quarters 1, 2, 3 and 4 of financial year 2014/2015 compiled cost per km rates for road maintenance in these districts. These six agencies were assessed under Call off Order 3 as issued by Uganda Road Fund (URF) to M/s. Dativa and Associates under a framework contract (Ref. URF/SRVCS/13-14/00036).

Unit rates were calculated and estimated basing on expenditure incurred during maintenance operations. This included purchase of road materials, fuel, road equipment, and payments to road gangs, payments to road overseers and for tools supplied to the road gangs. From the analysis and calculations undertaken, the Consultant (M/s. Dativa and Associates Certified Public Accountants) was able to compute the rates indicated in Table 4.7. Maintenance costs under Moyo DLG were low due to Roads Committees assisting in acquisition of materials especially gravel at a far lower cost. The consultant noted that in many instances, road gangs were not provided with the necessary tools, and they ended up using their own equipment whose associated costs were not factored in by the district. Therefore, the full cost of deploying road gangs could not be reflected. In general, unit rates paid to road gangs were roundly described as too low by all DAs (Designated Agencies).

Table 4. 7: Cost /km rate of unpaved road maintenance at Designated Agencies

Designated Agency (DA)	**Cost per km of unpaved road maintained**
Arua Municipal Council (Now City)	53,618,245
Arua DLG	31,048,697
Moyo UNRA station	31,865,881
Moyo DLG	1,177,232
AVERAGE Cost/km	29,427,513.75Ugx/km

Source: URF, (2015).

The 2014/2015 road maintenance rate of 29,427,513.75Ugx/km is also within range of the KSL rate of 26,442,032Ugx/km and the 2022 calculated average government rate of 32,674,895Ugx/km.

4.3.9 UNRA mechanized unpaved road maintenance projects and associated costs

The Uganda National Roads Authority (UNRA) is an agency of Government, under the Ministry of Works and Transport (MoWT) established by law, the UNRA Act of 2006, with the responsibility of maintaining, managing, and developing the National Road network. In addition, the Authority is required to render advisory services to Government and for related matters concerning National Roads, among others.

Mechanized unpaved road maintenance cost data from UNRA was selected to act as a cost comparison to the other computed cost/km rates of KSL and Gulu DLG. The researcher sampled 16 unpaved road maintenance projects in Uganda from the UNRA 2022 annual performance report as indicated in Table 4.8.

A total of 67,294,744,200Ugx was spent by UNRA during the financial year 2022/23 in mechanised unpaved road maintenance using framework contracts. An estimated 1,577.2km of unpaved roads was maintained. This gives an average of 42,667,223.05Ugx/km inclusive of 18% Value Added Tax (VAT). Excluding the VAT, gives a calculated rate of 34,987,122.9Ugx/km. The above sampled 16projects provided a VAT exclusive figure of 34,153,883Ugx/km for mechanized unpaved road maintenance works.

Table 4. 8: Sample UNRA mechanised unpaved road maintenance projects in Uganda and associated costs

Sample UNRA mechanised unpaved road maintenance projects in Uganda and associated costs (Table 4.8)							
S/n	**Contract name**	**Contractor and Supervisor**	**Commencement/ Completion**	**Km maintained**	**Contract Duration (Months)**	**Contract Price (UGX)**	**Cost/km (UGX)**
1	Mechanized Maintenance of Selected National Unpaved Roads under Framework Contracts for 3 Years Lot 25: Luwero Station. Call Off Order No. 002	**Contractor:** Suez Auto Enterprises Ltd **Supervisor:** UNRA Luwero	**Commenced:** 22/12/2021 **Completion:** 22/04/2022	34	4	601,416,000	17,688,705.9
2	Mechanized Maintenance of Selected National Unpaved Roads under Framework Contracts for 3 Years: Luwero Station Call Off Order No. 001	**Contractor:** National Enterprise Corporation **Supervisor:** UNRA Luwero	**Commenced:** 12/01/2022 **Completion:** 12/05/2022	45	4	613,010,520	13,622,456
3	Framework Contract for the Mechanised Maintenance of Selected Unpaved Roads Totalling to 138Km: Call Off 01: Kyapa – Kansensero road (41Km)	**Contractor:** M/s.Kasese Nail & Wood Industries Ltd **Supervisor:** UNRA Masaka	**Commenced:** 18/01/2021 **Completion**: 16/09/2021	41	8	2,071,105,922	50,514,778.5
4	Mechanised maintenance of Selected Unpaved national roads under Framework contract for 3 years (Kabwohe – Bwizibwera – Nyakambu – Nsika (47.2km) Call off Order no.1	**Contractor:** BAP engineering company limited **Supervisor:** UNRA Ibanda	**Commenced:** 31/12/2020 **Completion**: 6/8/2021	47.2	8	3,000,108,700	63,561,625
5	Mechanised maintenance of Selected Unpaved national roads under Framework contract for 3 years (Kashongi – Kantaganya 24.5km) Call off Order no.1	**Contractor:** Ms Capital Logistics and construction ltd **Supervisor:** UNRA Ibanda	**Commenced:** 26/11/2020 **Completion**: 25/3/2021	24.5	4	1,667,458,000	68,059,510.2
6	Mechanised maintenance of Nyakabirizi – Burere – Nsiika road (45km) and Nsiika – Bihanga – Katerera road (44km)	**Contractor:** Wanaik Construction CO.LTD **Supervisor:** UNRA Ibanda	**Commenced:** 23/10/2020 **Completion**: 29/7/2021	89	9	5,112,763,000	57,446,775.2
7	Mechanized Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 Years. Lot 12 for Moroto Station. (Contract Sum: 12,461,958,406); Call off order 001; Ariamoi – Lopei (28.4km)	**Contractor:** Capital Logistics And Construction Ltd Supervisor: UNRA Moroto	**Commenced:** 26/08/2021 **Completion**: 26/02/2022	28.4	6	494,464,840	17,410,733.8
8	Mechanized Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 Years Call off order 002; Nakiloro – Lomukura (85km)	**Contractor:** GIC Logistics and Engineers Ltd in Joint Venture with Strakon Limited **Supervisor:** UNRA Moroto	**Commenced:** 27/09/2021 **Completion**: 27/06/2022	85	9	874,794,770	10,291,703.17
9	Framework Contract for mechanised Maintenance of Selected Unpaved	**Contractor:** Azu Properties Ltd	**Commenced:** 9/12/2020	87	8	2,934,457,311	33,729,394.37

Sample UNRA mechanised unpaved road maintenance projects in Uganda and associated costs (Table 4.8)							
	National Roads Under Framework Contracts for 3 years Totaling to 327Km, Lot 08 for Roads under Fort Portal Station Kakabara – Bufunjo – Katooke (46km) and Fort Portal – Kijura Road (41km) (Call Off Order No.2)	**Supervisor:** UNRA Fort Portal					
10	Framework Contract for mechanized Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 years Totalling to 327Km, Lot 08 for Roads under Fort Portal Station, Kamwenge – Dura – Rwimi Road (60km) **(Call Off Order No3)**	**Contractor:** Azu Properties Ltd, **Supervisor:** UNRA Fort Portal	**Commenced:** 29/09/2021 **Completion**: 28/01/2022	60	4	487,295,750	8,121,595.8
11	Mechanized Maintenance of Selected Unpaved National Roads Under Framework Contract Totalling To 487.2km	**Contractor:** Rocktrust Contractors (U) Ltd **Supervisor: UNRA Jinja**	**Commenced:** 14/3/2019 **Completion**: 14/03/2022	487.2	36	33,860,159,881	69,499,507.1
12	Mechanised Maintenance of selected unpaved National Roads under Framework Contract Phase II- Call - off Order One. (Busolwe-Nabumali Junction (35.1Km) Road)	**Contractor:** Thunderbolt Technical Services Ltd **Supervisor:** UNRA Tororo	**Commenced:** 24/05/2021 **Completion**: 23/10/2021	35.1	5	1,486,162,399	42,340,809.08
13	Mechanized Maintenance of Selected Unpaved National Roads under Framework Contracts for Three Years: Lot 14: Lira Station; Agwata – Aduku road (29.4Km)	**Contractor:** Tegeka Enterprises Ltd **Supervisor:** UNRA Lira	**Commenced:** 28/04/2021 **Completion**: 28/10/2021	29.4	6	699,225,605	23,783,183.8
14	Mechanized Maintenance of Unpaved National Roads For 22 UNRA Stations Under Framework Contract For 3 Years Lot 24: Moyo Station: Aliodranusi – Goboro – Matu – Kei (35km)	**Contractor:** BLD Consult Ltd **Supervisor:** UNRA Moyo	**Commenced:** 21/12/2020 **Completion**: 20/06/2021	35	6	2,397,521,640	68,500,618.28
15	Mechanized Maintenance of Unpaved National Roads For 22 UNRA Stations Under Framework Contract For 3 Years Lot 24: Moyo Station: Moyo – Obongi Road (28+000-56+000) (28Km).	**Contractor:** BLD Consult Ltd **Supervisor:** UNRA Moyo	**Commenced:** 6/04/2021 **Completion**: 5/07/2021	28	3	2,313,621,658	82,629,344.9
16	Mechanized maintenance of selected unpaved national roads for 18 UNRA stations under framework contract for 3 years: Lot1-25: Lot 20 Arua station - Call-off order number 1(Wandi – Rhino camp road 51km	**Contractor:** PNR **Supervisor:** UNRA Arua	**Commenced:** 15/04/2021 **Completion**: 14/09/2021	51	6	2, 000,040,504	39,216,480.47
	AVERAGE cost/km (18%VAT inclusive)						41,651,076
	AVERAGE cost/km (18%VAT exclusive)						**34,153,883**

Source: UNRA, (2022 p.1-94)

4.3.10 Summary cost/km road maintenance costs at KSL

Basing on all the above machine production cost parameters, different aspects of machine production cost per hour have been summarized as indicated in Table 4.9.

Table 4. 9: Monthly cost aspects of Fleet operation at KSL

OPERATION COST ASPECTS		Nature of cost	Cost (Ugx)/month
1	Machinery repair and maintenance cost	Direct	3,180,436
2	Machine fuel costs/expenses	Direct	47,029,500
3	Machine insurance costs	Indirect	13,570,250
4	Operators' salaries	Direct	11,400,000
5	Machine depreciation costs	Indirect	15,450,000
TOTAL MONTHLY OPERATIONAL COSTS (Ugx)			**90,630,186**

From Table 4.9, total monthly road maintenance and production costs was **approximately 90,630,186** Ugx. Specific data can be obtained from the data logs in the appendix.

Table 4.10 shows the km of roads maintained at the Karongo satellite station and obtains the average km worked per month.

Table 4. 10: km of roads maintained at the Karongo satellite station and obtains the average km worked per month.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Average**
km	5.77	2.4	2.4	1.15	0.3	1.2	1	4	2.2	1.9	3	2.6	**2.33**

The average cost per km of roads maintained at the Karongo satellite station can be then computed by expressing the monthly maintenance cost as a fraction of the average km worked per month. Average cost/km =90,630,186/2.33=-38,897,076Ugx per km. The average km of road maintained at KSL's Karongo satellite station was approximately 2.33km of unpaved roads. Considering that machine insurance and depreciation costs are not factored into the district's road maintenance cost calculation (check attached cost calculation sheets in appendix), we arrive at a total of 61,609,936Ugx which is then divided by the average km of road-maintained amounting to 2.33km. This then gives an approximate cost per km maintained of 26,442,032Ugx/km.

This cost is lower than Gulu district's cost per km of 32,674,895Ugx/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 its own garages and thus does not need to outsource any repair/maintenance works.

The district also incurs an extra cost of road maintenance labour cost allowances which KSL does not incur since its workers are only paid monthly salaries.

4.3.11 Rainfall patterns at KSL

The highest amount of rainfall received at KSL was 165.6mm received in the month of May, while the lowest amount of rainfall was received in the month of December (4.2mm). This is shown in Figure 4.16. The rainfall data was collected from the Kakira Sugar Limited Meteorological Station where all weather data is observed, recorded, and analysed by an expert team of weather analysts (meteorologists).

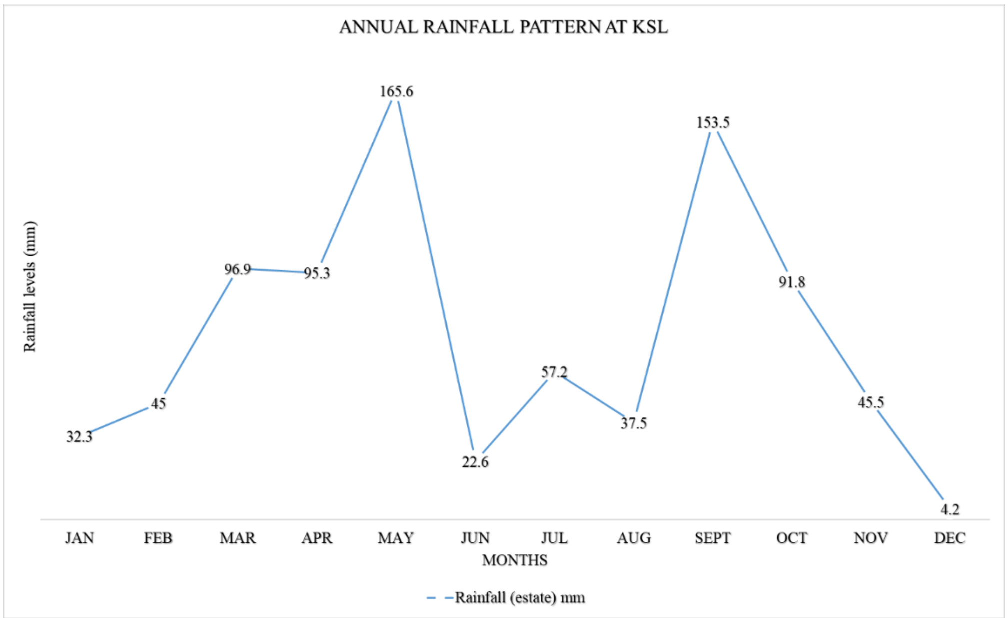


Figure 4. 16: Annual average rainfall pattern at KSL

In Figure 4.17, a graph comparing rainfall data and km of road maintained, clearly shows an interesting relationship between the two variables. In the months with less rainfall, there is more road maintenance work done compared to the months with high rainfall. i.e., compare January, August, November, and December; months with low rainfall but with a greater distance of road maintenance work carried out. Months with high rainfall displayed the stack opposite with fewer road maintenance works carried out as compared to the months with low rainfall. i.e., March, May, and September.

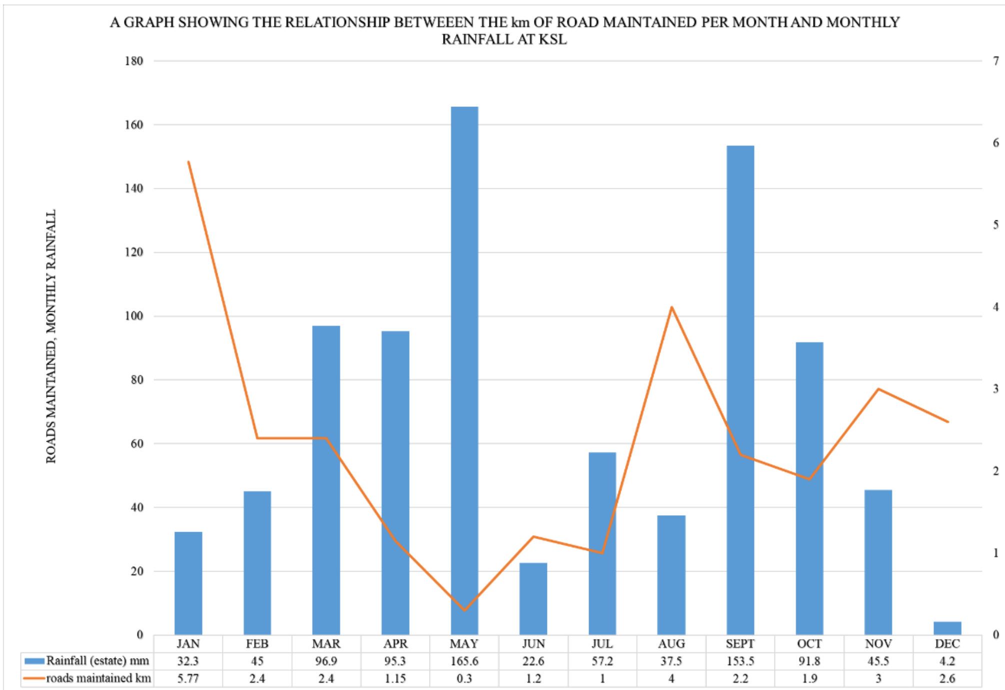


Figure 4. 17: Relationship between kilometres of road maintained per month and monthly rainfall at KSL

The findings in Figure 4.17 clearly show that road maintenance works are best carried out in the dry season, where there is less rainfall than in the wet season, where there is lots of rainfall. This could be because many road maintenance operations like marram soil excavation, loading, dumping, and spreading, compaction, and drainage excavations can barely be carried out under wet conditions since; machines will tend to get bogged down thus resulting in less machine efficiency and productivity.

4.3.12 Average length of unpaved road maintained per month at KSL

Based on the road research information collected, the road maintenance department at KSL, Karongo satellite station worked on an average of 2.33km of unpaved road per month. According to the KSL agricultural department, KSL has over 300km of unpaved roads spread across several divisions for maintenance. KSL also has approximately 6-7km of tarmac roads in the estate.

Karongo satellite office serves Karongo Division, and area of approximately 30km^2. The KSL estate is divided into several agricultural divisions with Karongo being one of them. The unpaved roads under Karongo division amount to approximately 120km. This also factors in fireguards/breaks placed between sugarcane plantations commonly referred to as "blocks". A sugarcane block usually measures approximately 460m x 360m. Karongo division has over 144 sugarcane blocks.

The map in Figure 4.18 gives a clear perspective of the area under maintenance.

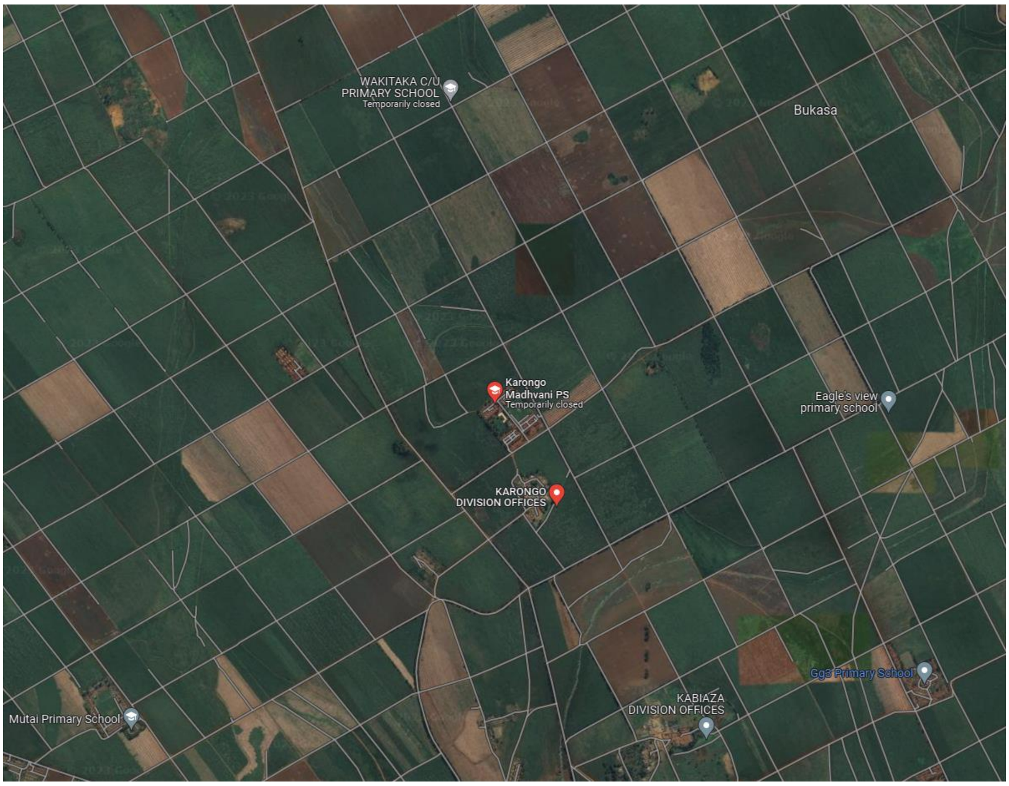


Figure 4. 18: View of the area under Karongo Satellite division with associated roads and sugarcane blocks.

Source: Courtesy of Google maps (GPS Coordinates 0°31'48.5"N 33°17'08.1"E)

4.4 Machine Days to Next failure and Downtime at KSL

This phase of the research involved analysing the machine days to next failure known as Mean Time Before Failure (MTBF) and the Mean Time To Repair (MTTR). As earlier stated, most of the repairs carried out at the Karongo satellite station were minor field-based incidents. If they were of greater magnitude, the machines would be transported back to the satellite repair workshop for incidental repairs. If more aggravated issues were identified, the machine would be transported to the main garage for major repairs.

The Mean Time To Repair (MTTR), was determined by calculating the approximate travel time by the field emergency repair crew, to the field location where the breakdown incident occurred; the assessment time and/repair time; time to return to the satellite station to source additional spares. These were summed up to arrive at a Time To Repair (TTR) for one recorded incident. They were then averaged for different recorded incidents to arrive at a Mean Time To Repair (MTTR). MTTR was then expressed by total downtime as a ratio of total number of failures.

The Mean-Time-Before-Failure (MTBF) was expressed by total operated hours as a ratio of the number of failures. The total operated machine hours and the recorded associated machine failure incidents for that selected month were obtained from machine records at KSL. These were then used to compute the MTBF which shows how long it takes before a machine experiences its next failure. These calculated MTTR and MTBF values for the different machines have been indicated in Table 4.11.

Table 4. 11: MTTR and MTBF for various equipment at KSL

SNo.	Equipment	MTBF (hrs)	MTTR (hrs)
1	Earthmover	60	1
2	Roller compactor	73	1
3	Wheel loader	44	1
4	Motor grader	43	1
5	Dumper truck	38	2
6	Backhoe excavator	72	2

The Ingersoll Rand Compactor had the highest MTTR at 73hours followed by the backhoe excavator at 72, earthmover at 60, the wheel loader and motor grader at 44 and 43 respectively, then the dumper truck with the lowest at 38. Average MTTR was calculated to be 1.333 which corresponds to the average downtime. This corresponds to 16.7% of the total operational time (assumed as 8hrs per day).

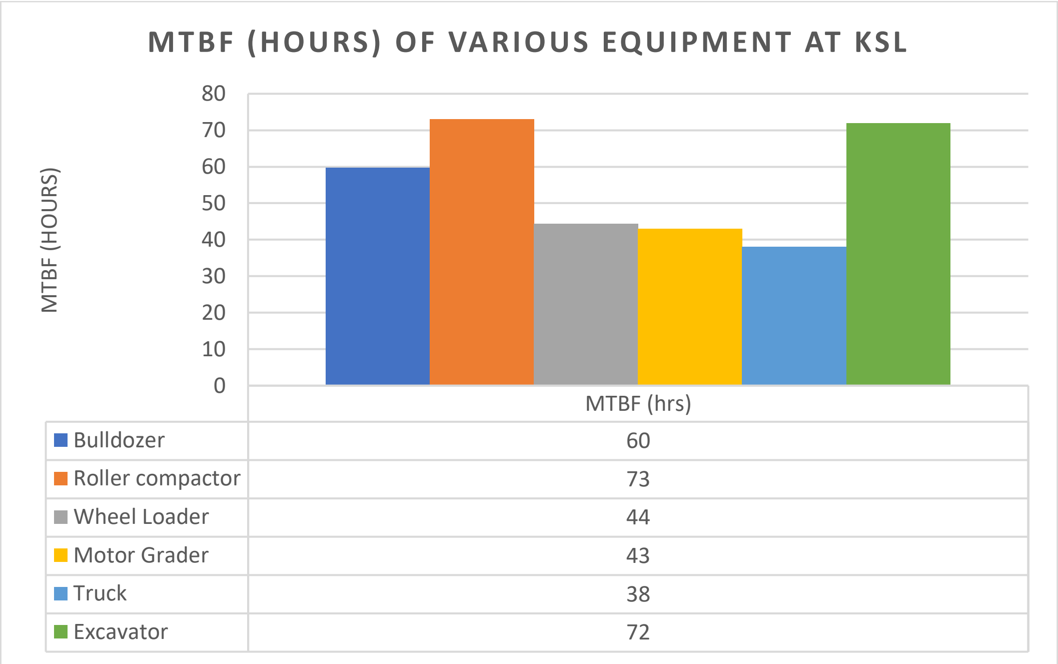


Figure 4. 19: MTBF of various equipment at KSL

4.4.1 Machine cumulative hours and MTBF for KSL equipment

Table 4. 12: Correlation analysis for Machine cumulative hours and MTBF *TATA truck excluded.

Correlations			
		Cumulative hours worked	MTBF
Cumulative hours worked	Pearson Correlation	1	-.847
	Sig. (2-tailed)		.070
	N	5	5
MTBF	Pearson Correlation	-.847	1
	Sig. (2-tailed)	.070	
	N	5	5

The two variables of Machine cumulative hours and MTBF of 5No. machines in unpaved road maintenance works, were considered to examine their relationship. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a strong negative linear relationship between the two variables ($r = -0.847$) that is insignificantly different from zero ($p < 0.070$).

4.4.2 Machine Weight and MTBF for KSL equipment

Table 4. 13: Correlation analysis for Machine Weight and MTBF

Correlations			
		Machine weight (kg)	MTBF
Machine weight (kg)	Pearson Correlation	1	-.597
	Sig. (2-tailed)		.211
	N	6	6
MTBF	Pearson Correlation	-.597	1
	Sig. (2-tailed)	.211	
	N	6	6

The two variables of Machine Weight (kg) and MTBF of 6No. machines in unpaved road maintenance works, were considered to examine their relationship. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a moderate negative linear relationship between the two variables (r = -0.597) that is insignificantly different from zero ($p < 0.211$).

4.4.3 Machine Weight and MTTR for KSL equipment

Table 4. 14: Correlation analysis for Machine Weight and MTTR

Correlations			
		Machine weight	MTTR
Machine weight	Pearson Correlation	1	.042
	Sig. (2-tailed)		.937
	N	6	6
MTTR	Pearson Correlation	.042	1
	Sig. (2-tailed)	.937	
	N	6	6

The two variables of Machine Weight (kg) and MTTR (hours) of 6No. machines in unpaved road maintenance works, were considered to examine their relationship. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a low positive linear relationship between the two variables (r = 0.042) that is insignificantly different from zero ($p < 0.937$).

4.4.4 Machine Weight and Daily production cost for KSL equipment

Table 4. 15: Correlation analysis for Machine Weight and Daily production cost

Correlations			
		Machine weight (kg)	Daily production Cost (Ugx)
Machine weight (kg)	Pearson Correlation	1	.250
	Sig. (2-tailed)		.633
	N	6	6
Daily production Cost (Ugx)	Pearson Correlation	.250	1
	Sig. (2-tailed)	.633	
	N	6	6

The two variables of Machine Weight (kg) and Daily production cost (Ugx) of 6No. machines in unpaved road maintenance works, were considered to examine their relationship. The scatter diagrams indicate a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a low positive linear relationship between the two variables (r = 0.250) that is insignificantly different from zero ($p < 0.633$).

4.4.5 MTTR and Daily production cost for KSL equipment

Table 4. 16: Correlation analysis for MTTR and Daily production cost

Correlations			
		MTTR	Daily production Cost (Ugx)
MTTR	Pearson Correlation	1	-.634
	Sig. (2-tailed)		.176
	N	6	6
Daily production Cost (Ugx)	Pearson Correlation	-.634	1
	Sig. (2-tailed)	.176	
	N	6	6

The two variables of MTTR (hours) and Daily production cost (Ugx) of 6No. machines in unpaved road maintenance works, were considered to examine their relationship. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a moderate negative linear relationship between the two variables (r = -0.634) that is insignificantly different from zero ($p < 0.176$).

4.4.6 MTTR and Cumulative Machine Hours

Table 4. 17: Correlation analysis for MTTR and Cumulative machine hours

Correlations			
		MTTR	Cumulative machine hours
MTTR	Pearson Correlation	1	-.674
	Sig. (2-tailed)		.212
	N	5	5
Cumulative machine hours	Pearson Correlation	-.674	1
	Sig. (2-tailed)	.212	
	N	5	5

The two variables of MTTR (hours) and Cumulative machine hours of 5No. machines in unpaved road maintenance works, were considered to examine their relationship. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a moderate negative linear relationship between the two variables (r = -0.674) that is insignificantly different from zero ($p < 0.212$).

4.4.7 Daily Production costs (Ugx) and Cumulative Machine Hours at KSL

Table 4. 18: Correlation analysis for MTTR and Cumulative machine hours

Correlations			
		Cumulative machine hours	Daily production Cost (Ugx)
Cumulative machine hours	Pearson Correlation	1	-.427
	Sig. (2-tailed)		.399
	N	6	6
Daily production Cost (Ugx)	Pearson Correlation	-.427	1
	Sig. (2-tailed)	.399	
	N	6	6

The two variables of Daily machine production costs (Ugx) and Cumulative machine hours of 6No. machines in unpaved road maintenance works, were considered to examine their relationship.

The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a low negative linear relationship between the two variables (r = -0.427) that is insignificantly different from zero ($p < 0.399$).

4.4.8 MTBF Graphs for various equipment at KSL

a) Earthmover/bulldozer

The graph in Figure 4.20 clearly indicates a weak negative correlation between the data points as indicated by the formula, $y = -0.2573x + 12.33$, and $R^2 = 0.055$.

The data points for equipment downtime were represented by the following equation, y = -0.0195x + 1.5561; R^2 = 0.1965. This also shows a weak negative correlation of 0.1965 as indicated by y = -0.0195x + 1.5561.

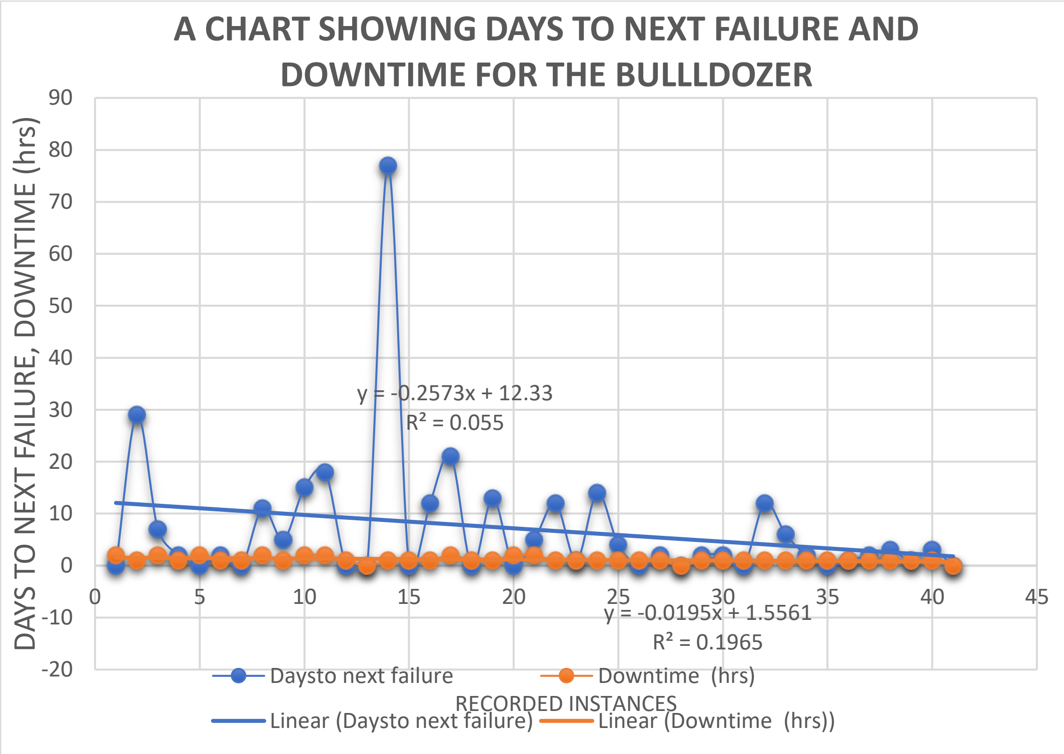


Figure 4. 20: Machine Days to next failure for the Bulldozer

b) Roller Compactor

The graph in Figure 4.21 clearly shows a weak negative correlation of R^2 = 0.013 between the data points of the machine days to next failure, and another weak negative correlation for the downtime hours of R^2 = 0.0301.

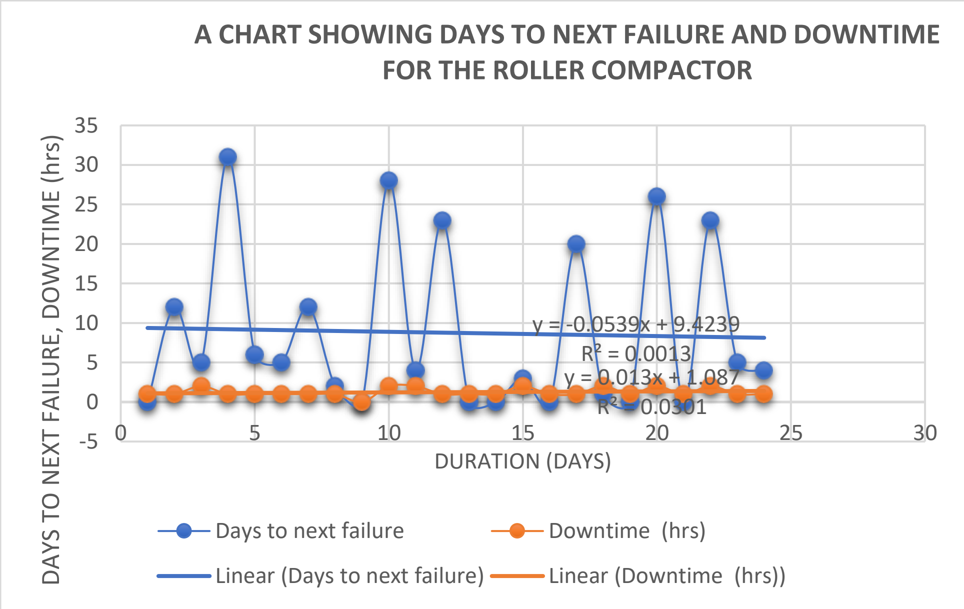


Figure 4. 21: Machine Days to next failure for the Roller Compactor

c) Front End Bucket Loader

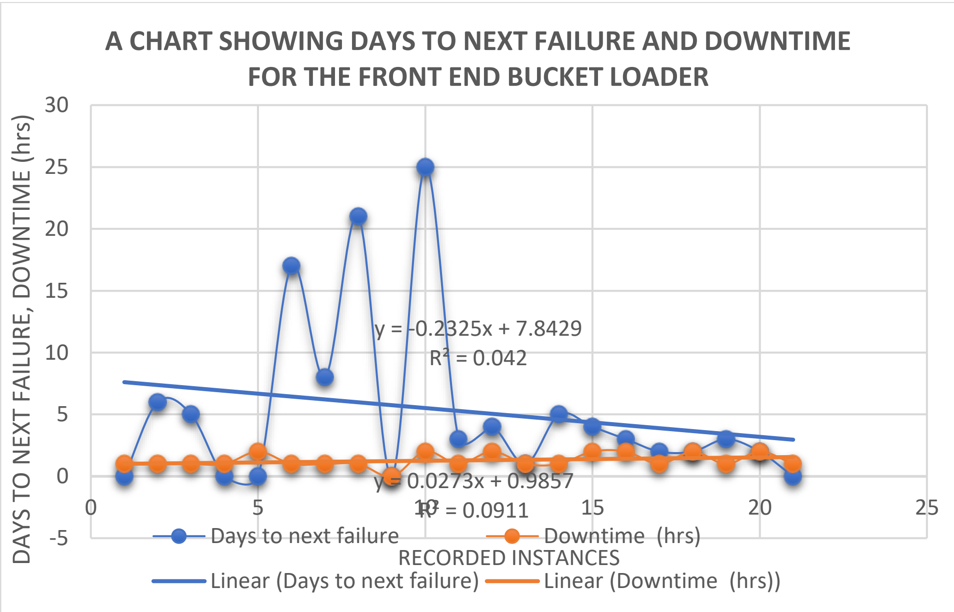


Figure 4. 22: Machine Days to next failure for the wheel loader

The graph in Figure 4.22 clearly shows a weak negative correlation of $R^2 = 0.042$ between the data points of the machine days to next failure, and another weak positive correlation for the downtime hours of $R^2 = 0.0911$.

d) **Motor grader**

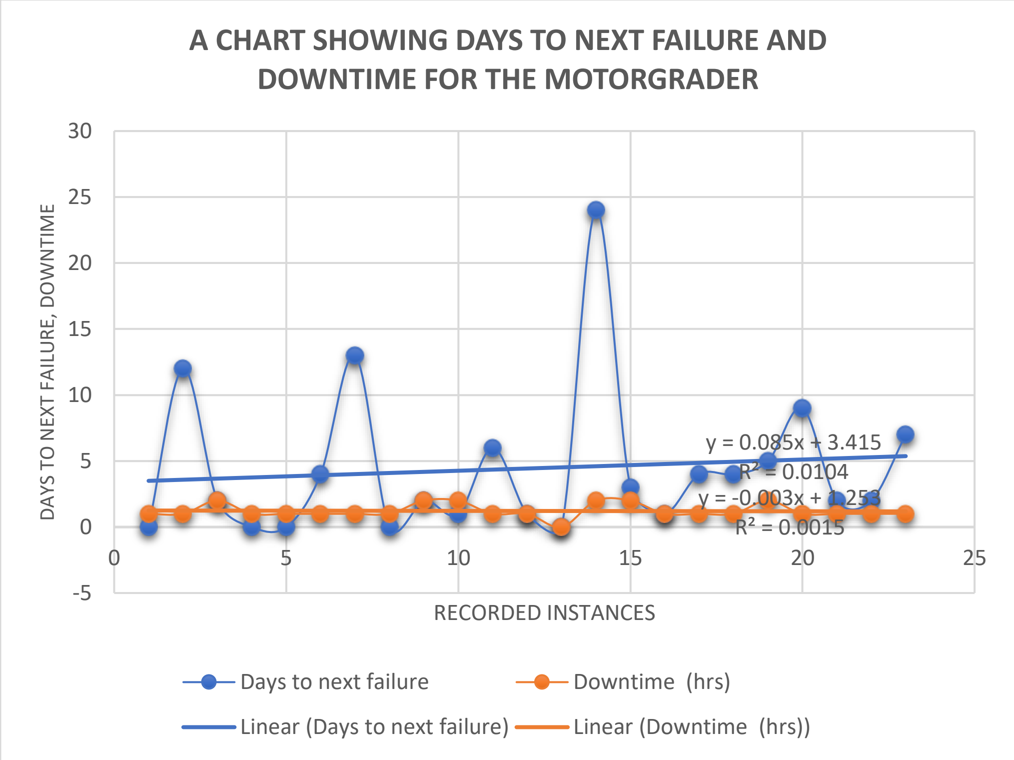


Figure 4. 23: Machine Days to next failure for the Motor grader

The graph in Figure 4.23 clearly shows a weak positive correlation of R^2 = 0.0104 between the data points of machine days to next failure, and another weak negative correlation for the downtime hours of R^2 = 0.0015.

e) **Dumper truck**

The graph below in Figure 4.24 clearly shows a weak negative correlation of R^2 = 0.04 between the data points of the machine days to next failure, and another weak negative correlation for the downtime hours of R^2 = 0.0006.

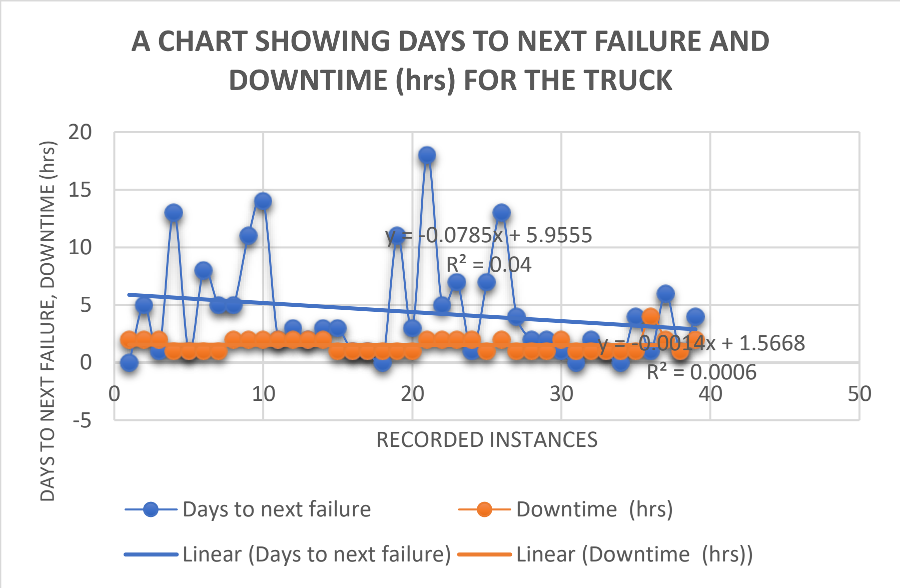


Figure 4. 24: Machine Days to next failure for the Dumper truck

d) Backhoe excavator

The graph in Figure 4.25 clearly shows a weak positive correlation of R^2 = 0.4693 between the data points indicating the machine days to next failure, and another weak positive correlation for the downtime hours of R^2 = 0.303.

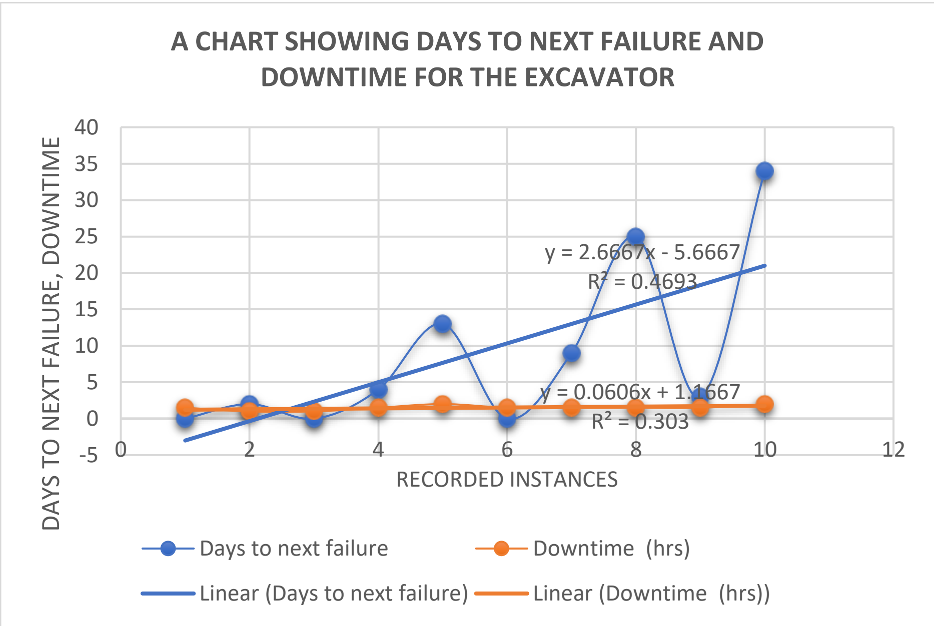


Figure 4. 25: Machine Days to next failure for the excavator

4.5 Methods of Testing and validating the cost models from KSL

4.5.1 Dumper truck

a) Correlation analysis

Based on the correlation analysis data carried out, all data sets tested had high positive linear relationship between the three variables (r = 0.923 and 1.000) that is significantly different from zero ($p < 0.01$).

b) Normality

A histogram of residuals for the dependant variable, Daily production costs, was plotted to determine normality. The distribution appeared normal and therefore, the model did not violate the assumption of normality.

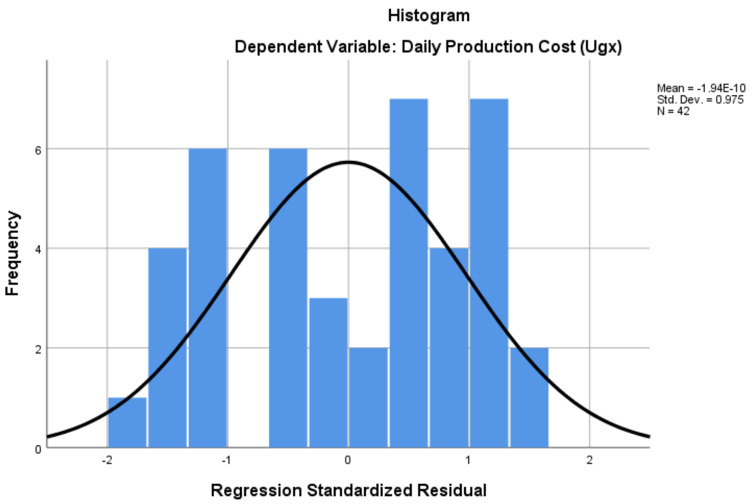


Figure 4. 26: Dumper truck histogram of residuals for dependant variable

c) Equality of variance

The assumption of constant variance of y for all values of x was checked for violation by plotting the residuals against the predicted values in Figure 4.27. Residuals are the difference between the actual and predicted costs. Apart from a few outliers, most residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

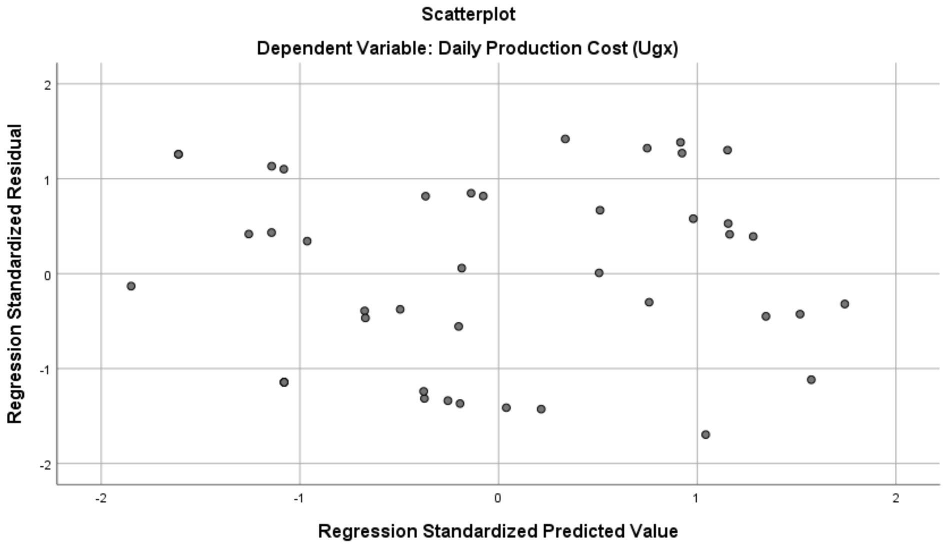


Figure 4. 27: Dumper truck test for constant variance

4.5.2 Excavator

a) Correlation analysis

Based on the correlation analysis data carried out, all data sets tested had high positive linear relationship between the three variables (r = 1.000, 0.960 and 0.995) that is significantly different from zero ($p < 0.01$).

b) Normality

In determining normality, a histogram of residuals for the dependant variable, Daily production costs was plotted. The distribution appeared normal and therefore, based upon the test, the model did not violate the assumption of normality.

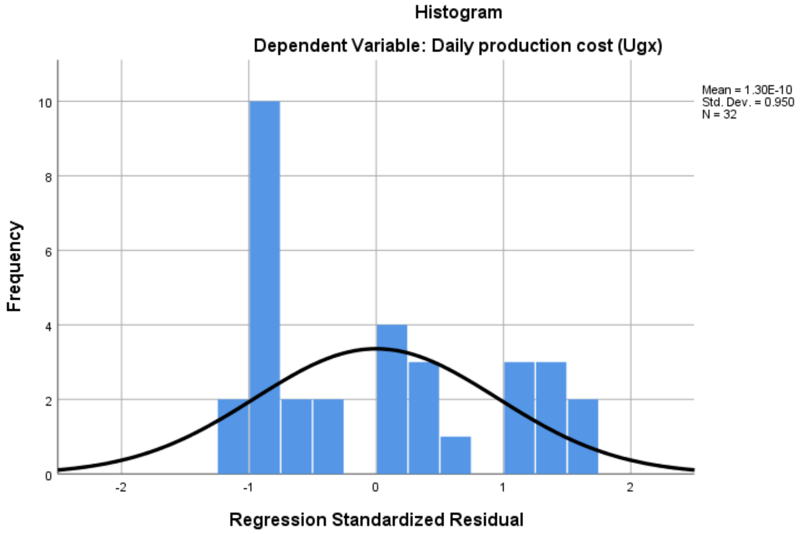


Figure 4. 28: Excavator histogram of residuals for dependant variable

c) Equality of variance

Most residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

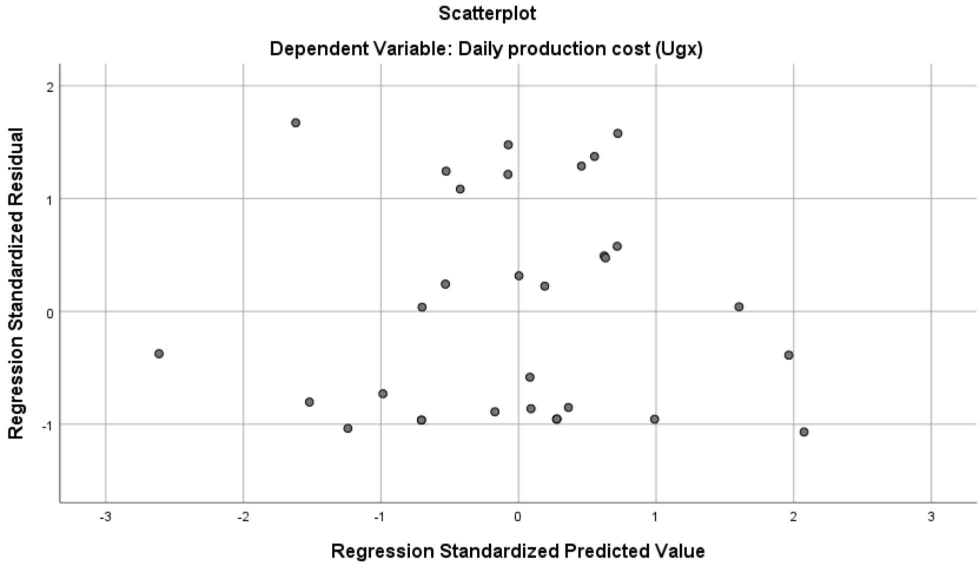


Figure 4. 29: Excavator test for constant variance

4.5.3 Roller compactor

a) Correlation analysis

Based on the correlation analysis data carried out.

All data sets tested had high positive linear relationship between the three variables (r = 1.000, 0.923 and 0.967) that is significantly different from zero ($p < 0.01$).

b) Normality

A histogram of residuals for the dependant variable, Daily production costs was plotted, to determine normality. The distribution appeared normal and therefore one, based upon the test, the model had not violated the assumption of normality.

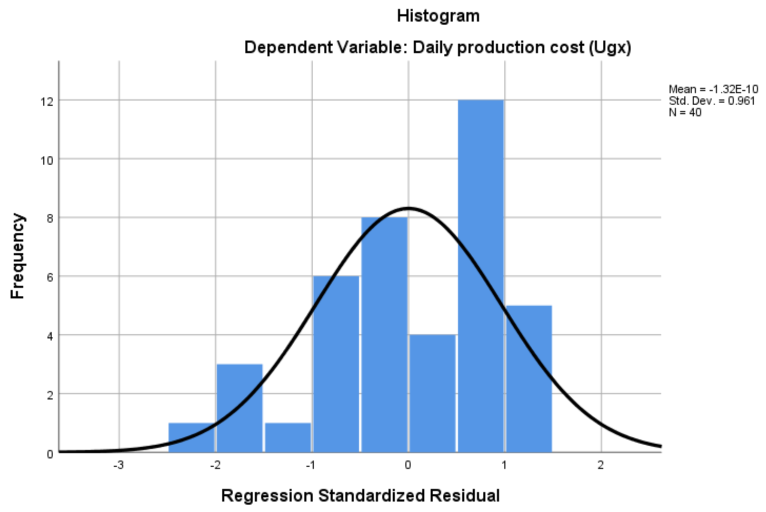


Figure 4. 30: Compactor histogram of residuals for dependant variable

c) Equality of variance

The majority of residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

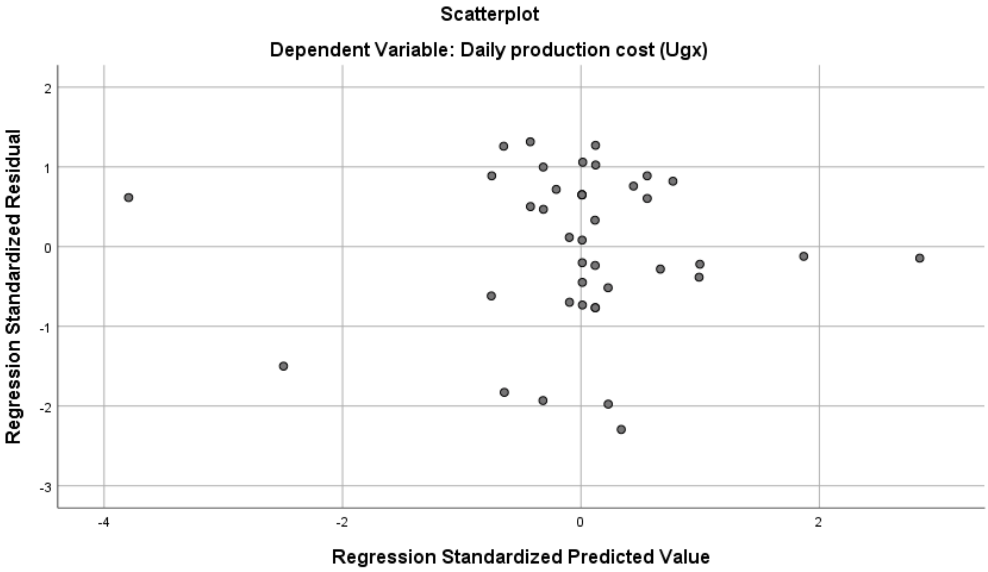


Figure 4. 31: Compactor test for constant variance

4.5.4 Front End Wheel Loader

a) Correlation analysis

Based on the correlation analysis data carried out.

All data sets tested had high positive linear relationship between the three variables (r = 1.000, 0.979 and 0.959) that is significantly different from zero ($p < 0.01$).

b) Normality

In the determination of normality, a histogram of residuals for the dependant variable, Daily production costs was plotted. The distribution appeared normal and therefore one can conclude that, based upon the test, the model had not violated the assumption of normality.

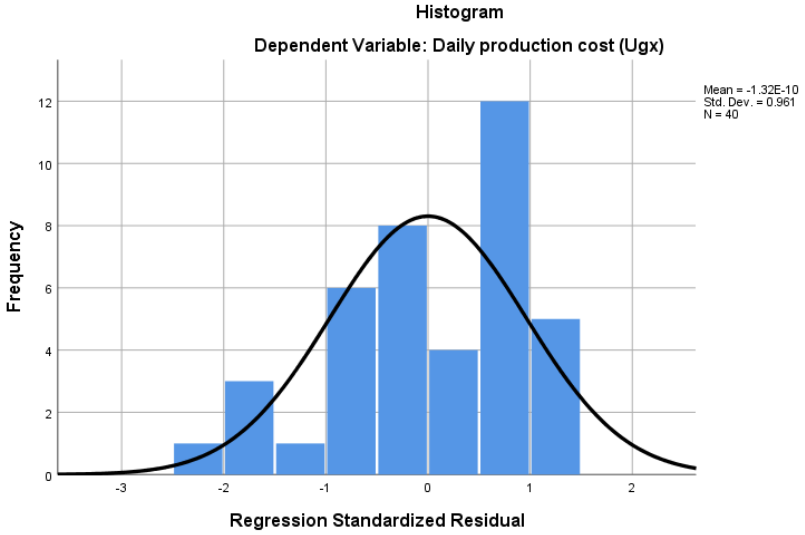


Figure 4. 32: Wheel loader histogram of residuals for dependant variable

c) Equality of variance

Most residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

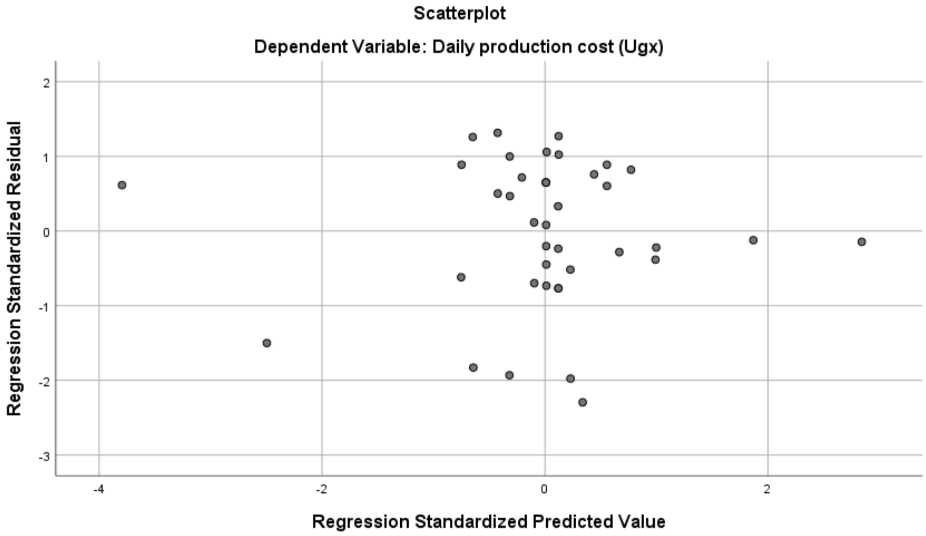


Figure 4. 33: Wheel loader test for constant variance

4.5.5 Motor Grader

a) Correlation analysis

Based on the correlation analysis data carried out.

All data sets tested had high positive linear relationship between the three variables (r = 1.000, 0.762 and 0.884) that is significantly different from zero ($p < 0.01$).

b) Normality

To determine normality, a histogram of residuals for the dependant variable, Daily production costs was plotted. The distribution appeared normal and therefore one can conclude that, based upon the test, the model had not violated the assumption of normality.

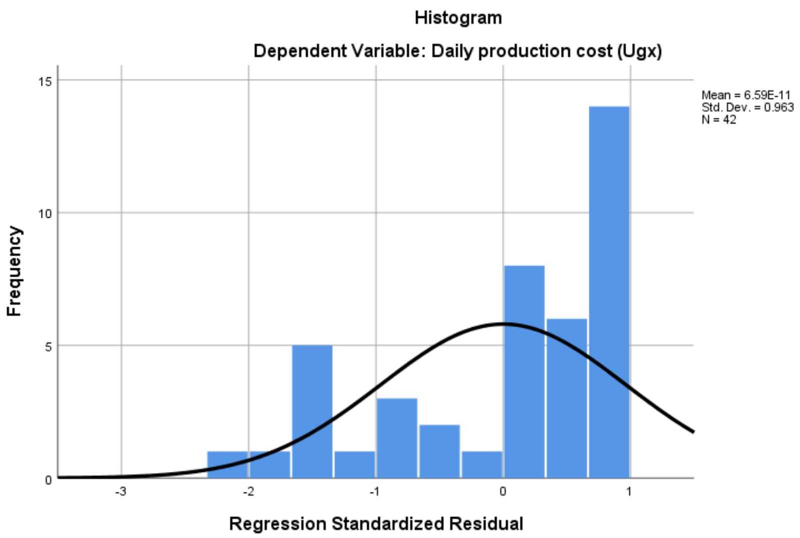


Figure 4. 34: Grader histogram of residuals for dependant variable

c) Equality of variance

Most residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

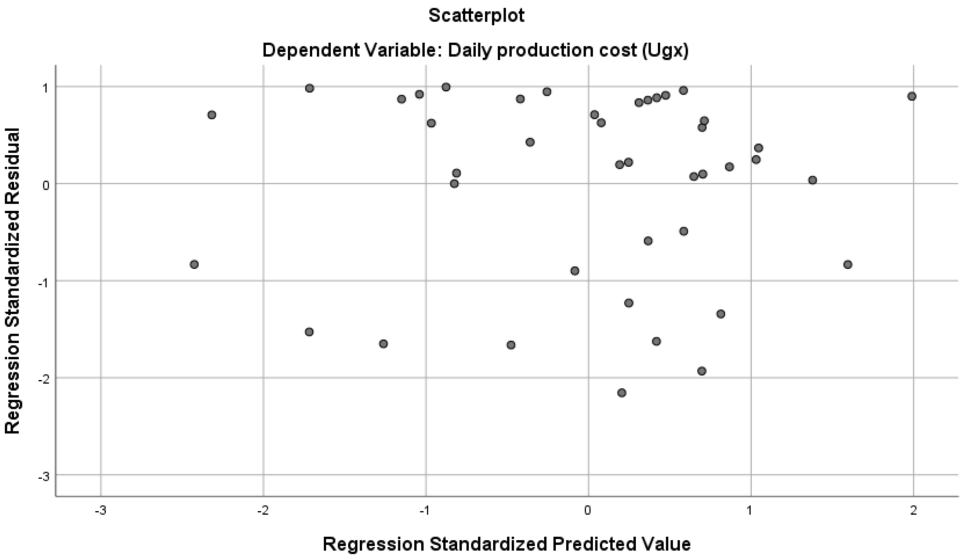


Figure 4. 35: Grader test for constant variance

4.5.6 Bulldozer/ Earthmover

a) Correlation analysis

Based on the correlation analysis data carried out.

All data sets tested had high positive linear relationship between the three variables (r = 1.000, 0.922 and 1.000) that is significantly different from zero ($p < 0.01$).

b) Normality

To determine normality, a histogram of residuals for the dependant variable, Daily production costs was plotted. Here the distribution appeared to be normal and therefore one can conclude that, based upon the test, the model has not violated the assumption of normality.

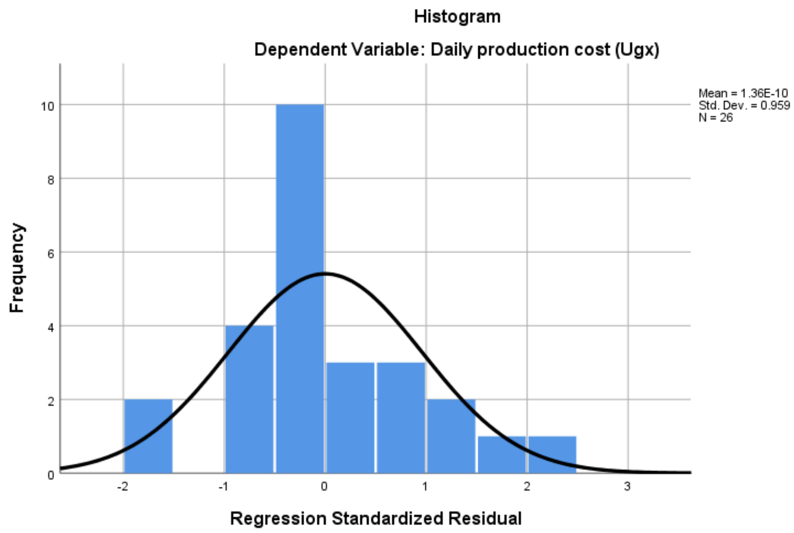


Figure 4. 36: Bulldozer histogram of residuals for dependant variable

c) Equality of variance

Most residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

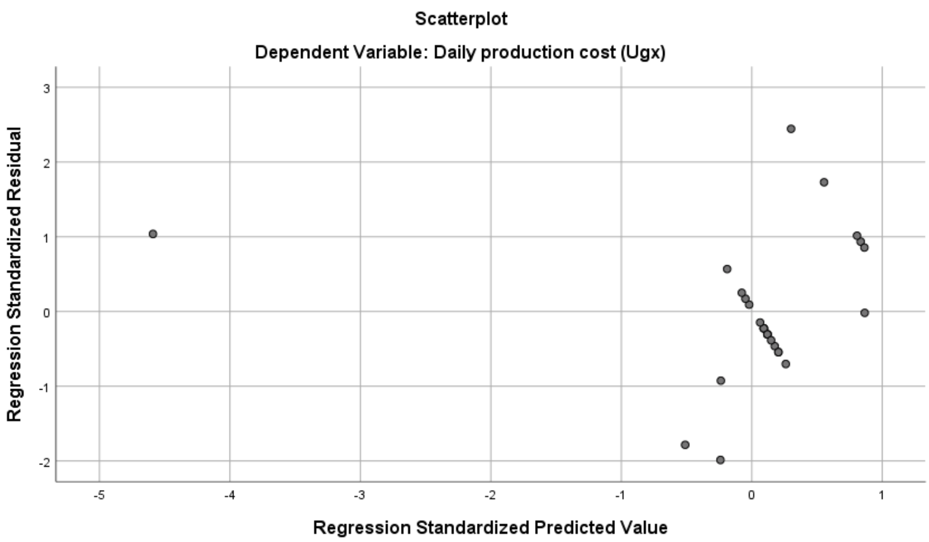


Figure 4. 37: Bulldozer test for constant variance

4.6 Methods of Testing and validating the cost models from Gulu DLG

a) Correlation analysis

Based on the correlation analysis data carried out, all data sets tested had high positive linear relationship between the three variables (r = 0.824, 1.000 and 0.883) that is significantly different from zero ($p < 0.01$).

b) Normality

A histogram of residuals for the dependant variable, Daily production costs, was plotted to determine normality. The distribution appeared normal and therefore, the model did not violate the assumption of normality.

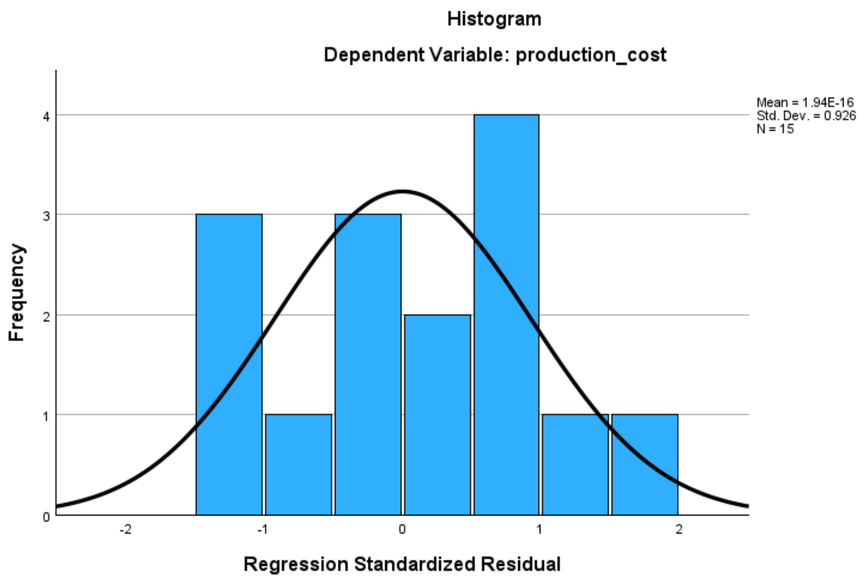


Figure 4. 38: Histogram of residuals for dependant variable

c) Equality of variance

The assumption of constant variance of y for all values of x was checked for violation by plotting the residuals against the predicted values. Residuals are the difference between the actual and predicted costs. Apart from a few outliers, most residual observations remained constant with the magnitude of the predicted values. Therefore, it is suggested that the equality of variance assumption has been proven.

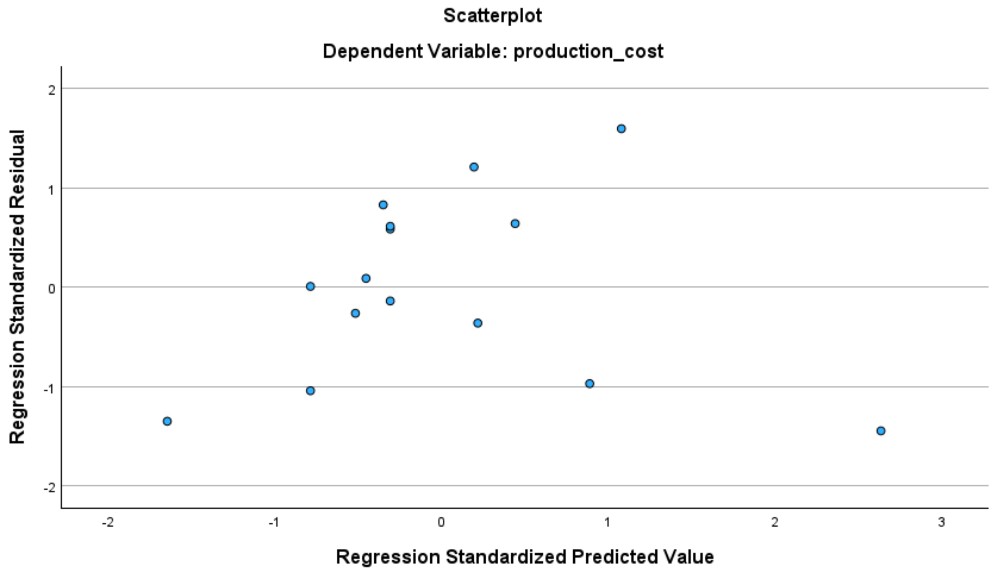


Figure 4. 39: Test for constant variance

4.7 Development of a cost model for parameters identified at KSL.

4.7.1 Cost modelling parameters

The deterministic cost model predicting daily machine production costs considered Repair cost, Maintenance costs, Fuel expenses/costs, Operator costs, and Insurance costs alongside costs due to machine depreciation as research parameters. The relationship between different factors/parameters and the daily machine production cost were developed as Linear Regression Cost models in the statistical package SPSS.

4.7.2 Development of the KSL cost model in Microsoft Excel and SPSS

The research parameters based on observational and archival data, included Machine Fuel Consumption, Repair Costs, Machine tyre/undercarriage costs, Insurance Costs, Maintenance Costs, and Machine Depreciation alongside the

Labour Costs. Different linear regression models were developed for different machinery since each was unique and had its own data sets that would influence machine performance. Model fit was tested through collinearity (using data correlations) and normality (using histograms of residual data sets).

4.7.3 Dumper truck data cost model

Table 4. 19: Dumper truck Correlation analysis for km covered, fuel consumed and Daily Tyre cost

Correlations				
		Km	fuel consumed (ltrs)	Tyre cost (Ugx)
kilometers	Pearson Correlation	1	.923**	1.000**
	Sig. (2-tailed)		.000	.000
	N	42	42	42
fuel consumed (ltrs)	Pearson Correlation	.923**	1	.923**
	Sig. (2-tailed)	.000		.000
	N	42	42	42
Daily Tyre cost (Ugx)	Pearson Correlation	1.000**	.923**	1
	Sig. (2-tailed)	.000	.000	
	N	42	42	42
**. Correlation is significant at the 0.01 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the kilometres covered and fuel consumption of 42 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.923$) that was significantly different from zero ($p < 0.01$).

The linear relationship between the kilometres covered and computed daily tyre cost consumed of 42 data sets was also assessed. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables (r = 1.000) that was significantly different from zero ($p < 0.01$).

When the linear relationship between the Daily tyre cost and fuel consumed of 42 data sets was investigated, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables (r = 0.923) that was significantly different from zero ($p < 0.01$).

Table 4. 20: Dumper truck Regression analysis for km covered, and fuel consumed and Daily machine production cost

Coefficients[a]

Truck 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)	841569.566	.139		6052636.410	.000	841569.284	841569.847		
	Km	59.803	.003	.033	23251.140	.000	59.798	59.808	.149	6.714
	fuel consumed (ltrs)	4499.998	.006	.970	692748.466	.000	4499.985	4500.011	.149	6.714

a. Dependent Variable: Daily Production Cost (Ugx)

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
1	1.000[a]	1.000	1.000	.27194	1.000	1712495470783.602	2	39	.000

a. Predictors: (Constant), fuel consumed (ltrs), km

b. Dependent Variable: Daily Production Cost (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	253282270837.235	2	126641135418.617	1712492556177.725	.000[b]
	Residual	2.884	39	.074		
	Total	253282270840.119	41			

a. Dependent Variable: Daily Production Cost (Ugx)

b. Predictors: (Constant), fuel consumed (ltrs), km

From the regression data in Table 4.20,

The Problem:

To investigate if Fuel costs and km of unpaved road maintained have an impact on road maintenance costs.

Hypothesis

H1: Fuel consumed, and km of unpaved road maintained have an impact on road maintenance costs.

The hypothesis tested if Fuel consumed, and km of unpaved road maintained have a significant impact on daily production costs. The dependent variable Daily Production Cost (Ugx) was regressed on predicting variables Fuel consumed and km of unpaved road maintained to test hypothesis H1. Fuel consumed significantly predicted Daily Production Cost (Ugx), $F(2,39) = 1712492556177.725$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Daily production cost ($\beta = 0.970$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Also, the $R^2 = 1.000$ depicts that the model explains 100.0% of the variance in Daily Production Cost (Ugx), and this is brought about by the variables used which were all key predictors. The table shows the summary of the findings.

Daily Production Cost (Ugx) = 841,569.566 + 59.803 x (km covered) + 4,499.998 x (fuel consumed) ……………………………………. **(Equation 4.3)**

Since $p < 0.05$, therefore, all β -coefficients obtained were highly statistically significant. The strongest predictors are Fuel consumed ($\beta = 0.970$) and then next in line is km covered ($\beta = 0.033$). The 95.0% Confidence Interval for β in the km row indicated a 95% confidence that the population value for the slope of the regression line between our variables lies between 59.798 and 59.808. This indicated the average daily km covered by the dumper trucks.

4.7.4 Excavator data cost model

Table 4. 21: Excavator Correlation analysis for Machine Hours worked, fuel consumed and Daily tyre cost

Correlations				
		Hours worked	Fuel consumed (ltrs)	Tyre cost (Ugx)
Hours worked	Pearson Correlation	1	.960**	.995**
	Sig. (2-tailed)		.000	.000
	N	32	32	32
Fuel consumed (ltrs)	Pearson Correlation	.960**	1	.964**
	Sig. (2-tailed)	.000		.000
	N	32	32	32
Daily Tyre cost (Ugx)	Pearson Correlation	.995**	.964**	1
	Sig. (2-tailed)	.000	.000	
	N	32	32	32
**. Correlation is significant at the 0.01 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the Machine Hours worked and fuel consumption of 32 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.960$) that was significantly different from zero ($p < 0.01$).

When the linear relationship between the Fuel consumed and Daily tyre cost of 32 data sets was assessed, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.964$) that was significantly different from zero ($p < 0.01$).

On investigating the linear relationship between the Machine hours worked and Daily tyre cost of 32 data sets, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.995$) that was significantly different from zero ($p < 0.01$).

Table 4. 22: Excavator regression analysis for Machine Hours worked, fuel consumed, and Daily machine production cost

Coefficients[a]

Excavator 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)	940969.976	244.453		3849.295	.000	940470.014	941469.937		
	Hours worked	1153.344	77.409	.058	14.899	.000	995.024	1311.663	.078	12.862
	Fuel consumed (ltrs)	4531.694	18.585	.944	243.839	.000	4493.684	4569.704	.078	12.862

a. Dependent Variable: Daily production cost (Ugx)

Model Summaryb

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	1.000[a]	1.000	1.000	318.66301	1.000	428680.381	2	29	.000

a. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

b. Dependent Variable: Daily production cost (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	87061654886.652	2	43530827443.326	428680.381	.000[b]
	Residual	2944837.348	29	101546.115		
	Total	87064599724.000	31			

a. Dependent Variable: Daily production cost (Ugx)

b. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

From the regression data in Table 4.22.

<u>The Problem:</u>

To investigate if Fuel consumed and machine hours worked have an impact on road maintenance daily production costs.

Hypothesis

H1: Fuel consumed, and machine hours worked have an impact on road maintenance costs.

The hypothesis tested if Fuel consumed, and machine hours worked carry a significant impact on daily production costs. The dependent variable Daily Production Cost (Ugx) was regressed on predicting variable Fuel consumed and machine hours worked to test hypothesis H1. Fuel consumed significantly predicted Daily Production Cost (Ugx), $F(2,29) = 428680.381$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Daily production cost ($\beta = .944$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Moreover, the $R^2 = 1.000$ depicts that the model explains 100.0% of the variance in Daily Production Cost (Ugx), due to all the variables used being key predictors. The table shows the summary of the findings.

Daily Production Cost (Ugx) = 940,969.976 + 1,153.344 x (machine hours covered) + 4,531.694 x (fuel consumed). ……………………. **(Equation 4.4)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant. The strongest identified predictors are Fuel consumed ($\beta = 0.944$) and then next in line is machine Hours worked ($\beta = 0.058$).

4.7.5 Roller Compactor data cost model

Table 4. 23: Roller compactor Correlation analysis for Machine Hours worked, fuel consumed and Daily tyre cost

Correlations				
		Hours worked	Fuel consumed (ltrs)	Tyre cost (Ugx)
Hours worked	Pearson Correlation	1	.923**	.967**
	Sig. (2-tailed)		.000	.000
	N	40	40	40
Fuel consumed (ltrs)	Pearson Correlation	.923**	1	.932**
	Sig. (2-tailed)	.000		.000
	N	40	40	40
Daily Tyre cost (Ugx)	Pearson Correlation	.967**	.932**	1
	Sig. (2-tailed)	.000	.000	
	N	40	40	40
**. Correlation is significant at the 0.01 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the Machine Hours worked and fuel consumption of 40 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.923$) that was significantly different from zero ($p < 0.01$).

On assessing the linear relationship between the Machine Hours worked and Daily tyre cost of 40 data sets, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.967$) that was significantly different from zero ($p < 0.01$).

When the linear relationship between the Machine fuel consumed and Daily tyre cost of 40 data sets was assessed, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables (r = 0.932) that was significantly different from zero ($p < 0.01$).

Table 4. 24: Roller compactor regression analysis for Machine Hours worked, fuel consumed and Daily machine production cost

Coefficients[a]

Roller compactor Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	889527.934	94.352		9427.789	.000	889336.759	889719.109		
	Hours worked	208.239	28.482	.005	7.311	.000	150.530	265.949	.148	6.763
	Fuel consumed (ltrs)	4508.778	3.293	.995	1369.180	.000	4502.106	4515.451	.148	6.763

a. Dependent Variable: Daily production cost (Ugx)

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
1	1.000[a]	1.000	1.000	72.62566	1.000	6402115.315	2	37	.000

a. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

b. Dependent Variable: Daily production cost (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	67535750399.074	2	33767875199.537	6402115.315	.000[b]
	Residual	195156.026	37	5274.487		
	Total	67535945555.100	39			

a. Dependent Variable: Daily production cost (Ugx)

b. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

From the regression data in Table 4.24.

The Problem:

To investigate if Fuel consumed and machine hours worked have an impact on road maintenance daily production costs.

Hypothesis

H1: Fuel consumed, and machine hours worked have an impact on road maintenance costs.

The hypothesis tested if Fuel consumed, and machine hours worked carry a significant impact on daily production costs. The dependent variable Daily Production Cost (Ugx) was regressed on predicting variables Fuel consumed and machine hours worked to test hypothesis H1. Fuel consumed significantly predicted Daily Production Cost (Ugx), $F (2,37) = 6402115.315$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Daily production cost ($\beta = 0.995$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Moreover, the $R^2 = 1.000$ depicts that the model explains 100.0% of the variance in Daily Production Cost (Ugx), due to all the variables used being key predictors. The table shows the summary of the findings.

Daily Production Cost (Ugx) = 889,527.934 + 208.239 x (machine hours covered) + 4,508.778 x (fuel consumed) ………………..………. **(Equation 4.5)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant. Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant. The strongest predictors are Fuel consumption ($\beta =0.995$) and next in line is machine Hours worked ($\beta =0.005$).

4.7.6 Front End wheel Loader machine data cost model

Table 4. 25: Wheel loader Correlation analysis for Machine Hours worked Daily tyre cost and fuel consumed

Correlations				
		Hours worked	Tyre cost (Ugx)	Fuel consumed (ltrs)
Hours worked	Pearson Correlation	1	.979**	.959**
	Sig. (2-tailed)		.000	.000
	N	42	42	42
Daily Tyre cost (Ugx)	Pearson Correlation	.979**	1	.970**
	Sig. (2-tailed)	.000		.000
	N	42	42	42
Fuel consumed (ltrs)	Pearson Correlation	.959**	.970**	1
	Sig. (2-tailed)	.000	.000	
	N	42	42	42
**. Correlation is significant at the 0.01 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the Machine Hours worked and fuel consumption of 42 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.959$) that was significantly different from zero ($p < 0.01$).

On assessing the linear relationship between the Machine Hours worked and Calculated Daily tyre cost of 42 data sets, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.979$) that was significantly different from zero ($p < 0.01$).

When the linear relationship between the Machine Calculated Daily tyre cost and fuel consumption of 42 data sets was investigated, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables (r = 0.970) that was significantly different from zero ($p < 0.01$).

Table 4. 26: Wheel loader Regression analysis for Machine Hours worked, fuel consumed and Daily machine production cost

Coefficients[a]

Wheel loader Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	889527.934	94.352		9427.789	.000	889336.759	889719.109		
	Hours worked	208.239	28.482	.005	7.311	.000	150.530	265.949	.148	6.763
	Fuel consumed (ltrs)	4508.778	3.293	.995	1369.180	.000	4502.106	4515.451	.148	6.763

a. Dependent Variable: Daily production cost (Ugx)

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
1	1.000[a]	1.000	1.000	72.62566	1.000	6402115.315	2	37	.000

a. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

b. Dependent Variable: Daily production cost (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	67535750399.074	2	33767875199.537	6402115.315	.000[b]
	Residual	195156.026	37	5274.487		
	Total	67535945555.100	39			

a. Dependent Variable: Daily production cost (Ugx)

b. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

From the regression data in Table 4.26.

<u>The Problem:</u>

To investigate if Fuel consumed and machine hours worked have an impact on road maintenance daily production costs.

<u>Hypothesis</u>

H1: Fuel consumed, and machine hours worked have an impact on road maintenance costs.

The hypothesis tested if Fuel consumed, and machine hours worked carry a significant impact on daily production costs. The dependent variable Daily Production Cost (Ugx) was regressed on predicting variables Fuel consumed, and machine hours worked to test hypothesis H1. Fuel consumed significantly predicted Daily Production Cost (Ugx), $F(2,37) = 33767875199.537$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Daily production cost ($\beta = 0.995$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Moreover, the $R^2 = 1.000$ depicts that the model explains 100.0% of the variance in Daily Production Cost (Ugx), due to all the variables used being key predictors. The table shows the summary of the findings.

Daily Production Cost (Ugx) = 889,527.934 + 208.239 x (machine hours covered) + 4,508.778 x fuel consumed). …………….……….. **(Equation 4.6)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant. Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant. The strongest predictors are Fuel consumed (β =0.995) and then followed by machine Hours worked (β =0.005).

4.7.7 Motor Grader machine data cost model

Table 4. 27: Motor grader Correlation analysis for Machine Hours worked, daily tyre cost and fuel consumed

Correlations				
		Hours worked	Fuel consumed (ltrs)	Tyre cost (Ugx)
Hours worked	Pearson Correlation	1	.762**	.884**
	Sig. (2-tailed)		.000	.000
	N	45	45	45
Fuel consumed (ltrs)	Pearson Correlation	.762**	1	.925**
	Sig. (2-tailed)	.000		.000
	N	45	45	45
Tyre cost (Ugx)	Pearson Correlation	.884**	.925**	1
	Sig. (2-tailed)	.000	.000	
	N	45	45	45
**. Correlation is significant at the 0.01 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the Machine Hours worked and fuel consumption of 45 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a fairly strong positive linear relationship between the two variables ($r = 0.762$) that was significantly different from zero ($p < 0.01$).

When the linear relationship between the Machine Hours worked and Calculated Daily tyre cost of 45 data sets was assessed, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a fairly strong positive linear relationship between the two variables ($r = 0.884$) that was significantly different from zero ($p < 0.01$).

On investigating the linear relationship between the Machine Calculated Daily tyre cost and fuel consumed of 45 data sets, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.925$) that was significantly different from zero ($p < 0.01$).

Table 4. 28: Motor grader Regression analysis for Machine Hours worked, fuel consumed and Daily machine production cost

Coefficients[a]

Motor grader 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)	1023142.072	322.086		3176.614	.000	1022490.592	1023793.552		
	Hours worked	922.714	148.407	.015	6.217	.000	622.533	1222.895	.080	12.555
	Fuel consumed (ltrs)	4543.602	11.042	.986	411.465	.000	4521.267	4565.938	.080	12.555

a. Dependent Variable: Daily production cost (Ugx)

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
1	1.000[a]	1.000	1.000	356.10311	1.000	1093841.702	2	39	.000

a. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

b. Dependent Variable: Daily production cost (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	277418875007.392	2	138709437503.696	1093841.702	.000[b]
	Residual	4945567.584	39	126809.425		
	Total	277423820574.976	41			

a. Dependent Variable: Daily production cost (Ugx)

b. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

From the regression data in Table 4.28.

<u>The Problem:</u>

To investigate if Fuel consumed and machine hours worked have an impact on road maintenance daily production costs.

Hypothesis

H1: Fuel consumed, and machine hours worked have an impact on road maintenance costs.

The hypothesis tested if Fuel consumed, and machine hours worked carry a significant impact on daily production costs. The dependent variable Daily Production Cost (Ugx) was regressed on predicting variables Fuel consumed, and machine hours worked to test hypothesis H1. Fuel consumed significantly predicted Daily Production Cost (Ugx), $F(2,39) = 138709437503.696$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Daily production cost ($\beta = 0.986$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Moreover, the $R^2 = 1.000$ depicts that the model explains 100.0% of the variance in Daily Production Cost (Ugx), due to all the variables used being key predictors. The table shows the summary of the findings.

Daily Production Cost (Ugx) = 1,023,142.072 + 922.714 x (machine hours covered) + 4,543.602 x (fuel consumed). ………………………. **(Equation 4.7)**

Since $p < 0.05$, therefore, all β -coefficients in our table are highly statistically significant. The strongest predictors in our coefficients table are Fuel consumed ($\beta = 0.968$) and then followed by machine Hours worked ($\beta = 0.015$).

4.7.8 Earthmover machine data cost model

Table 4. 29: Earthmover correlation analysis for Machine Hours worked, daily Undercarriage cost and fuel consumed

Correlations				
		Hours worked	Fuel consumed (ltrs)	Undercarriage cost (Ugx)
Hours worked	Pearson Correlation	1	.922**	1.000**
	Sig. (2-tailed)		.000	.000
	N	26	26	26
Fuel consumed (ltrs)	Pearson Correlation	.922**	1	.922**
	Sig. (2-tailed)	.000		.000
	N	26	26	26
Undercarriage cost (Ugx)	Pearson Correlation	1.000**	.922**	1
	Sig. (2-tailed)	.000	.000	
	N	26	26	26
**. Correlation is significant at the 0.01 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the Machine Hours worked and fuel consumption of 26 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient shows a fairly strong positive linear relationship between the two variables ($r = 0.922$) that is significantly different from zero ($p < 0.01$).

On assessing the linear relationship between the Machine Hours worked and Calculated Daily Undercarriage cost of 26 data sets, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a fairly strong positive linear relationship between the two variables ($r = 1.000$) that was significantly different from zero ($p < 0.01$).

When the linear relationship between the Machine Calculated Daily Undercarriage cost and fuel consumed of 26 data sets was assessed, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables ($r = 0.922$) that was significantly different from zero ($p < 0.01$).

Table 4. 30: Earthmover regression analysis for Machine Hours worked, fuel consumed, and Daily machine production cost

Coefficients[a]

Earthmover Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	986204.343	.181		5449534.804	.000	986203.969	986204.717		
	Hours worked	24545.627	.050	.208	488124.255	.000	24545.523	24545.731	.149	6.694
	Fuel consumed (ltrs)	4500.010	.002	.805	1893256.053	.000	4500.006	4500.015	.149	6.694

a. Dependent Variable: Daily production cost (Ugx)

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	Change Statistics F Change	Change Statistics df1	Change Statistics df2	Change Statistics Sig. F Change
1	1.000[a]	1.000	1.000	.13173	1.000	18500230653591.180	2	23	.000

a. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

b. Dependent Variable: Daily production cost (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	642066721141.639	2	321033360570.820	18500643688143.960	.000[b]
	Residual	.399	23	.017		
	Total	642066721142.039	25			

a. Dependent Variable: Daily production cost (Ugx)

b. Predictors: (Constant), Fuel consumed (ltrs), Hours worked

From the regression data in Table 4.30.

The Problem:

To investigate if Fuel consumed and machine hours worked have an impact on road maintenance daily production costs.

Hypothesis

H1: Fuel consumed, and machine hours worked have an impact on road maintenance costs.

The hypothesis tested if Fuel consumed, and machine hours worked carry a significant impact on daily production costs. The dependent variable Daily Production Cost (Ugx) was regressed on predicting variables Fuel consumed, and machine hours worked to test hypothesis H1. Fuel consumed significantly predicted Daily Production Cost (Ugx), $F(2,23) = 18500643688143.960$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Daily production cost ($\beta = 0.805$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Moreover, the $R^2 = 1.000$ depicts that the model explains 100.0% of the variance in Daily Production Cost (Ugx), due to all the variables used being key predictors. The table shows the summary of the findings.

Daily Production Cost (Ugx) = 986,204.343 + 24,545.627 x (machine hours worked) + 4,500.010 x (fuel consumed). ……………………. **(Equation 4.8)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant.

The strongest predictors identified are Fuel consumed (β =0.805) and next in line is the machine hours worked (β =0.208).

4.7.9 Combined KSL data cost model

Table 4.31 shows sample unpaved roads at KSL Karongo satellite station and their calculated associated costs. The regression model in Table 4.32 was generated based on this data.

Table 4. 31: Sample KSL Karongo satellite station unpaved roads maintained and associated costs

Road location	km	fuel (ltrs)	fuel cost (Ugx)	labour (Ugx)	Repair costs (Ugx)	Maintenance cost (Ugx)	cost/km
AA10	0.1	693	3,118,500.00	1,368,000.00	318,043.60	4,804,543.60	48,045,436.00
L21	0.3	1397	6,286,500.00	3,192,000.00	742,101.73	10,220,601.73	34,068,672.44
BU57	0.3	2027	9,121,500.00	2,736,000.00	636,087.20	12,493,587.20	41,645,290.67
PP9	1.3	3003	13,513,500.00	3,192,000.00	742,101.73	17,447,601.73	13,421,232.10
H19	0.6	2252	10,134,000.00	2,736,000.00	636,087.20	13,506,087.20	22,510,145.33
L20	0.3	1020	4,590,000.00	1,368,000.00	318,043.60	6,276,043.60	20,920,145.33
DD13	0.2	639	2,875,500.00	912,000.00	212,029.07	3,999,529.07	19,997,645.33
BU31	0.3	1054	4,743,000.00	912,000.00	212,029.07	5,867,029.07	19,556,763.56
G9	0.6	2367	10,651,500.00	3,192,000.00	742,101.73	14,585,601.73	24,309,336.22
H19	0.7	2972	13,374,000.00	2,736,000.00	636,087.20	16,746,087.20	23,922,981.71
ZAZA2	0.3	1033	4,648,500.00	912,000.00	212,029.07	5,772,529.07	19,241,763.56
VV2	0.3	903	4,063,500.00	1,368,000.00	318,043.60	5,749,543.60	19,165,145.33
JJ14	0.3	1439	6,475,500.00	1,368,000.00	318,043.60	8,161,543.60	27,205,145.33
						AVERAGE	**25,693,054.07**

The key independent variables were km maintained; fuel consumed. Labour costs and machine repair costs. The labour costs were generated from the calculated daily rate obtained from the monthly staff salary rates indicated in Figure 4.14. A workday was considered to be 8hours and a typical work month was considered to have 25days. Machine repair costs were calculated from the costs provided by the KSL maintenance managers.

Table 4. 32: KSL combined cost model with km-maintained variable only

Coefficients[a]										
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	4209921.387	1351377.328		3.115	.010	1235559.942	7184282.832		
	Km	12660955.423	2575175.260	.829	4.917	<.001	6993032.891	18328877.955	1.000	1.000

a. Dependent Variable: Maintenance cost (Ugx)

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
1	.829[a]	.687	.659	2782729.55752	.687	24.172	1	11	<.001

a. Predictors: (Constant), km

b. Dependent Variable: Maintenance cost (Ugx)

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	187180834313164.300	1	187180834313164.300	24.172	<.001[b]
	Residual	85179421693261.110	11	7743583790296.465		
	Total	272360256006425.440	12			

a. Dependent Variable: Maintenance cost (Ugx)

b. Predictors: (Constant), km

From the regression data in Table 4.32.

The Problem:

To investigate if km maintained has an impact on road maintenance daily production costs.

Hypothesis

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

The hypothesis tested if km maintained has a significant impact on road maintenance production costs. The dependent variable road maintenance cost

(Ugx) was regressed on the predicting variable km maintained, to test hypothesis H1. km maintained significantly predicted maintenance production Cost (Ugx), $F (11, 12) = 24.172$, $p < 0.001$, which indicates that the km maintained plays a significant role in shaping maintenance production cost ($\beta = 0.829$, $p < 0.001$). These results clearly direct the positive effect of the km maintained. Moreover, the $R^2 = 0.687$ depicts that the model explains 68.7% of the variance in Daily Production Cost (Ugx). The table shows the summary of the findings.

Road maintenance production Cost (Ugx) = 4,209,921.387 + 12,660,955.423 x (km maintained) ……………………………………………………. **(Equation 4.9)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant.

The strongest predictors are Fuel consumed (β =0.815) and then next in line is the Calculated machine repair cost (β =0.213). The regression model automatically excluded the Machine hours due to multicollinearity.

4.8 Development of a cost model for parameters identified at Gulu DLG

4.8.1 Cost modelling parameters

The deterministic cost model predicting unpaved road maintenance road cost considered kilometres of unpaved road maintained, fuel consumed by equipment, labour used on site, tools and other warning equipment used, material/gravel ferried onsite as research parameters. The relationship between different factors/parameters and the daily machine production cost were developed as Linear Regression Cost models in the statistical package SPSS.

4.8.2 Development of the Gulu DLG cost model in Microsoft Excel and SPSS

The research parameters based on observational and archival data, included,

- Machine Fuel Consumption, Kilometres of unpaved road maintained, Fuel consumed by equipment, Labour used on site, tools and other warning tape used, and Material/gravel ferried onsite.

One linear regression model was developed for the different road maintenance projects. Model fit was tested through collinearity (using data correlations) and normality (using histograms of residual data sets).

4.8.3 Gulu DLG Unpaved Road maintenance linear regression data cost models

Table 4. 33: Gulu DLG Correlation analysis for unpaved road km maintained, machine fuel consumed and labour input

Correlations				
		Km	fuel	Labour
km	Pearson Correlation	1	.883**	.624*
	Sig. (2-tailed)		<.001	.013
	N	15	15	15
fuel	Pearson Correlation	.883**	1	.631*
	Sig. (2-tailed)	<.001		.012
	N	15	15	15
labour	Pearson Correlation	.624*	.631*	1
	Sig. (2-tailed)	.013	.012	
	N	15	15	15
**. Correlation is significant at the 0.01 level (2-tailed).				
*. Correlation is significant at the 0.05 level (2-tailed).				

A Pearson correlation coefficient was cyphered to assess the linear relationship between the km of unpaved roads maintained and fuel consumption of 15 data sets. The scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient shows a very strong positive linear relationship between the two variables (r = 0.883) that is significantly different from zero (p < 0.001).

When the linear relationship between the labour costs incurred and km of unpaved roads maintained for 15 data sets was investigated, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a strong positive linear relationship between the two variables (r = 0.624) that was significantly different from zero (p < 0.013).

Table 4. 34: Gulu DLG Correlation analysis for all variables considered

Correlations							
		production_cost	km	fuel	Labour	tools	Gravel
Pearson Correlation	production_cost	1.000	.824	.845	.739	.517	.968
	km	.824	1.000	.883	.624	.270	.711
	fuel	.845	.883	1.000	.631	.105	.690
	labour	.739	.624	.631	1.000	.440	.658
	tools	.517	.270	.105	.440	1.000	.626
	gravel	.968	.711	.690	.658	.626	1.000
Sig. (1-tailed)	production_cost	.	<.001	<.001	<.001	.024	<.001
	km	.000	.	.000	.007	.166	.001
	fuel	.000	.000	.	.006	.355	.002
	labour	.001	.007	.006	.	.051	.004
	tools	.024	.166	.355	.051	.	.006
	gravel	.000	.001	.002	.004	.006	.
N	production_cost	15	15	15	15	15	15
	km	15	15	15	15	15	15
	fuel	15	15	15	15	15	15
	labour	15	15	15	15	15	15
	tools	15	15	15	15	15	15
	gravel	15	15	15	15	15	15

When the linear relationship between the labour costs incurred and fuel consumed for 15 data sets was assessed, the scatter diagrams indicated a linear relationship between the two variables. Pearson's bivariate correlation coefficient showed a high positive linear relationship between the two variables (r = 0.631) that was significantly different from zero ($p < 0.012$).

Table 4. 35: Gulu DLG regression analysis for Machine fuel consumed, km maintained, and road maintenance cost

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	10007072.015	4838000.689		2.068	.061	-534025.955	20548169.985		
	Km	5371000.240	4761826.461	.353	1.128	.281	-5004128.346	15746128.827	.219	4.556
	Fuel	1.617	.951	.533	1.701	.115	-.454	3.688	.219	4.556

a. Dependent Variable: Maintenance _cost

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.861[a]	.742	.698	6651270.44073	.742	17.213	2	12	<.001

a. Predictors: (Constant), fuel, km

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1522972299724132.500	2	761486149862066.200	17.213	<.001[b]
	Residual	530872781709200.500	12	44239398475766.710		
	Total	2053845081433333.000	14			

a. Dependent Variable: production_cost

b. Predictors: (Constant), fuel, km

From the regression data Table 4.35.

<u>The Problem:</u>

To investigate if km maintained and fuel cost have an impact on road maintenance overall production costs.

<u>Hypothesis</u>

H1: km maintained, and fuel consumed costs have an impact on road maintenance overall production costs.

The hypothesis tested if km maintained, and fuel cost carry a significant impact on overall production costs. The dependent variable overall Production Cost

(Ugx) was regressed on predicting variables km maintained and fuel consumed, to test hypothesis H1. Fuel consumed significantly predicted Overall Production Cost (Ugx), $F(2,12) = 17.213$, $p < 0.001$, which indicates that the Fuel consumed can play a significant role in shaping Overall production cost ($\beta = 0.533$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed. Moreover, the $R^2 = 0.742$ depicts that the model explains 74.2% of the variance in overall Production Cost (Ugx). The table shows the summary of the findings.

Road maintenance Cost (Ugx) = 10,007,072.015 + 5,371,000. 240 x (km covered) + 1.6171 x (fuel consumed cost) ………………………. **(Equation 4.10)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant.

The strongest predictors are Fuel consumed (β =0.533) and then next in line is km maintained (β =0.353). All predictor variables had a VIF below 10 indicating no multicollinearity issues exist.

In another model that only considered km maintained, the following output model was produced.

Table 4. 36: Gulu DLG regression analysis for km maintained and road maintenance cost

Coefficients[a]										
DLG Road cost Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	13498419.867	4689230.405		2.879	.013	3367953.477	23628886.256		
	Km maintained	12527018.524	2387786.652	.824	5.246	<.001	7368519.082	17685517.966	1.000	1.000

a. Dependent Variable: production_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
1	.824[a]	.679	.655	7119182.33320	.679	27.524	1	13	<.001

a. Predictors: (Constant), km

b. Dependent Variable: production_cost

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1394969239219049.800	1	1394969239219049.800	27.524	<.001[b]
	Residual	658875842214283.200	13	50682757093406.410		
	Total	2053845081433333.000	14			

a. Dependent Variable: production_cost

b. Predictors: (Constant), km

From the regression data in Table 4.36.

The Problem:

To investigate if km maintained has an impact on road maintenance overall production costs.

Hypothesis

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

The hypothesis tested if km maintained can carry a significant impact on overall production costs. The dependent variable overall Production Cost (Ugx) was regressed on predicting variable km maintained to test hypothesis H1. Km maintained significantly predicted Overall Production Cost (Ugx), $F(1,13) = 27.524$, $p < 0.001$, which indicates that the km maintained can play a significant role in shaping Overall production cost ($\beta = 0.824$, $p < 0.001$). These results clearly direct the positive effect of the km maintained. Moreover, the $R^2 = 0.679$ depicts that the model explains 67.9% of the variance in overall Production Cost (Ugx). The table shows the summary of the findings.

The fitted regression model was:

Road maintenance Cost (Ugx) = 13,498,419.867 + 12,527,018. 524 x (km maintained) ……………….……………….…………………………. **(Equation 4.11)**

Since $p < 0.05$, therefore, all β -coefficients indicated are highly statistically significant. km maintained was a strong predictor with a beta coefficient of β =.824. the predictor variable had a variance inflation factor (VIF) below 10 indicating no multicollinearity issues.

4.9 Development of a cost model for UNRA cost data

4.9.1 Cost modelling parameters

The deterministic cost model predicting unpaved road maintenance costs considered kilometres of unpaved road maintained, and the provided contract sum as research parameters. The relationship between different factors/parameters and the unpaved road maintenance costs were developed as Linear Regression Cost models in the statistical package SPSS.

4.9.2 Development of the UNRA cost model in SPSS

The research parameters based on UNRA's annual performance report included kilometres of unpaved road maintained, and the contract sum for the works. One linear regression model was developed for the different road maintenance projects. Model fit was tested through collinearity (using data correlations) and normality (using histograms of residual data sets).

4.9.3 UNRA Unpaved Road maintenance linear regression data cost models

Table 4. 37: UNRA unpaved Road maintenance regression analysis for km maintained, and 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)	759433615.783	561133700.553		1.353	.193	-419464543.230	1938331774.797		
	km maintained	20530261.801	10200913.541	.429	2.013	.059	-901062.288	41961585.889	1.000	1.000

a. Dependent Variable: contract sum (Ugx)

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
1	.429[a]	.184	.138	1158115963.47857	.184	4.051	1	18	.059

a. Predictors: (Constant), km maintained

b. Dependent Variable: contract sum (Ugx)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5432690170010996700.000	1	5432690170010996700.000	4.051	.059[b]
	Residual	24142186527550013000.000	18	1341232584863889660.000		
	Total	29574876697561010000.000	19			

a. Dependent Variable: contract sum (Ugx)

b. Predictors: (Constant), km maintained

From the regression data Table 4.37.

The Problem:

To investigate if km maintained has an impact on road maintenance overall production costs.

<u>Hypothesis</u>

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

The hypothesis tested if km maintained, carries a significant impact on overall production costs. The dependent variable overall Production Cost (Ugx) was regressed on predicting variable km maintained, to test hypothesis H1. Km maintained significantly predicted Overall Production Cost (Ugx), $F (1,18) = 4.051$, $p < 0.001$, which indicates that the km maintained plays a moderate significant role in shaping Overall production cost ($\beta = 0.428$, $p < 0.001$). These results clearly direct the positive effect of the Fuel consumed.

Road maintenance Cost (Ugx) = 759,433,615.783 + 20,530,261.801 x (km covered) ……………………………………………………………………. **(Equation 4.12)**

Since $p < 0.05$, therefore, the β -coefficient indicated is moderately statistically significant. The predictor variable had a Variance Inflation Factor VIF below 10 indicating no multicollinearity issues exist. The UNRA model had a low R^2 value for the predictor variable (km maintained) of .184 accounting for only 18.4% of the observed result. This means that other factors account for 81.6% of the observed value. More in-depth data beyond mechanised road maintenance total project sums and km maintained will be required for future research models for UNRA data.

4.10 Cost model applicability

Regarding R^2 values in regression analysis, different scholars have different opinions on what constitutes as good R square (R^2) variance: Falk and Miller (1992) recommended that R^2 values should be equal to or greater than 0.10 for the variance explained of a particular endogenous construct to be deemed adequate. Cohen (1988) suggested R^2 values for endogenous latent variables are assessed as follows: 0.26 (substantial), 0.13 (moderate), 0.02 (weak).

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) & Hair et al. (2013) suggested in scholarly research that focuses on marketing issues, 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 1.0. since R^2 shows how well a regression model (independent variable) predicts the outcome of observed data (dependent variable), this shows that all cited factors (fuel, km, machine hours, tyre costs, undercarriage costs) were great predictors of the production cost (cost of unpaved road maintenance). Regression research is a great approach to measuring predictive analytics and forecasting to understand the impact that key unpaved road cost drivers/factors had on overall/daily production costs. Considering the earlier stated objective of predicting unpaved road maintenance costs, the developed models can be used by road maintenance planners and supervisors in preliminary cost prediction considering that they predict between 67.9-100% of the production outcomes researched.

This will further improve preliminary cost planning and general budget planning at the DLGs and in the private sector environment. Considering that two of the models had a low prediction percentage (Gulu DLG with 67.9% and UNRA with 18.4%), the researcher advocates for future research to accommodate more data sets, spread across multiple case study areas, to further refine the model accuracy.

4.11 Discussion and Comparison with previous findings 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 poor working conditions, uncertainties during equipment operation, and location of the site. This agrees with the findings from other countries by Arditi et al., (1997); Edwards et al., (1998). Also, site location was noted to affect the MTTR of the equipment at KSL in agreement with Day & Benjamin, (1991). But since all equipment used at Karongo satellite station, which was a central point from the areas under maintenance, similar MTTR data was noted for equipment under this area ranging from 1-2hours.

Equipment-related factors included age, type, quality, complexity of operation, and degree of usage. The company equipment at KSL was generically applied to all sites 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. In the case of KSL, age influenced the MTBF (Mean Time Before Failure). Considering Table 4.12, with Pearson's bivariate correlation coefficient ($r = -0.847$) showing a strong negative linear relationship between the

MTBF and Cumulative machine hours. This implies that an increase in machine cumulative hours (age) leads to a decrease in MTBF, thus frequent breakdowns and a higher operational cost. This agrees with the findings of Nwanya et al., (2017). This however disagrees with Marinelli et al., (2014), whose model found the impact of machine age on equipment condition levels to be negligible.

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 would include skill level of operators and mechanics, fatigue, 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 brings. This agrees with Cooper, (1994); Roberts and Alfred, (1974) and 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 road allowances.

All operators at KSL had minimum grade G and F for agricultural and engineering equipment operation. KSL also has 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 particular equipment availability, the researcher relied on the MoWT, (2020) annual sector performance report for financial year 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, lack of proper equipment operation, maintenance and management training as also cited in the URF (2022) annual report. This agrees 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 unanticipated events particularly those related to natural calamities and events. Examples included floods, 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 damaging of road networks by flooding and causing further loss of accessibility of road sections. Affected 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, and 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 put in an effort to rectify any bottlenecks in time. The low MTTRs (Mean Time To Repair) of 1-2 hours is evidence of this. Regarding Gulu DLG, MTTR data was not availed. However, long repair and maintenance durations was cited during the interviews with road maintenance staff. A case in point was the unpaved road maintenance works on Bunyoro road, Gulu were the grader used was borrowed from Moyo DLG. The URF 2022 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 & 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, resources, and rental facilities, substitute equipment on hand, the location and sophistication of a workshop, and other project-specific requirements were also found to be a useful factor in determining the cost of road maintenance operation. 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 the appendix. These repair stations were all well equipped with spare parts and trained workers. This is reflected in the low MTTRs seen during this research at KSL.

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 2022 report citing delayed maintenance affecting delivery of maintenance operations, this agrees with the findings of Day & Benjamin, 1991 who found that a company’s action plan and procedures, the local and national market conditions, requirements of the project owner and, to some extent, site-related factors do affect equipment production costs.

In Table 4.15, Pearson's bivariate correlation coefficient (r = 0.250) shows a low positive linear relationship between Machine Weight (kg) and Daily production cost (Ugx) of 6No. sampled machines. This implies that an increase/decrease in machine weight had a negligible effect of daily production costs. This disagrees with Edwards et al., (2002) whose regression model for tracked hydraulic excavators operating in the UK opencast mining industry found machine weight a key predictor of maintenance cost, which is a key component of daily production cost.

Table 4.11 indicated an average MTTR of 1.333 which corresponds to a downtime percentage of 16.7% out of the total machine operational time. Downtime data analysed by Nepal and Park (2004) were found to represent an average of 6% of planned working time for equipment. Dyson (2018) found a downtime of 36% for mining dump trucks. Edwards et al., (2000) found downtime to be 1.8% of total production time for equipment operating in the quarrying and mining industry. The downtime data observed is midway both observations and supports the findings of Nepal and Park (2004), and Edwards et al., (2000) who indicated that downtime data is usually “chaotic”.

In Table 4.14, Pearson's bivariate correlation coefficient shows a low positive linear relationship (r = 0.042) between MTTR and machine weight. This agrees with Edwards et al., (2000) who found that downtime does not increase with machine weight. In Tables 4.19, 4.21, 4.23, 4.25, 4.27, 4.29, 4.33 and 4.34; equipment operating hours was found to have a strong correlation with tyre costs, fuel costs, km of roads maintained, tool and material costs, and undercarriage costs, all elements of operating and owning costs. This agrees with CAT (2017) that indicated that the total number of actual operation hours on a machine is an important factor in the determination of operating and ownership cost. Based on Figure 4.3, average machine utilisation was 84.7%. This is fairly robust in agreement with (CAT, 2017) which specified that an 83% job efficiency is robust.

From literature review carried out using Muhwezi et al., (2021), Mbabazi et al, (2020), Byaruhanga et al., (2017), Booth et al., (2015), URF (2022), including onsite observations and interviews, low number of equipment, high machine failure and subsequent downtime, low staffing/labour alongside low staff capabilities, funding challenges, and poor records 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 38,897,076Ugx per km inclusive of depreciation and insurance costs.

The average km of road maintained at KSL's Karongo satellite station was approximately 2.33km of unpaved roads. Excluding the depreciation and insurance cots, the road maintenance rate was established as 26,442,032Ugx/km. This cost is lower than Gulu district's cost per km of 32,674,895Ugx/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 its own garages and thus does not need to outsource any repair/maintenance works. The district also incurs an extra cost of road maintenance labour cost allowances which KSL does not incur since its workers are only paid monthly salaries. The KSL (26,442,032Ugx/km) and Gulu DLG (32,674,895Ugx/km) mechanised unpaved road maintenance costs also compares well with the UNRA's costs of 34,987,122.9Ugx/km for all national mechanized unpaved road maintenance projects carried out in 2022. The sampled 16No. UNRA projects gave a calculated rate of 34,153,883Ugx/km.

The deterministic regression models developed for KSL factored each equipment's production cost differently. This was because there was more in-depth data on equipment costs and operations at KSL. The one developed at Gulu DLG factored in a single regression model that focussed on road maintenance cost (overall production cost) and km of road maintained.

The data collected and analysed focussed on maintenance operation, equipment operations 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 challenges faced, and how to address them. The cost model solution is an attempt at predicting overall road maintenance costs to ensure proper planning, while also leaving room for further refinement of road maintenance cost prediction models.

4.12 Chapter Summary

This chapter presented, analysed, and discussed results pertaining to control parameters for equipment maintenance and downtime; aspects of production during unpaved road maintenance; possible correlations between different equipment production factors; cost modelling of road maintenance cost factors considering identified road maintenance cost factors; cost model testing and validation; and providing a comparison of results obtained in this research with previously done research. Results were illustrated both in a tabular and graphical format for easy comprehension. The next chapter offers conclusions and recommendations to major research findings.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes, concludes, and offers recommendations on the study findings based on the research objectives.

5.2 Summary of results

The models for predicting daily/overall road maintenance production costs for induvial machines (private sector setting) and combined equipment (DLGs) were generated in tandem with the identified predictor variables. All models were tested for model fit and they all passed. All case study data was tested for construct validity, internal validity, external validity, and reliability.

The following sub-sections list the earlier planned research objectives and how/if they were achieved. They also indicate the target group to apply the findings and any limitations faced.

5.2.1 Research objective 1 (To establish the factors affecting the cost of mechanized unpaved road maintenance works)

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 and have been explained in-depth in chapter 2 and 4 of this thesis. 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. 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 DLGs since data was not readily available for this category of the case study.

5.2.2 Research objective 2 (To determine the costs of mechanized unpaved road maintenance operations)

The earlier identified cost driver factors affecting unpaved road maintenance were computed basing on data logs, company records and government agency annual report data 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 and 32,674,895Ugx/km respectively. The UNRA unpaved road maintenance costs were calculated as 34,987,122.9Ugx/km for all 2022 unpaved road maintenance projects. The sampled data (16 data sets gave a calculated rate of 34,153,883Ugx/km). Data logs have also been attached in the main text and appendix. This successfully achieved the second research objective and set a foundation for the cost model in the third research objective.

5.2.3 Research objective 3 (Develop a deterministic model to predict the costs of mechanized unpaved road maintenance operations)

Cost models for individual equipment based at KSL were generated due to the equipment specific data sets obtained. These had very significant R^2 values ranging from 0.69-1.0 thus improving the reliability of the research. A combined cost model for KSL was also generated with a 0.67 R^2 value.

The data sets obtained from Gulu DLG was 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 so as to create a unified basis for comparison with other cost models. Data logs in the main text and appendix indicate a breakdown of these costs. The main predictor variables at the DLG were fuel consumed, km maintained, labour costs, toll costs, gravel purchased. All linear regression models used had very significant R^2 values with the least being 0.67 and the highest being 1.

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. The KSL models for individual machines can also be used in cost prediction of daily production costs for works that involve similar equipment make/capacity/output and in situations where individual machines are used and not a fleet.

The UNRA model had a low R^2 value for the predictor variable (km maintained) of 0.184 accounting for only 18.4% of the observed result. This means that other factors account for 81.6% of the observed value. More in-depth data beyond mechanised road maintenance total project sums and km maintained will be required for future research models for UNRA data.

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 so as 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 production costs alongside individual factor costs for various equipment types used in unpaved road maintenance.

5.3 Conclusions

Overall, the following are the researcher's conclusions:

The research study established that the factors affecting the cost of mechanized unpaved road maintenance works are 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 and 32,674,895Ugx/km respectively. The UNRA unpaved road maintenance costs were calculated as 34,987,122.9Ugx/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 are generic and thus can be applied to all equipment in different work environments. The cost generated at KSL, however, are for individual machines with specific capabilities and outputs. Considering that different 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. The earlier generated individualistic models, only applicable to particular machines, were revised to a singular regression cost model factoring in km of road maintained, fuel costs and labour costs in order to harmonise it with the Gulu DLG cost model. 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. 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 and diverse make of equipment used.

The research focus and interest did not delve deep into equipment breakdown analysis, forecasts, and modelling. Also, the research did not delve into equipment 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.

5.4 Recommendations

The following are the researcher's recommendations:

Basing on the research findings and factors identified, KSL and Gulu DLG need to create a centralised electronic database where all unpaved road maintenance data is collected, analysed, and recorded, with more emphasis on equipment production analytics and management. Most data accessed was in hardcopy format and risked getting damaged/destroyed. The central digitised database would also act as a more reliable reference for more accurate 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 or equipment under downtime due to mechanical faults.

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.

Concerning the difficulty in obtaining raw data or systematic broken-down data on road maintenance costs at UNRA, the researcher recommends the creation of a public cost database where some publicly non-sensitive data can be shared by UNRA.

Considering that the research did not delve deep into equipment breakdown analysis, downtime forecasts, and downtime modelling alongside equipment 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 KSL and Gulu DLG research regression cost models accounting for approximately 67%-71% of the calculated road maintenance costs, and the UNRA model accounting for only 18.4%, more cost data from various road maintenance operations will have to be factored in in future cost models.

5.5 Chapter Summary

This chapter provided conclusions to the earlier observed and documented research findings obtained in chapter four, while also providing workable suggestions regarding aspects of equipment maintenance that need to be improved or modified.

REFERENCES

Al-Agele H. K., A. J. Al-Hassan (2016). *The reasons of costs deviation in the Iraqi construction projects.* Field Assessment Department of Civil Engineering, College of Engineering. University of Baghdad, Iraq.

Alinaitwe H., Apolot R., and Tindiwensi D. (2013). *Investigation into the causes of delays and cost overruns in Uganda's public sector construction projects*. Journal of Construction in Developing Countries. 18 (2), 33-47.

Alzubaidi, H. (1999). *Operation and maintenance of gravel roads - a literature study*. Swedish National Road and Transport Research Institute.

Ahmed, S., Dlask, P., and Hassan, B. (2014). *Construction Maeconomic Conference*. Faculty of Civil Engineering, Tishreen University, Lattakia, Syria.

Ahmed, H. M., & Yusuff, R. M. (2016). Factors Affecting Quality During the Construction Phase in Iraqi Government Companies. International Journal of Applied Engineering Research 11(13), 7974-7981. https://www.ripublication.com/ijaer16/ijaerv11n13_14.pdf.

Amin, M. E. (2005). *Social Science Research: Conception methodology and analysis*. Kampala: Makerere University Printery.

Anjaneyappa, V., Amarnath, M. and Srinivasamurthy B. (2014). *Compacting Characteristics of Light Compacting Equipment*. Journal of Construction Engineering and Management, 140(3), 1-8.

Arditi, D., Kale, S. & Tangkar, M. (1997). *Innovation in construction equipment and its flow into the construction industry*. Journal of Construction Engineering and Management, 123 (4), 371-378.

Bagaka, O., and Kobia, M. (2010). *Enhancing Trust and Accountability in Government.* CAPAM African Regional Conference, Abuja, 18th May 2010.

Bascetin, A., (2003). *A decision support system for optimal equipment selection in open pit mining: Analytical hierarchy process.* Istanbul Yerbilimleri Dergisi 16 (2), 1–11.

Benamghar, L., and Limi, A. (2011). *Efficiency in Public Procurement in Rural Road Projects in Nepal*. World Bank Policy Research Working Paper No. 5736. https://doi.org/10.1596/1813-9450-5736.

Berg, B. L. (2009). *Qualitative research methods for the social sciences (7th ed.)*. Boston, MA: Allyn & Bacon.

Blank Leland, Tarquin Anthony J. (2017). *Engineering economy*, Eighth edition, New York: McGraw-Hill Education.

BMAU Briefing paper 21/19 (2019). *"Maintenance of National Roads: What are the key challenges?"* (Briefing Paper). Kampala, Uganda. [Online]. Available at https://www.finance.go.ug/sites/default/files/Publications/BMAU%20Policy%20Brief%2021-19-Maintenance%20of%20National%20Roads-%20What%20are%20the%20key%20challenges.pdf Accessed 16th October 2023.

BMAU (May 2017). *"The Force Account Policy for Road Maintenance*

Works: Which areas need improvement?" (Briefing Paper). Kampala, Uganda. [Online]. Available at https://www.finance.go.ug/sites/default/files/9-17%20Force%20Account%20Policy.pdf. Accessed 16th October 2023.

BMAU (2015). *Briefing paper (17/15):Using Force Account for road maintenance: Were Local Governments ready?* Budget Monitoring and Accountability Unit. (BMAU), Kampala: Ministry of Finance Planning and Economic Development.

Booth, D., and Golooba-Mutebi, F. (2015). *Reforming the roads sector in Uganda: A six-year retrospective.* Working paper 424. Overseas Development Institute.

Burrow, M.P., Geddes, R.N., Pinard, M.I., Gongera, K., Bopoto. C., Ghataora, G.S., Gillett, S. and Petts, R., (2016). *Specification for Rural Road Asset Management Performance.* International Conference on Transport and Road Research. 16th – 18th March 2016, Whitesands Hotel, Mombasa, Kenya.

Byaruhanga, A., and Basheka, B.C. (2017). *Contractor Monitoring and Performance of Road Infrastructure Projects in Uganda: A Management Model*. Journal of Building Construction and Planning Research, [online] 05(01), 30–44. doi: https://doi.org/10.4236/jbcpr.2017.51003.

Caterpillar (2015). *Caterpillar Performance Handbook*, 45th edition. Caterpillar, Peoria, Illinois, U.S.A.

Caterpillar (2017). *Internal publication SEBD0351-47: Caterpillar Performance Handbook*. 47th edition. Caterpillar, Peoria, Illinois, U.S.A.

CAT, (2020). '*The cost of idle time*.' Available at: https://catsimulators.com/the-cost-of-idle-time/ (Accessed: 16th July 2022).

Camp, W. G. (2001). *Formulating and Evaluating Theoretical Frameworks for Career and Technical Education Research*. Journal of Vocational Educational Research, 26(1), 4–25. doi: https://doi.org/10.5328/jver26.1.4.

Chamzini, A.Y., Yakhchali, S.H., (2012). *Tunnel Boring Machine (TBM) selection using fuzzy multicriteria decision making methods.* Tunnelling and Underground Space Technology, 30, 194–204. doi: *https://doi.org/10.1016/j.tust.2012.02.021*

Chan, C.M.R., Harris, F.C., (1989). *A database/spreadsheet application for equipment selection*. Construction Management and Economics, 7(3), 235–247. doi: https://doi.org/10.1080/01446198900000025

Chan, F.T.S., Ip, R.W.L. and Lau, H. (2001). *Integration of expert system with analytic hierarchy process for the design of material handling equipment selection system.* Journal of Materials Processing Technology, [online] 116(2), 137–145. doi: https://doi.org/10.1016/S0924-0136(01)01038-X.

Chin, W.W. (1998). *The Partial Least Squares Approach to Structural Equation Modeling.* Modern Methods for Business Research, 295, 295-336.

Clark, V. L., & Creswell, J. W. (2010). *Understanding research: A consumer's guide*. Upper Saddle River, NJ: Merrill/Pearson Educational.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences (2nd ed.)*. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Cooper, K.G. (1994). *The $2,000 hour: How managers influence project performance through the rework cycle*. IEEE Engineering Management Review, 22(4), 12-23.

Cundill, M.A., and Withnall, S.J. (1995). *Road transport investment model RTIM3. TRB.* Sixth International Conference on Low-Volume Roads, Conference Proceedings 6, Volume 1. Washington DC: National Academy Press, 187-192. IKRAM's.

David. G. Carmichael, Xuesong Shen, Vachara Peansupap (2019). *The relationship between heavy equipment cost efficiency and cleaner production in construction.* Journal of Cleaner Production, 211, 521–529. *doi: https://doi.org/10.1016/j.jclepro.2018.11.167*

Day, D.A. & Benjamin, N.B.H. (1991) *Construction Equipment Guide*, 2nd edn, John Wiley & Sons, Inc., NY.

De Vos, A., Strydom, H., Fouché, C., & Delport, C. (2005). *Research at grass roots: For the social sciences and human service professions (3rd ed.)*. Pretoria, South Africa: Van Schaik.

Dixon, J., Gulliver, A., Gibbon, D. & Hall, M. (2001). *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*. Washington, DC: World Bank.

Dhillon, Balbir. (2008). *Mining Equipment Reliability, Maintainability, and Safety*. *Mining Equipment Reliability, Maintainability, and Safety*. Springer, Berlin. ISBN: 978-1-84800-287-6. 10.1007/978-1-84800-288-3.

Dyson, G. (2018). *Exploring Factors that Affect Reliability of Open Pit Heavy Mining Dump Trucks: A Case of Bisha Mining Share Company, Eritrea*.

International Journal of Science and Research (IJSR) ISSN: 2319-7064, SJIF (2019): 7.583, DOI: 10.21275/SR20528131656.

Eden, C, Williams, T. & Howick S. (2000). *The role of feedback dynamics in disruption and delay on the nature of disruption and delay (D&D) in major projects.* Journal of the Operational Research Society, 51(3), 291–300. *doi: https://doi.org/10.1057/palgrave.jors.2600919*

Edwards, D.J., Holt, G.D. & Harris, F.C. (1998). *Financial management of construction plant: conceptualizing cost prediction.* Journal of Financial Management of Property and Construction, 3(2), 59-73.

Edwards, D.J., Holt, G.D. & Harris, F.C. (2000). *A model for predicting plant maintenance costs.* Construction Management and Economics, 18(1), 65–75. *doi: https://doi.org/10.1080/014461900370960*

Edwards, D.J., Holt, G.D. & Harris, F.C. (2002). *Predicting downtime costs of tracked hydraulic excavators operating in the UK opencast mining industry*. Construction Management and Economics, 20(7), 581–591. *doi: https://doi.org/10.1080/01446190210163552*

Eisenhardt, K. M. (1989). *Building Theories from Case Study Research.* The Academy of Management Review, [online] 14(4), 532–550. *doi: https://doi.org/10.2307/258557*

Eisenhardt, K. M., & Graebner, M. E. (2007). *Theory building from cases: Opportunities and challenges*. Academy of Management Journal, 50(1), 25–32. https://doi.org/10.5465/AMJ.2007.24160888.

Elo, S., & Kyngas, H. (2008). *The qualitative content analysis process*. Journal of advanced nursing, 62(1), 107–115. doi: https://doi.org/10.1111/j.1365-2648.2007.04569.x.

Enshassi, A., Mohamed, S. and Abushaban, S. (2009). *Factors Affecting the Performance of Construction Projects in the Gaza Strip*. Journal of Civil Engineering and Management, [online] 15(3), 269–280. doi: https://doi.org/10.3846/1392-3730.2009.15.269-280

Edwards, D.J., Holt, G.D. & Harris, F.C. (2002). *Predicting downtime costs of tracked hydraulic excavators operating in the UK opencast mining industry*. Construction Management and Economics, 20(7), 581–591. doi: 10.1080/01446190210163552.

Edwards, D. J., Holt, G. D. and Harris, F. C. (2000). *A model for predicting plant maintenance costs*. Construction Management and Economics, 18(1), 65–75. doi: 10.1080/014461900370960.

ElMisalami, T., (2010). *Construction Equipment Management using Capital Budgeting under A Multi-Period Uncertainty Model.* Eighth Alexandria international conference on Structural and Geotechnical Engineering, "AICSGE7", Faculty of Engineering, Alexandria University, Alexandria, EGYPT. Pro. 8, No. MG, 17-26.

Elazouni, A.M. & Basha, I.M. (1996). *Evaluating the performance of construction equipment operations in Egypt*. Journal of Construction Engineering and Management, 122 (2), 109-114.

Ethiopian Roads Authority, ERA (2002). *Pavement Design Manual, Flexible Pavements and Gravel Roads*. ERA. Ethiopia.

Ethiopian Roads Authority, ERA (2002). *Gravel and Low volume road design manual*. ERA. Ethiopia.

Ethiopian Roads Authority, ERA (2011). *Design Manual for Low Volume Roads: Road Maintenance Booklet Part A*: ERA. Ethiopia.

Esmaeili, M., Braazazi, A. A., and Borna, S. (2011). *Reliability of a Fleet of Loaders in Sangan Iron Mine*. Journal of Arch. Min. Sci., 56(4), 629 – 640.

Farquhar, J. D. (2012). *Case study research for business*. Thousand Oaks, CA: Sage.

Feifei, C., Yaowu, W. and Xianzhang L. (2010). *Multi-Objective Dynamic Simulation-Optimization for Equipment Allocation of Earthmoving Operations.* Construction Research Congress, 328-338. doi: https://doi.org/10.1061/41109(373)33

Fellows, R., and Liu, A. (2015). *Research Methods for construction.* John Wiley & Sons, Ltd.

Frank. R. Falk and Miller. B. Nancy (1992). *A primer for soft modeling*. The University of Akron Press. Ohio. USA.

Frein J.P. (1980). *Handbook of Construction Management and Organization*. 2nd ed. New York: Van Nostrand Reinhold, 137–298.

Gates, M., Scarpa, A., 1980. *Criteria for the selection of construction equipment.* J. Constr. Div. 106 (2), 207–219.

Giancristofaro, R. and Salmaso, L. (2003). *Model performance analysis and model validation in logistic regression.* Statistica, LXIII (2), 10.6092/issn.1973-2201/358.

Gransberg, D.D., Popescu, C.M., Ryan, R.C., (2006). *Construction Equipment Management for Engineers, Estimators and Owners*. Taylor & Francis, London.

Grant, C. & Osanloo, A. (2014). *Understanding, Selecting, and Integrating a Theoretical Framework in Dissertation Research: Creating the Blueprint for 'House'. Administrative Issues.* Journal: Connecting Education, Practice and Research, 4(2), 12–26. DOI: 10.5929/2014.4.2.9

Gongera, K., & Petts, R. C. (2003). *"A Tractor and Labour Based Routine Maintenance System for Rural Roads."* (LCS Working Paper No. 5). Institution of Agricultural Engineers. Zambia. [Online]. Available at https://www.research4cap.org/ral/Pettsetal-2017-IntroductionTractorBasedRuralRoadMaintenanceZambia-T22017-170501-1.pdf. Accessed 16th October 2023.

Gustafsson, J. (2017). *Single case studies vs. multiple case studies: A comparative study (Dissertation).* Academy of Business, Engineering and Science, Halmstad University, Halmstad, Sweden. Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:hh:diva-33017.

Hair, J., Ringle, C. and Sarstedt, M. (2011). *PLS-SEM: Indeed, a Silver Bullet*. Journal of Marketing Theory and Practice, 19, 139-151. https://doi.org/10.2753/MTP1069-6679190202.

Hair, J.F., Ringle, C.M. and Sarstedt, M. (2013). *Partial Least Squares Structural Equation Modeling: Rigorous Applications, Better Results and Higher Acceptance*. Long Range Planning, 46(1-2), 1–12. doi: https://doi.org/10.1016/j.lrp.2013.01.001

Haidar, A., Naoum, S., Howes, R., Tah, J., (1999). *Genetic algorithms application and testing for equipment selection*. J. Constr. Eng. Manage. 125 (1), 32–38.

Hammad, A., Zhang, C., Hussein, M., and Cardinal, G. (2007). *Equipment Workspace Analysis in Infrastructure Projects.* Canadian Journal of Civil Engineering, 34(10), 1247–1256. doi: https://doi.org/10.1139/l07-048

Hilangwa Maimbo and Graham Pervan. (2005). *Designing a Case Study Protocol for Application in IS research*. School of Information Systems, Curtin University.

Hesse-Biber, S., & Nagy Leavy, P. (2011). *The Practice of Qualitative Research (2nd ed.)*. New York: Sage.

Henning, E., Van Rensburg, W., & Smit, B. (2004). *Finding your way in qualitative research*. Pretoria, South Africa: Van Schaik.

Henning, T. F. P., Bennett, C. R., & Kadar, P. (2007). *Guidelines for Selecting Surfacing Alternatives for Unsealed Roads*. Transportation Research Record, 1989-2(1), 237–246. doi: https://doi.org/10.3141/1989-69

Https://www.aje.com/arc/How-To-Write-Limitations-Of-The-Study/. Retrieved November 18, 2023, from https://www.aje.com/arc/how-to-write-limitations-of-the-study/.

Iyer, K., & Jha, K. (2006). *Critical factors affecting schedule performance: Evidence from Indian construction projects*. Journal of construction engineering and management, 132(8), 871-881.

Lazar. J, Feng. J.H, and Hochheiser. H. (2010) *Research Methods in Human-Computer Interaction*. Wiley Publishing.

Kannan, G., (2011). *Field Studies in Construction Equipment Economics and Productivity*. Journal of Construction Engineering and Management, 137 (10), 823-828.

Kim, B., Lee H., Park, H., and Hyoungkwan K. (2012). *Greenhouse Gas Emissions from Onsite Equipment Usage in Road Construction*. Journal of Construction Engineering and Management, 138(8), 982-990.

Liehr P. & Smith M. J. (1999). *Middle Range Theory: Spinning Research and Practice to Create Knowledge for the New Millennium*. Advances in Nursing Science, 21(4), 81-91.

Lucko, G. (2011). *Modeling the Residual Market Value of Construction Equipment under Changed Economic Conditions.* Journal of Construction Engineering and Management, 137(10), 806-816.

Luse, A., Mennecke, B., & Townsend, A. (2012). *Selecting a Research Topic: A Framework for Doctoral Students*. International Journal of Doctoral Studies, 7, 143–152. doi: https://doi.org/10.28945/1572

Maloney, W.F. & McFillen, J.M. (1986) *Motivational implications of construction work*. Journal of Construction Engineering and Management, 112(1), 137-151.

Marinelli, M., Petroutsatou, K. (2014) *Earthmoving trucks condition level prediction using neural networks. Journal of Quality in Maintenance Engineering.* 20(2) 182-192. DOI 10.1108/JQME-09-2012-0031.

Marshall, C., & Rossman, G. B. (2011). *Designing qualitative research (5th ed.)*. London, UK: Sage.

Marks, E., Cheng, T., and Teizer, j. (2013). *Laser Scanning for Safe Equipment Design That Increases Operator Visibility by Measuring Blind Spots*. Journal of Construction Engineering and Management, 139(8), 1006-1014.

Marzouk, M. and Moselhi, O. (2004). *Multi-objective optimization of earthmoving operations.* Journal of Construction Engineering and Management, 130(1), 105-113.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation (2nd ed.)*. San Francisco, CA: Jossey-Bass.

Mbabazi, E. (2019). *Impact of unpaved road condition on rural transport services*.

Proceedings of the Institution of Civil Engineers – Municipal Engineer 172(4): 239–245, https://doi.org/10.1680/jmuen.18.00048.

Mbabazi, E., Bopoto, C., and Pinard, M. (2020). *Economic growth through effective rural road asset management*. 26th World Road Congress.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Source Book (2nd ed.)*. Newbury Park, CA: Sage.

Mingers, J. (2001). *Combining IS Research Methods: Towards Pluralist Methodology*. Information Systems Research 12(3), 240–259. doi: https://doi.org/10.1287/isre.12.3.240.9709

Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). (2015). *Agriculture Sector Strategic Plan: 2015/16-2019/20*. Kampala.

Ministry of Public service (MoPS). (2022). *Circular standing instruction (CSI) No. 1 of 2022, salary structure for financial year 2022/2023*. Kampala, Uganda.

Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). (2018) *Annual sector performance report FY2017/18*. Kampala.

Ministry of Works and Transport (MoWT). (2020). *Annual sector performance report FY2019/20*. Kampala.

Ministry of Works and Transport (MoWT). (2003). *District Road manuals. Volume 5: Administrative & Operational Guidelines for District Road Works. Policy Document for Road Maintenance.* Kampala.

Ministry of Works and Transport (MoWT). (2013). *Revised guidelines for labour based routine maintenance, mechanized routine maintenance and rehabilitation of district and community access roads (CAR)*. Kampala.

Ministry of Works and Transport (MoWT). (2010). *Road maintenance management manual*. Kampala.

Ministry of Works and Transport (MoWT). (2010). *Uganda Road Design Manual Volume I: Geometric Design*. Entebbe.

Mitchell, Z., Hildreth, J., and Vorster, M. (2011). *Using the Cumulative Cost Model to Forecast Equipment Repair Costs: Two Different Methodologies.* Journal of Construction Engineering and Management, 137 (10), 817-822.

Mitropoulos, P. & Tatum, C.B. (1999). *Technology adoption decisions in construction organizations.* Journal of Construction Engineering and Management, 125(5), 330-338.

Muhwezi, L., Abonga, A.A., and Sengonzi. R., (2020). *Factors Influencing Cost Performance of Unpaved Road Maintenance Projects in Uganda*. International Journal of Construction Engineering and Management, 9(1), 1-10 DOI: 10.5923/j.ijcem.20200901.01.

Muhwezi, L., Basoona, N. K., and Acai, J. (2021). *An Assessment of Rural Road Networks Management in Uganda as a Driver of Economic Development: A Case Study of Kabarole District.* International Journal of Construction Engineering and Management, 10(1), 8-16.

Mukiibi, P., (2011). *Road Infrastructure and Economic growth in Uganda 1980-2010.* A thesis submitted to the Directorate of Research and Graduate training in partial fulfillment of the requirements for the award of Master of Arts degree in Economics of Makerere University.

NEMA (2009). *Uganda: Atlas of Our Changing Environment*. National Environment Management Authority (NEMA). Kampala Uganda.

Neil, J. M. (1989). *Concepts and methods of schedule compression*. Transactions of the American Association of Cost Engineers, S9 71-77.

Nepal, M.P. (2001). *Impact of Construction Equipment Downtime on Road Projects in Nepal.* Thesis no. ST-01-38, Asian Institute of Technology, Bangkok, Thailand.

Nepal, M.P., and Park, M. (2004). *Downtime model development for construction equipment management.* Engineering, Construction and Architectural Management, 11(3), 199-210.

Ng, S., Tang, Z., and Ekambaram, P. (2009). *Factors contributing to the success of equipment-intensive subcontractors in construction.* International Journal of Project Management, 27(7), 736–744. doi: https://doi.org/10.1016/j.ijproman.2008.09.006

Ngezahayo, E., Burrow, M.P.N., and Ghataora, G.S. (2019). *Factors Affecting Erosion in Unpaved Roads*. Proc. of the 4th Intern. Conf. on Geotechnical

Research and Eng., Rome, April 7 - 9, 2019, Accessible at http://avestia.com/CSEE2019_Proceedings/files/paper/ICGRE/ICGRE_108.pdf.

Nwanya, S.C., Udofia, J.I., and Ajayi, O.O. (2017). *Optimization of machine downtime in the plastic manufacturing*. Cogent Engineering, [online] 4(1). doi: https://doi.org/10.1080/23311916.2017.1335444

Oke, A., Aigbavboa, C., & Dlamini, E. (2017). *Factors Affecting Quality of Construction Projects in Swaziland.* Paper presented at the 9th International Conference on Construction in the 21st Century: Revolutionizing the Architecture, Engineering and Construction Industry through Leadership, Collaboration, and Technology, Dubai, United Arab Emirates.

Oguya S.A., and Muturi, W, (2016). *Factors affecting performance of road construction projects in arid and semi-arid areas in Kenya*. International Journal of Social Sciences and Information Technology, 2(8).

Otim, G., and Alinaitwe H., M. (2013). *Factors affecting the performance of pavement road construction projects in Uganda*. School of Built Environment / College of Engineering, Design, Art and Technology, Makerere University. Uganda. https://www.irbnet.de/daten/iconda/CIB_DC26254.pdf.

Oxford Economics. (2017). *Global infrastructure outlook: Infrastructure investment needs, 50 countries, 7sectors to 2040*. Global infrastructure hub.

Oyedele, O. A. (2015). *Evaluation of construction cost estimation methods in Nigeria*. Being Paper Delivered at the FIG Working Week, Sofia, Bulgaria, 17 -21, May 2015.

Pathmanathan, V. (1980). *Construction equipment downtime costs*. Journal of Construction Division, 106(4), 604-607.

Parliament of the republic of Uganda. (2008). *Uganda Road Fund (URF) Act 2008*. Kampala, Uganda.

Petts, R. (2013). *How much should developing countries spend on road maintenance?* Briefing Note, Intech Asset Management, UK&AFCAP Steering Group.

Perri, 6., & Bellamy, C. (2012). *Principles of methodology research design in social science*. London, UK: Sage.

Peurifoy, R.L., Clifford, J., Schexnayder., Robert, L., Schmitt., Aviad, S. (2018) *Construction Planning, Equipment and Method*. 9th edn, McGraw-Hill Book Company, NY.

Peshkin, A. (1993). *The Goodness of Qualitative Research*. Educational Researcher, 22(2), 23-29.

PIARC (World Road Association). (1994). *International Road Maintenance Handbook: Practical Guidelines for Rural Road Maintenance*. Vols. 1-4. Wokingham, U.K.: Transport Research Laboratory.

Pinto, I., H. Pereira, and A. Usenius. (2002). *Sawing Simulation of Pinus pinaster Alt*. In: Proc. Fourth Workshop of IUFRO Connection between forest resources

and wood quality: modelling approaches and simulation software. WP S5.01.04 British Columbia, Canada, 8–15 September 2002 429–348.

Piper C.J., & Vachon, S. (2001). *Accounting for productivity losses in aggregate planning*. International Journal of Production Research, 39(17), 4001-4012.

PPDA Act (2014). *Statutory instruments supplement to The Uganda Gazette No. 9 Volume CVII*. Dated 14th February 2014. Printed by UPPC, Entebbe, by Order of the Government.

Rabinovich, M., & Kacen, L. (2010). *Advanced relationships between categories analysis as a qualitative research tool*. Journal of Clinical Psychology, 66(7), 698–708.

Richards, L. and Morse, J.M. (2007). *Readme First for a User's Guide to Qualitative Methods*. Sage Publications, Thousand Oaks.

Roberts, E.B. & Alfred, P. (1974). *A simple model of R & D project dynamics*. R & D Management, 5(1), 1–15. doi: https://doi.org/10.1111/j.1467-9310.1974.tb01217.x

Saldana, J. (2013). *The Coding Manual for Qualitative Researchers (2nd ed.)*. London: Sage.

Santo, O., Lating, P., and Kirabira, J.B. (2019). *Premature failure of district road construction equipment: case of northern Uganda*. International Journal of Research and Review. 6(9), 75-79.

Satyanarayana, J. (2012). *Managing Transformation: Objectives to Outcomes.* New Delhi, India: PHI Learning Pvt. Ltd.

Siedlecki, Sandra. (2020). *Understanding Descriptive Research Designs and Methods*. Clinical nurse specialist [online] 34(1), 8–12. doi: https://doi.org/10.1097/NUR.0000000000000493

Schaufelberger, J.E., and Migliaccio, G.C. (2019). *Construction Equipment Management*. 2nd edition. New York: Routledge.

Schaufelberger, J.E., (1999). *Construction Equipment Management.* Prentice-Hall, N.J.

Sekaran, U. and Bougie, R. (2016). *Research Methods for Business: A Skill-Building Approach*. 6th Edition, Wiley, New York.

Sessions, J., Berry, M., and Sup-Han, H. (2021). *Machine Rate Estimates and Equipment Utilisation – A Modified Approach*. Croatian Journal of forest engineering 42(3). https://doi.org/10.5552/crojfe.2021.1026.

Seung, C.O., and Sinha, S.K. (2006). *Construction equipment productivity estimation using artificial neural network model.* Construction Management and Economics, 24(10), 1029-44.

Shapira, A., Goldenberg, M., (2005). *AHP-based equipment selection model for construction projects*. J. Constr. Eng. Manage., 1263–1273.

Shobana, K.S., & Ambika, D.R. (2016). *Evaluation of Factors Affecting Quality in Construction Projects*. International Journal of Innovative Research in Science, Engineering and Technology, IJIRSET, 5(3), 3526-3529.

Sohu, Samiullah & Abdullah, Abd Halid & Nagapan, Sasitharan & Jhatial, Ashfaque & Ullah, Kaleem & Ali, Imtiaz. (2018). *Significant Mitigation Measures for Critical Factors of Cost Overrun in Highway Projects* Journal of Engineering, Technology and Applied Science Research. 8. 10.48084/etasr.1916.

Sözen, Z. & Giritli H. (1987). *Equipment policy as one of the factors affecting construction productivity: a comparative study. In: Managing Construction Worldwide: Productivity and Human Factors in Construction*, (eds P.R.

Lansley, & P.A. Harlow), 691-696. 5th International Symposium, CIOB, CIB, London.

Stewart Robinson (2004). *Simulation: the practice of model development and use*. John Wiley & Sons Ltd, England.

Stock, E. A., & de Veen, J. (1996). *Expanding Labour-Based Methods for Road Works in Africa.* (Sub-Saharan Africa Transport Program (SSATP) Working Paper Series No.22). Washington, DC: World Bank.

Tatari, O., Skibniewski, M., (2006). *Integrated agent-based construction equipment management: Conceptual design*. J. Civil Eng. Manage. 12(3), 231–236. doi: https://doi.org/10.3846/13923730.2006.9636397

Tatum, C., Vorster, M., Klingler, M., and Paulson, B., (2006). *Systems Analysis of Technical Advancement in Earthmoving Equipment.* Journal of Construction Engineering and Management, 137(10), 976-986.

Taylor, B. C., & Lindlof, T. R. (2010). *Qualitative communication research methods*. Thousand Oaks, CA: Sage.

Thomas, D. R. (2006). *A general inductive approach for analyzing qualitative evaluation data*. American Journal of Evaluation, 27(2), 237-246.

Thomas, H.R. & Raynar, K.A. (1997). *Scheduled overtime and labour productivity: quantitative analysis*. Journal of Construction Engineering and Management, 123(2), 181-188.

Tripathy, D.P. (2013). *Effective Maintenance Practices for Mining Equipment*. NIT: Department of Mining Engineering, NIT, Rourkela.

Uganda Bureau of Statistics (UBOS). (2018). *Uganda National Household Survey 2016/2017*. Kampala, Uganda; UBOS.

Uganda Road Fund (URF). (2021). *Annual Report- Financing Road Maintenance 2020/2021*. Kampala, Uganda; URF.

Uganda National Roads Authority (2022). *Project status report June 2022*. Kampala. Uganda.

Uganda National Roads Authority (2023). *Annual performance report FY 2022/23*. Kampala. Uganda.

Uganda Road Fund (URF). (2015). *Monitoring and Evaluation of Road Maintenance Programmes for DAs in the Northern / Northwestern Region. Q1-4 FY 2014/15 (July 2014 – June 2015)*. Kampala, Uganda; URF.

Valdovinos, V.P.E. & Lorick, H. C. (2013). *"Getting Maintenance Work Done: In-House or by Others."* (Water Online). [Online]. Available at https://www.wateronline.com/doc/getting-maintenance-work-done-in-house-or-by-others-0001. Accessed 16th October 2023.

Wasike, W.S. (2001). *Road Infrastructure Policies in Kenya: Historical Trends and Current Challenges*. Kenya Institute for Public Policy Analysis Working Paper No. 1, Nairobi.

World Bank. (2010). *Africa Infrastructure: A Time for Transformation.* Chapter 10: Roads: Beyond the Interurban Network.

World Bank (2017). *The World Bank Annual Report 2017*. Technical report, The World Bank, Washington DC.

World Bank (2022). *Rural Access Index (RAI) 2022*. Available at: https://datacatalogfiles.worldbank.org/ddh-published/0038250/DR0085889/rural-access-index-data.xls?versionId=2023-05-01T13:57:47.9379613Z/ (Accessed 10 November 2022).

World Highways. (2015). *Sustainable Road construction: current practices and future.* Route One Publishing Ltd Waterbridge Court, 50 Spital Street, Dartford, Kent, DA1 2DT UK.

Xu, J., Meng, J., Zeng, Z., Wu, S., and Shen, M. (2013). *Resource Sharing-Based Multi-objective Multistage Construction Equipment Allocation under Fuzzy Environment*. Journal of Construction Engineering and Management, 139(2), 161-173.

Yang, J., Edwards, D.J., and Love, P.E.D. (2003). *A computational intelligent fuzzy model approach for excavator cycle time simulation*. Automation in Construction, 12(6), 725-35.

Yin, R. K (2018). *Case Study Research: Design and Methods, 8th edn*. Sage Publications Inc, Thousand Oaks, California.

Zainal, Z. (2007). *Case Study as a Research Method*. Jurnal Kemanusiaan, 9, 1-6.

APPENDICES

SITE PHOTOGRAPHS FROM KSL CASE STUDY SITE

Figure A. 1: CAT D6 earthmover in action at the quarry site.

Figure A. 2: CAT 950H Front End Loader.

Figure A. 3: TATA 2516C at the quarry site.

Figure A. 4: Quarry site operations.

Figure A. 5: The field researcher at the site.

Figure A. 6: The CAT 950H undergoing onsite repairs.

Figure A. 7: Onsite maintenance truck.

Figure A. 8: The JCB 3CX heading out to site.

Figure A. 9: The satellite station at Karongo.

Figure A. 10: TATA 2516C refueling.

Figure A. 11: The repair workshop at the satellite station.

Figure A. 12: Repair of the Ingersoll rand vibrator drum.

Figure A. 13: A CAT D6 earthmover under repair.

Figure A. 14: The main heavy plant repair workshop.

Figure A. 15: The TATA 2516C lorry maintenance section.

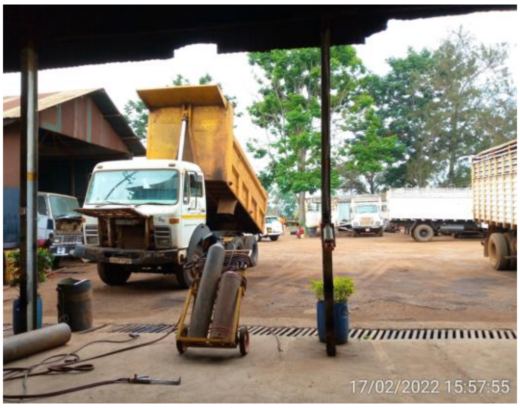


Figure A. 16: A TATA 2516C undergoing maintenance.

Figure A. 17: Pickup truck at the satellite station for rapid field response.

Figure A. 18: Entrance to the satellite workshop.

ROAD MAINTENANCE EQUIPMENT USED IN KSL

Industry name	Equipment Model
Earthmover/Bulldozer	CAT D6
Roller compactor	IR COMP ROLLER
Wheel loader	CAT 950H FEL
Motor grader	MGRADER CAT 120H
Dumper truck	TATA 2516C
Backhoe excavator	JCB 3CX

KSL DATA COLLECTION AUTHORISATION LETTER

Patrick Mbabazi, please assist with this request as best as you can.
14/2/22

Samuel, Please advise (no cost for KSL four days research)
14/2/22

KYAMBOGO UNIVERSITY

Department of Civil and Environmental Engineering
P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

11th February, 2022

The General Manager
Kakira Sugar Ltd

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MR. OBETI MOSES ANDREW REG: 19/U/GMET/20960/WKD

This is to introduce the above-named final year student who is undertaking a Master of Science in Construction Technology and Management at the Faculty of Engineering, Department of Civil and Environmental Engineering, Kyambogo University. Moses is undertaking a research study titled: **"INVESTIGATING EQUIPMENT PRODUCTIVITY IN FEEDER ROAD MAINTENANCE IN UGANDA".** This is one of the requirements for graduation at Kyambogo University to conduct research and submit a dissertation/thesis by graduate students before awarding them a degree.

The purpose of this communication, therefore, is to humbly request your office and the relevant staff to assist him access the necessary information and guidance to help him successfully conduct his research at your organisation. The information will only be used for academic purposes and shall be kept confidential.

We thank you in advance for your cooperation and we hope the findings of this research will also benefit the organisation.

Yours faithfully,

KYAMBOGO UNIVERSITY HEAD OF DEPARTMENT 14 FEB 2022

Dr. Muhwezi Lawrence
Senior Lecturer and Head of Department,
Civil and Environmental Engineering
Faculty of Engineering, Kyambogo University
Tel. +256772402883/702 402883
Email: lmuhwezi@kyu.ac.ug/lmuhwezi@hotmail.com

KSL EQUIPMENT DAILY LOGS

	TATA		COMPACTOR		EXCAVATOR		FEL		GRADER		BULLDOZER	
	UAP526		KSL230		KSL245		KSL188		KSL246		KSL169	
	km	litres	hour	litres	hour	litres	hour	litres	hour	litres	hour	litres
	160	71					8	103			UR	
	110	50	7.9	59	11	49	8	104	8	128	UR	
	174	74	UR		10.4	45	7.9	104	8.4	135	9	191
	174	77	8.4	60	10.5	45	8.1	103	8.7	139	8.5	186
	173	78	8.8	60	10	47	8	97	8.2	129	3	61
			UR		12.3	57						
	78	40	UR				5.9	74				
	130	60	UR		15	69	7.3	98	8.2	131	10.5	175
	145	68	UR		8	32	7.3	90	8.3	134	9	195
	38	20	8	60	11.2	53	8.2	109	8.7	138	10	216
	64	30	7.9	59	10.3	47	8.2	100	8.1	131	UR	
	154	64	8.8	64	10	44	8.3	109	8.5	135	10	206
											9	195
	165	73	5.5	36			7.5	101			9	198
	74	35	8.1	59	9	38	7	79	8	128	9	201
	152	69	9.2	65	10.9	48	8.5	115	8	131		
	50	24	UR		9.4	40	8	102	8.4	135		
	83	40			7	29	UR		7.9	129		
	50	24			17.4	67	7	89	8.3	132		
	12	44										
	43	49	8.9	64					8.6	136		
	105	45			9.2	40			7.8	127		
	126	57	8.8	59	11.6	54			8.2	132		
	102	47	8.4	59	11.4	51			9.1	135		
	146	67	7.9	57	6.4	28			8	129		
					4	17						
	72	33	7.8	63					8.4	136		
	72	33	7.9	52					8.6	139		
	105	49	8.3	59					8	129		
TOTAL	2757	1321	130.6	935	205	900	123.2	1577	182.4	2918	87	1824

	TATA		COMPACTOR		EXCAVATOR		FEL		GRADER		BULLDOZER	
	UAP526		KSL230		KSL245		KSL235		KSL246		KSL169	
	km	litres	hour	litres	hour	litres	hour	litres	hour	litres	hour	litres
			7.7	55			8	107	8.4	137	9	199
	117	55	8.5	61			8.5	112	8.2	132	9	196
	70	33	7.5	56			8	105	8.6	130	9	196
											10	215
					11.6	53	9.3	115				
			10.2	68	9	38	5.1	53	7.4	123	9	195
	65	32	8.1	58	11	50	8.6	111	7.9	129		
	72	33	8.2	59	11	49	8.5	109	8.3	136	9	196
			5.2	24	11.8	52	9	109	8.4	131	9	197
			6.7	53	9.2	38	7.6	101	8.1	129	9	199
			7.4	52	11	49	6.9	88	5.5	89	9	185
	107	48	11	85	11.8	54	10	132	7.9	127	9	190
	97	45	8.3	61	10.2	46	7.5	100	8.2	133	10	197
	64	32			10.1	41	9.5	121	8.9	128	UR	
			8.4	60	8	35	8.5	108	8.2	130	8	179
			8	56			6	78	8.2	134	9	189
											UR	
			8.2	60			8.1	107	9.1	143	10	217
			8.7	60			7	92			9	194
			7.5	53			4.9	66			10.2	216
	112	52	9.2	68	16.5	63	5	66	8.4	139	UR	
	141	64	8.6	62			7.4	95	8.4	137	UR	
	169	81	7.8	56			6	76	8.2	129		
	150	71									UR	
	146	71	11.1	76			5	55	6.8	109	UR	
	136	67	8	55			6	81	7.8	125		
	124	60	8.4	58			5.8	82	8.2	131		
	92	45	8.8	66			9.4	125	8.5	137		
	98	48	7.9	59			6.5	82	7.9	127		
TOTAL	1760	837	199.4	1421	131.2	568	192.1	2476	185.5	2965	147.2	3160

KSL ROADS MAINTAINED DATA

MONTH	**DEC**								
LOCATION	L21	H19	AA10	BU57	PP9	**TOTAL (km)**			
DISTANCE (km)	0.3	0.6	0.1	0.3	1.3	2.6			
MONTH	**NOV**								
LOCATION	H19	L20	BU31	G9	VV2	ZAZA2	JJ14	DD13	**TOTAL (km)**
DISTANCE (km)	0.7	0.3	0.3	0.6	0.3	0.3	0.3	0.2	3.00
MONTH	**OCT**								
LOCATION	V16	GA4/3	EE2	P7B	CD4	AA6	AA12	**TOTAL (km)**	
DISTANCE (km)	0.3	0.3	0.3	0.3	0.2	0.3	0.2	1.9	
MONTH	**JUN**								
LOCATION	AA10B	N23-KL12	**TOTAL (km)**						
DISTANCE (km)	0.6	0.6	1.2						
MONTH	**MAY**								
LOCATION	KK6	**TOTAL (km)**							
DISTANCE (km)	0.3	0.3							
MONTH	**APRIL**								
LOCATION	H4	KK1/8	GA2	P7A	MM6	**TOTAL (km)**			
DISTANCE (km)	0.2	0.3	0.15	0.3	0.2	1.15			
MONTH	**MARCH**								
LOCATION	MM6	BU21	WX22	8T21	GG11	BU38	**TOTAL (km)**		
DISTANCE (km)	0.2	0.5	0.6	0.4	0.2	0.5	2.4		
MONTH	**JULY**								
LOCATION	D17	AA10B	**TOTAL (km)**						
DISTANCE (km)	0.4	0.6	1						

MONTH	**AUGUST**														
LOCATION	U220	B413/14	H3	H9	BU17	BU57	BU8	BU43	ZAZA2	V16/17	D12	G8	A18	**TOTAL (km)**	
DISTANCE (km)	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.4	0.5	0.2	0.2	4	
MONTH	**JANUARY**														
LOCATION	II15	JJ11	HH11	KK11-KK13	JJ1B	KHA3	C12	FF4	BU28	G10	PP6	OO6	MM3	PP3	**TOTAL (km)**
DISTANCE (km)	0.3	0.35	0.32	0.9	0.2	0.6	0.3	0.3	0.1	0.55	0.6	0.45	0.5	0.3	5.77

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**AVERAGE**
km	5.77	2.4	2.4	1.15	0.3	1.2	1	4	2.2	1.9	3	2.6	2.33

Estimated tire service life of hauling units (trucks) [Adapted from CAT Manual 2017]

No.	Condition	factor	
I	**maintenance**		
	excellent	1.090	**E-4 bias xtra thread** 
	average	0.981	
	poor	0.763	
II	**speeds (maximum)**		
	16km/h	1.090	
	32km/h	0.872	
	48km/h	0.763	
III	**surface conditions**		
	soft earth-no rock	1.090	
	soft earth-some rock	0.981	
	well maintained-gravel road	0.981	**E-3 standard bias tread** 
	poorly maintained-gravel road	0.763	
	blasted-sharp rock	0.654	
IV	**wheel positions**		
	trailing	1.090	
	front	0.981	
	driver (rear dump)	0.872	
	(bottom dump)	0.763	
	(self-propelled scraper)	0.654	
V	**Loads (see No. VIII note)**		
	T&RA/ETRTO* Recommended loading	1.090	
	20% overload	0.872	**E-4 Radial xtra thread** 
	40% overload	0.545	
VI	**Curves**		
	none	1.090	
	medium	0.981	
	severe	0.872	
VII	**Grades (drive tyres only)**		
	level	1.090	
	5% max	0.981	
	15% max	0.763	
VIII	**Other miscellaneous combinations***		
	none	1.090	
	medium	0.981	***VEHICLE TYRE USE TIME GUIDE (ADAPTED FROM CAT MANUAL 2017)**
	severe	0.872	

***VEHICLE TYRE USE TIME GUIDE (ADAPTED FROM CAT MANUAL 2017)**

Type of tyre	base average hours		
	hours	miles	km
E-3 std. bias tread	2,510	25,100	40,400
E-4 bias xtra tread	3,510	35,100	56,500
E-4 radial xtra tread	4,200	42,000	67,600

UNRA MECHANISED ROAD MAINTENANCE COST DATA (UNRA, 2022)

S/n	Contract name	Contractor and Supervisor	Commencement/Completion	Km maintained	Contract Duration (Months)	Contract Price (UGX)
1	Mechanized Maintenance of Selected National Unpaved Roads under Framework Contracts for 3 Years Lot 25: Luwero Station. Call Off Order No. 002	Contractor: Suez Auto Enterprises Ltd Supervisor: UNRA Luwero	Commenced: 22/12/2021 Completion: 22/04/2022	34	4	601,416,000
2	Mechanized Maintenance of Selected National Unpaved Roads under Framework Contracts for 3 Years: Luwero Station Call Off Order No. 001	Contractor: National Enterprise Corporation Supervisor: UNRA Luwero	Commenced: 12/01/2022 Completion: 12/05/2022	45	4	613,010,520
3	Framework Contract for the Mechanised Maintenance of Selected Unpaved Roads Totalling to 138Km: Call Off 01: Kyapa – Kansensero road (41Km)	Contractor: M/s.Kasese Nail & Wood Industries Ltd Supervisor: UNRA Masaka	Commenced: 08/05/2021 Completion: 07/08/2021	41	3	3,150,405,843
4	Framework Contract for the Mechanised Maintenance of Selected Unpaved Roads Totalling to 138Km: Call Off 02: Kyapa – Kansensero road (41Km)	Contractor: M/s.Kasese Nail & Wood Industries Ltd Supervisor: UNRA Masaka	Commenced: 18/01/2021 Completion: 16/09/2021	41	8	2,071,105,922
5	Mechanised maintenance of Selected Unpaved national roads under Framework contract for 3 years (Kabwohe – Bwizibwera – Nyakambu – Nsika (47.2km) Call off Order no.1	Contractor: BAP engineering company limited Supervisor: UNRA Ibanda	Commenced: 31/12/2020 Completion: 6/8/2021	47	8	3,000,108,700
6	Mechanised maintenance of Selected Unpaved national roads under Framework contract for 3 years (Kashongi – Kantaganya 24.5km) Call off Order no.1	Contractor: Dalach Investment Limited Supervisor: UNRA Kotido	11/4/2021 to 3/4/2022 Commenced: 11/4/2021 Completion: 3/4/2022	25	4	889,067,983
7	Mechanized Maintenance of Kotido – Nakaperumelu – Lopei Roads under Framework Contracts; PHASE II; Call-off Order No.2	Contractor: Dalach Investment Limited Supervisor: UNRA Kotido	11/4/2021 to 3/4/2022 Commenced: 11/4/2021 Completion: 3/4/2022	69	4	889,067,983
8	Mechanised Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 Years totalling to 363km; Lot 19: Moroto Station (Contract Sum:14,745,730,760); Call off order 002; Apeitolim – Iriiri	Contractor: Strakon Limited Supervisor: UNRA Moroto	Commenced: 14/3/2019 Completion: 14/04/2020	109	13	2,725,528,128
9	Mechanised Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 Years; Phase 2: Call off order 001; Matany – Lopei and Lokopo Link (19.5km)	Contractor: Strakon Limited Supervisor: UNRA Moroto	Commenced: 06/04/2021 Completion: 06/07/2021 Extended to 06/10/2021	20	6	2,183,637,790
10	Mechanised maintenance of Nyakabirizi – Burere – Nsiika road (45km) and Nsiika – Bihanga – Katerera road (44km)	Contractor: Wanaik Construction CO.LTD Supervisor: UNRA Ibanda	Commenced: 23/10/2020 Completion: 29/7/2021	89	9	5,112,763,000
11	Mechanized Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 Years. Lot 12 for Moroto Station. (Contract Sum: 12,461,958,406); Call off order 001; Ariamoi – Lopei (28.4km)	Contractor: Capital Logistics And Construction Ltd Supervisor: UNRA Moroto	Commenced: 26/08/2021 Completion: 26/02/2022	28	6	494,464,840
12	Mechanized Maintenance of Selected Unpaved National Roads Under	Contractor: GIC Logistics and	Commenced: 27/09/2021	85	9	874,794,770

S/n	Contract name	Contractor and Supervisor	Commencement/Completion	Km maintained	Contract Duration (Months)	Contract Price (UGX)
	Framework Contracts for 3 Years Call off order 002; Nakiloro – Lomukura (85km)	Engineers Ltd in Joint Venture with Strakon Limited Supervisor: UNRA Moroto	Completion: 27/06/2022			
13	Framework Contract for mechanised Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 years Totaling to 327Km, Lot 08 for Roads under Fort Portal Station Kakabara – Bufunjo – Katooke (46km) and Fort Portal – Kijura Road (41km) (Call Off Order No.2)	Contractor: Azu Properties Ltd Supervisor: UNRA Fort Portal	Commenced: 9/12/2020	87	8	2,934,457,311
14	Framework Contract for mechanized Maintenance of Selected Unpaved National Roads Under Framework Contracts for 3 years Totaling to 327Km, Lot 08 for Roads under Fort Portal Station, Kamwenge – Dura – Rwimi Road (60km) **(Call Off Order No3)**	Contractor: Azu Properties Ltd, Supervisor: UNRA Fort Portal	Commenced: 29/09/2021 Completion: 28/01/2022	60	4	487,295,750
15	Mechanized Maintenance of Selected Unpaved National Roads Under Framework Contract Totalling To 487.2km	Contractor: Rocktrust Contractors (U) Ltd Supervisor: UNRA Jinja	Commenced: 14/3/2019 Completion: 14/03/2022	487	36	33,860,159,881
16	Mechanised Maintenance of selected unpaved National Roads under Framework Contract Phase II- Call - off Order One. (Busolwe-Nabumali Junction (35.1Km) Road)	Contractor: Thunderbolt Technical Services Ltd Supervisor: UNRA Tororo	Commenced: 24/05/2021 Completion: 23/10/2021	35	5	1,486,162,399
17	Mechanized Maintenance of Selected Unpaved National Roads under Framework Contracts for Three Years: Lot 14: Lira Station; Agwata – Aduku road (29.4Km)	Contractor: Tegeka Enterprises Ltd Supervisor: UNRA Lira	Commenced: 28/04/2021 Completion: 28/10/2021	29	6	699,225,605
18	Mechanized Maintenance of Unpaved National Roads For 22 UNRA Stations Under Framework Contract For 3 Years Lot 24: Moyo Station: Aliodranusi – Goboro – Matu – Kei (35km)	Contractor: BLD Consult Ltd Supervisor: UNRA Moyo	Commenced: 21/12/2020 Completion: 20/06/2021	35	6	2,397,521,640
19	Mechanized Maintenance of Unpaved National Roads For 22 UNRA Stations Under Framework Contract For 3 Years Lot 24: Moyo Station: Moyo – Obongi Road (28+000-56+000) (28Km).	Contractor: BLD Consult Ltd Supervisor: UNRA Moyo	Commenced: 6/04/2021 Completion: 5/07/2021	28	3	2,313,621,658
20	Mechanized maintenance of selected unpaved national roads for 18 UNRA stations under framework contract for 3 years: Lot1-25: Lot 20 Arua station - Call-off order number 1(Wandi – Rhino camp road 51km	Contractor: PNR Supervisor: UNRA Arua	Commenced: 15/04/2021 Completion: 14/09/2021	51	6	2,000,040,504
21	Mechanized maintenance of selected unpaved national roads for 18 UNRA stations under framework contract for 3 years: Lot1-25: Lot 20 Arua station - Call-off order number 2 (Koboko – Lodonga road 18km	Contractor: PNR Supervisor: UNRA Arua	Commenced: 02/12/2021 Completion: 01/03/2022	18	3	302,511,487

KSL DUMPER TRUCK COST DATA

km	km covered /hour	fuel ltrs	fuel cost	tyre cost	labour cost	depreciation cost	insurance cost	minor repair cost	maintenance cost	Daily PRODUCTION COST (Ugx)
160	20	71	319,500	9,568.46	456,000	18,000	15,810	99,306	252,454	1,170,638
110	14	50	225,000	6,578.31	456,000	18,000	15,810	99,306	252,454	1,073,148
174	22	74	333,000	10,405.70	456,000	18,000	15,810	99,306	252,454	1,184,975
174	22	77	346,500	10,405.70	456,000	18,000	15,810	99,306	252,454	1,198,475
173	22	78	351,000	10,345.89	456,000	18,000	15,810	99,306	252,454	1,202,915
78	10	40	180,000	4,664.62	456,000	18,000	15,810	99,306	252,454	1,026,234
130	16	60	270,000	7,774.37	456,000	18,000	15,810	99,306	252,454	1,119,344
145	18	68	306,000	8,671.41	456,000	18,000	15,810	99,306	252,454	1,156,241
38	5	20	90,000	2,272.51	456,000	18,000	15,810	99,306	252,454	933,842
64	8	30	135,000	3,827.38	456,000	18,000	15,810	99,306	252,454	980,397
154	19	64	288,000	9,209.64	456,000	18,000	15,810	99,306	252,454	1,138,779
165	21	73	328,500	9,867.47	456,000	18,000	15,810	99,306	252,454	1,179,937
74	9	35	157,500	4,425.41	456,000	18,000	15,810	99,306	252,454	1,003,495
152	19	69	310,500	9,090.03	456,000	18,000	15,810	99,306	252,454	1,161,159
50	6	24	108,000	2,990.14	456,000	18,000	15,810	99,306	252,454	952,560
83	10	40	180,000	4,963.64	456,000	18,000	15,810	99,306	252,454	1,026,533
50	6	24	108,000	2,990.14	456,000	18,000	15,810	99,306	252,454	952,560
12	2	44	198,000	717.63	456,000	18,000	15,810	99,306	252,454	1,040,287
43	5	49	220,500	2,571.52	456,000	18,000	15,810	99,306	252,454	1,064,641
105	13	45	202,500	6,279.30	456,000	18,000	15,810	99,306	252,454	1,050,349
126	16	57	256,500	7,535.16	456,000	18,000	15,810	99,306	252,454	1,105,605
102	13	47	211,500	6,099.89	456,000	18,000	15,810	99,306	252,454	1,059,169
146	18	67	301,500	8,731.22	456,000	18,000	15,810	99,306	252,454	1,151,801
72	9	33	148,500	4,305.81	456,000	18,000	15,810	99,306	252,454	994,375
72	9	33	148,500	4,305.81	456,000	18,000	15,810	99,306	252,454	994,375
105	13	49	220,500	6,279.30	456,000	18,000	15,810	99,306	252,454	1,068,349
117	15	55	247,500	6,996.93	456,000	18,000	15,810	99,306	252,454	1,096,066
70	9	33	148,500	4,186.20	456,000	18,000	15,810	99,306	252,454	994,256
65	8	32	144,000	3,887.19	456,000	18,000	15,810	99,306	252,454	989,457
72	9	33	148,500	4,305.81	456,000	18,000	15,810	99,306	252,454	994,375
107	13	48	216,000	6,398.90	456,000	18,000	15,810	99,306	252,454	1,063,968
97	12	45	202,500	5,800.88	456,000	18,000	15,810	99,306	252,454	1,049,870
64	8	32	144,000	3,827.38	456,000	18,000	15,810	99,306	252,454	989,397
112	14	52	234,000	6,697.92	456,000	18,000	15,810	99,306	252,454	1,082,267
141	18	64	288,000	8,432.20	456,000	18,000	15,810	99,306	252,454	1,138,002
169	21	81	364,500	10,106.68	456,000	18,000	15,810	99,306	252,454	1,216,176
150	19	71	319,500	8,970.43	456,000	18,000	15,810	99,306	252,454	1,170,040
146	18	71	319,500	8,731.22	456,000	18,000	15,810	99,306	252,454	1,169,801
136	17	67	301,500	8,133.19	456,000	18,000	15,810	99,306	252,454	1,151,203
124	16	60	270,000	7,415.55	456,000	18,000	15,810	99,306	252,454	1,118,985
92	12	45	202,500	5,501.86	456,000	18,000	15,810	99,306	252,454	1,049,571
98	12	48	216,000	5,860.68	456,000	18,000	15,810	99,306	252,454	1,063,430
										1,079,215

KSL EXCAVATOR COST DATA

Hours	fuel ltrs	fuel cost	tyre cost	labour cost	depreciation cost	insurance cost	minor repair cost	maintenance cost	Daily PRODUCTION COST (Ugx)
11	49	220,500	14,442.92	456,000	72,000	63,240	107,000	242,463	1,175,646
10	45	202,500	13,655.12	456,000	72,000	63,240	107,000	242,463	1,156,859
11	45	202,500	13,786.42	456,000	72,000	63,240	107,000	242,463	1,156,990
10	47	211,500	13,129.92	456,000	72,000	63,240	107,000	242,463	1,165,333
12	57	256,500	16,149.81	456,000	72,000	63,240	107,000	242,463	1,213,353
15	69	310,500	19,694.88	456,000	72,000	63,240	107,000	242,463	1,270,898
8	32	144,000	10,503.94	456,000	72,000	63,240	107,000	242,463	1,095,207
11	53	238,500	14,705.51	456,000	72,000	63,240	107,000	242,463	1,193,909
10	47	211,500	13,523.82	456,000	72,000	63,240	107,000	242,463	1,165,727
10	44	198,000	13,129.92	456,000	72,000	63,240	107,000	242,463	1,151,833
9	38	171,000	11,816.93	456,000	72,000	63,240	107,000	242,463	1,123,520
11	48	216,000	14,311.62	456,000	72,000	63,240	107,000	242,463	1,171,015
9	40	180,000	12,342.13	456,000	72,000	63,240	107,000	242,463	1,133,046
7	29	130,500	9,190.95	456,000	72,000	63,240	107,000	242,463	1,080,394
17	67	301,500	22,846.07	456,000	72,000	63,240	107,000	242,463	1,265,050
9	40	180,000	12,079.53	456,000	72,000	63,240	107,000	242,463	1,132,783
12	54	243,000	15,230.71	456,000	72,000	63,240	107,000	242,463	1,198,934
11	51	229,500	14,968.11	456,000	72,000	63,240	107,000	242,463	1,185,172
6	28	126,000	8,403.15	456,000	72,000	63,240	107,000	242,463	1,075,107
4	17	76,500	5,251.97	456,000	72,000	63,240	107,000	242,463	1,022,455
12	53	238,500	15,230.71	456,000	72,000	63,240	107,000	242,463	1,194,434
9	38	171,000	11,816.93	456,000	72,000	63,240	107,000	242,463	1,123,520
11	50	225,000	14,442.92	456,000	72,000	63,240	107,000	242,463	1,180,146
11	49	220,500	14,442.92	456,000	72,000	63,240	107,000	242,463	1,175,646
12	52	234,000	15,493.31	456,000	72,000	63,240	107,000	242,463	1,190,197
9	38	171,000	12,079.53	456,000	72,000	63,240	107,000	242,463	1,123,783
11	49	220,500	14,442.92	456,000	72,000	63,240	107,000	242,463	1,175,646
12	54	243,000	15,493.31	456,000	72,000	63,240	107,000	242,463	1,199,197
10	46	207,000	13,392.52	456,000	72,000	63,240	107,000	242,463	1,161,096
10	41	184,500	13,261.22	456,000	72,000	63,240	107,000	242,463	1,138,465
8	35	157,500	10,503.94	456,000	72,000	63,240	107,000	242,463	1,108,707
17	63	283,500	21,664.37	456,000	72,000	63,240	107,000	242,463	1,245,868
									1,160,936

KSL ROLLER COMPACTOR COST DATA

Hours	fuel ltrs	fuel cost	tyre cost	labour cost	depreciation cost	insurance cost	minor repair cost	maintenance cost	Daily PRODUCTION COST (Ugx)
8	59	265,500	2219.73	456,000	96,000	84,320	56,957	196,173	1,157,170
8	60	270,000	2360.22	456,000	96,000	84,320	56,957	196,173	1,161,810
9	60	270,000	2472.61	456,000	96,000	84,320	56,957	196,173	1,161,923
8	60	270,000	2247.83	456,000	96,000	84,320	56,957	196,173	1,161,698
8	59	265,500	2219.73	456,000	96,000	84,320	56,957	196,173	1,157,170
9	64	288,000	2472.61	456,000	96,000	84,320	56,957	196,173	1,179,923
6	36	162,000	1545.38	456,000	96,000	84,320	56,957	196,173	1,052,995
8	59	265,500	2275.93	456,000	96,000	84,320	56,957	196,173	1,157,226
9	65	292,500	2585.01	456,000	96,000	84,320	56,957	196,173	1,184,535
9	64	288,000	2500.71	456,000	96,000	84,320	56,957	196,173	1,179,951
9	59	265,500	2472.61	456,000	96,000	84,320	56,957	196,173	1,157,423
8	59	265,500	2360.22	456,000	96,000	84,320	56,957	196,173	1,157,310
8	57	256,500	2219.73	456,000	96,000	84,320	56,957	196,173	1,148,170
8	63	283,500	2191.64	456,000	96,000	84,320	56,957	196,173	1,175,142
8	52	234,000	2219.73	456,000	96,000	84,320	56,957	196,173	1,125,670
8	59	265,500	2332.12	456,000	96,000	84,320	56,957	196,173	1,157,282
8	55	247,500	2163.54	456,000	96,000	84,320	56,957	196,173	1,139,114
9	61	274,500	2388.32	456,000	96,000	84,320	56,957	196,173	1,166,338
8	56	252,000	2107.34	456,000	96,000	84,320	56,957	196,173	1,143,557
10	68	306,000	2865.98	456,000	96,000	84,320	56,957	196,173	1,198,316
8	58	261,000	2275.93	456,000	96,000	84,320	56,957	196,173	1,152,726
8	59	265,500	2304.03	456,000	96,000	84,320	56,957	196,173	1,157,254
5	24	108,000	1461.09	456,000	96,000	84,320	56,957	196,173	998,911
7	53	238,500	1882.56	456,000	96,000	84,320	56,957	196,173	1,129,833
7	52	234,000	2079.24	456,000	96,000	84,320	56,957	196,173	1,125,529
11	85	382,500	3090.77	456,000	96,000	84,320	56,957	196,173	1,275,041
8	61	274,500	2332.12	456,000	96,000	84,320	56,957	196,173	1,166,282
8	60	270,000	2360.22	456,000	96,000	84,320	56,957	196,173	1,161,810
8	56	252,000	2247.83	456,000	96,000	84,320	56,957	196,173	1,143,698
8	60	270,000	2304.03	456,000	96,000	84,320	56,957	196,173	1,161,754
9	60	270,000	2444.52	456,000	96,000	84,320	56,957	196,173	1,161,895
8	53	238,500	2107.34	456,000	96,000	84,320	56,957	196,173	1,130,057
9	68	306,000	2585.01	456,000	96,000	84,320	56,957	196,173	1,198,035
9	62	279,000	2416.42	456,000	96,000	84,320	56,957	196,173	1,170,866
8	56	252,000	2191.64	456,000	96,000	84,320	56,957	196,173	1,143,642
11	76	342,000	3118.87	456,000	96,000	84,320	56,957	196,173	1,234,569
8	55	247,500	2247.83	456,000	96,000	84,320	56,957	196,173	1,139,198
8	58	261,000	2360.22	456,000	96,000	84,320	56,957	196,173	1,152,810
9	66	297,000	2472.61	456,000	96,000	84,320	56,957	196,173	1,188,923
8	59	265,500	2219.73	456,000	96,000	84,320	56,957	196,173	1,157,170
									1,156,818

KSL FRONT END WHEEL LOADER COST DATA

Hours	fuel ltrs	fuel cost	tyre cost	labour cost	depreciation cost	insurance cost	minor repair cost	maintenance cost	Daily PRODUCTION COST (Ugx)
8	103	463,500	12,512.37	456,000	144,000	126,480	75,750	220,364	1,498,607
8	104	468,000	12,512.37	456,000	144,000	126,480	75,750	220,364	1,503,107
8	104	468,000	12,355.97	456,000	144,000	126,480	75,750	220,364	1,502,950
8	103	463,500	12,668.77	456,000	144,000	126,480	75,750	220,364	1,498,763
8	97	436,500	12,512.37	456,000	144,000	126,480	75,750	220,364	1,471,607
6	74	333,000	9,227.87	456,000	144,000	126,480	75,750	220,364	1,364,822
7	98	441,000	11,417.54	456,000	144,000	126,480	75,750	220,364	1,475,012
7	90	405,000	11,417.54	456,000	144,000	126,480	75,750	220,364	1,439,012
8	109	490,500	12,825.18	456,000	144,000	126,480	75,750	220,364	1,525,919
8	100	450,000	12,825.18	456,000	144,000	126,480	75,750	220,364	1,485,419
8	109	490,500	12,981.58	456,000	144,000	126,480	75,750	220,364	1,526,076
8	101	454,500	11,730.35	456,000	144,000	126,480	75,750	220,364	1,488,825
7	79	355,500	10,948.32	456,000	144,000	126,480	75,750	220,364	1,389,043
9	115	517,500	13,294.39	456,000	144,000	126,480	75,750	220,364	1,553,389
8	102	459,000	12,512.37	456,000	144,000	126,480	75,750	220,364	1,494,107
7	89	400,500	10,948.32	456,000	144,000	126,480	75,750	220,364	1,434,043
8	107	481,500	12,512.37	456,000	144,000	126,480	75,750	220,364	1,516,607
9	112	504,000	13,294.39	456,000	144,000	126,480	75,750	220,364	1,539,889
8	105	472,500	12,512.37	456,000	144,000	126,480	75,750	220,364	1,507,607
9	115	517,500	14,545.63	456,000	144,000	126,480	75,750	220,364	1,554,640
5	53	238,500	7,976.64	456,000	144,000	126,480	75,750	220,364	1,269,071
9	111	499,500	13,450.80	456,000	144,000	126,480	75,750	220,364	1,535,545
9	109	490,500	13,294.39	456,000	144,000	126,480	75,750	220,364	1,526,389
9	109	490,500	14,076.42	456,000	144,000	126,480	75,750	220,364	1,527,171
8	101	454,500	11,886.75	456,000	144,000	126,480	75,750	220,364	1,488,981
7	88	396,000	10,791.92	456,000	144,000	126,480	75,750	220,364	1,429,386
10	132	594,000	15,640.46	456,000	144,000	126,480	75,750	220,364	1,632,235
8	100	450,000	11,730.35	456,000	144,000	126,480	75,750	220,364	1,484,325
10	121	544,500	14,858.44	456,000	144,000	126,480	75,750	220,364	1,581,953
9	108	486,000	13,294.39	456,000	144,000	126,480	75,750	220,364	1,521,889
6	78	351,000	9,384.28	456,000	144,000	126,480	75,750	220,364	1,382,979
8	107	481,500	12,668.77	456,000	144,000	126,480	75,750	220,364	1,516,763
7	92	414,000	10,948.32	456,000	144,000	126,480	75,750	220,364	1,447,543
5	66	297,000	7,663.83	456,000	144,000	126,480	75,750	220,364	1,327,258
5	66	297,000	7,820.23	456,000	144,000	126,480	75,750	220,364	1,327,415
7	95	427,500	11,573.94	456,000	144,000	126,480	75,750	220,364	1,461,668
6	76	342,000	9,384.28	456,000	144,000	126,480	75,750	220,364	1,373,979
5	55	247,500	7,820.23	456,000	144,000	126,480	75,750	220,364	1,277,915
6	81	364,500	9,384.28	456,000	144,000	126,480	75,750	220,364	1,396,479
6	82	369,000	9,071.47	456,000	144,000	126,480	75,750	220,364	1,400,666
9	125	562,500	14,702.03	456,000	144,000	126,480	75,750	220,364	1,599,796
7	82	369,000	10,166.30	456,000	144,000	126,480	75,750	220,364	1,401,761
									1,468,586

KSL MOTORGRADER COST DATA

Hours	fuel ltrs	fuel cost	tyre cost	labour cost	depreciation cost	insurance cost	minor repair cost	maintenance cost	Daily PRODUCTION COST (Ugx)
8	128	576,000	22,147.48	456,000	132,000	115,940	104,737	258,833	1,665,658
8	135	607,500	23,254.86	456,000	132,000	115,940	104,737	258,833	1,698,265
9	139	625,500	24,085.39	456,000	132,000	115,940	104,737	258,833	1,717,096
8	129	580,500	22,701.17	456,000	132,000	115,940	104,737	258,833	1,670,711
8	131	589,500	22,701.17	456,000	132,000	115,940	104,737	258,833	1,679,711
8	134	603,000	22,978.01	456,000	132,000	115,940	104,737	258,833	1,693,488
9	138	621,000	24,085.39	456,000	132,000	115,940	104,737	258,833	1,712,596
8	131	589,500	22,424.33	456,000	132,000	115,940	104,737	258,833	1,679,435
9	135	607,500	23,531.70	456,000	132,000	115,940	104,737	258,833	1,698,542
8	128	576,000	22,147.48	456,000	132,000	115,940	104,737	258,833	1,665,658
8	131	589,500	22,147.48	456,000	132,000	115,940	104,737	258,833	1,679,158
8	135	607,500	23,254.86	456,000	132,000	115,940	104,737	258,833	1,698,265
8	129	580,500	21,870.64	456,000	132,000	115,940	104,737	258,833	1,669,881
8	132	594,000	22,978.01	456,000	132,000	115,940	104,737	258,833	1,684,488
9	136	612,000	23,808.54	456,000	132,000	115,940	104,737	258,833	1,703,319
8	127	571,500	21,593.80	456,000	132,000	115,940	104,737	258,833	1,660,604
8	132	594,000	22,701.17	456,000	132,000	115,940	104,737	258,833	1,684,211
9	135	607,500	25,192.76	456,000	132,000	115,940	104,737	258,833	1,700,203
8	129	580,500	22,147.48	456,000	132,000	115,940	104,737	258,833	1,670,158
8	136	612,000	23,254.86	456,000	132,000	115,940	104,737	258,833	1,702,765
9	139	625,500	23,808.54	456,000	132,000	115,940	104,737	258,833	1,716,819
8	129	580,500	22,147.48	456,000	132,000	115,940	104,737	258,833	1,670,158
8	137	616,500	23,254.86	456,000	132,000	115,940	104,737	258,833	1,707,265
8	132	594,000	22,701.17	456,000	132,000	115,940	104,737	258,833	1,684,211
9	130	585,000	23,808.54	456,000	132,000	115,940	104,737	258,833	1,676,319
7	123	553,500	20,486.42	456,000	132,000	115,940	104,737	258,833	1,641,497
8	129	580,500	21,870.64	456,000	132,000	115,940	104,737	258,833	1,669,881
8	136	612,000	22,978.01	456,000	132,000	115,940	104,737	258,833	1,702,488
8	131	589,500	23,254.86	456,000	132,000	115,940	104,737	258,833	1,680,265
8	129	580,500	22,424.33	456,000	132,000	115,940	104,737	258,833	1,670,435
6	89	400,500	15,226.39	456,000	132,000	115,940	104,737	258,833	1,483,237
8	127	571,500	21,870.64	456,000	132,000	115,940	104,737	258,833	1,660,881
8	133	598,500	22,701.17	456,000	132,000	115,940	104,737	258,833	1,688,711
9	128	576,000	24,639.08	456,000	132,000	115,940	104,737	258,833	1,668,149
8	130	585,000	22,701.17	456,000	132,000	115,940	104,737	258,833	1,675,211
8	134	603,000	22,701.17	456,000	132,000	115,940	104,737	258,833	1,693,211
9	143	643,500	25,192.76	456,000	132,000	115,940	104,737	258,833	1,736,203
8	139	625,500	23,254.86	456,000	132,000	115,940	104,737	258,833	1,716,265
8	137	616,500	23,254.86	456,000	132,000	115,940	104,737	258,833	1,707,265
8	129	580,500	22,701.17	456,000	132,000	115,940	104,737	258,833	1,670,711
7	109	490,500	18,825.36	456,000	132,000	115,940	104,737	258,833	1,576,836
8	125	562,500	21,593.80	456,000	132,000	115,940	104,737	258,833	1,651,604
8	131	589,500	22,701.17	456,000	132,000	115,940	104,737	258,833	1,679,711
9	137	616,500	23,531.70	456,000	132,000	115,940	104,737	258,833	1,707,542
8	127	571,500	21,870.64	456,000	132,000	115,940	104,737	258,833	1,660,881
									1,678,444

KSL BULLDOZER COST DATA

Hours	fuel ltrs	fuel cost	Undercarriage cost	labour cost	depreciation cost	insurance cost	minor repair cost	maintenance cost	Daily PRODUCTION COST (Ugx)
9	191	859,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,066,617
8.5	186	837,000	208639.30	456,000	156,000	137,020	55,263	181,921	2,031,844
3	61	274,500	73637.40	456,000	156,000	137,020	55,263	181,921	1,334,342
10.5	175	787,500	257730.90	456,000	156,000	137,020	55,263	181,921	2,031,435
9	195	877,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,084,617
10	216	972,000	245458.00	456,000	156,000	137,020	55,263	181,921	2,203,663
10	206	927,000	245458.00	456,000	156,000	137,020	55,263	181,921	2,158,663
9	195	877,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,084,617
9	198	891,000	220912.20	456,000	156,000	137,020	55,263	181,921	2,098,117
9	201	904,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,111,617
9	199	895,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,102,617
9	196	882,000	220912.20	456,000	156,000	137,020	55,263	181,921	2,089,117
9	196	882,000	220912.20	456,000	156,000	137,020	55,263	181,921	2,089,117
10	215	967,500	245458.00	456,000	156,000	137,020	55,263	181,921	2,199,163
9	195	877,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,084,617
9	196	882,000	220912.20	456,000	156,000	137,020	55,263	181,921	2,089,117
9	197	886,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,093,617
9	199	895,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,102,617
9	185	832,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,039,617
9	190	855,000	220912.20	456,000	156,000	137,020	55,263	181,921	2,062,117
10	197	886,500	245458.00	456,000	156,000	137,020	55,263	181,921	2,118,163
8	179	805,500	196366.40	456,000	156,000	137,020	55,263	181,921	1,988,071
9	189	850,500	220912.20	456,000	156,000	137,020	55,263	181,921	2,057,617
10	217	976,500	245458.00	456,000	156,000	137,020	55,263	181,921	2,208,163
9	194	873,000	220912.20	456,000	156,000	137,020	55,263	181,921	2,080,117
10.2	216	972,000	250367.16	456,000	156,000	137,020	55,263	181,921	2,208,572
									2,069,921

GULU DLG COST DATA (FROM PROJECT BOQs)

Sno.	Road	Planned road length (km)	fuel consumed (ltrs)	labour (Ugx)	Tools (Ugx)	Gravel/Materials used (Ugx)	cost with culvert (Ugx)	Maintenance cost/km with culvert (Ugx)
1	Mechanized maintenance of Nile Avenue road	2.0	10,918,000.0	3,615,000.0	1,750,000.0	19,717,000.0	36,000,000	18,000,000
2	Bell-Panycwala road.	1.6	8,586,000.0	3,595,000.0	1,740,000.0	24,079,000.0	38,000,000	23,750,000
3	Pida-techo road.	1.8	8,193,800.0	4,065,000.0	1,949,700.0	22,609,500.0	36,818,000	20,454,444
4	Laliya-Akonyibedo road	1.9	11,103,500.0	3,705,000.0	1,980,000.0	29,426,500.0	46,215,000	24,323,684
5	Forgod-Paminano road	3.6	21,200,000.0	5,210,000.0	1,324,000.0	26,266,000.0	54,000,000	15,000,000
6	Panyagira road	2.1	12,031,000.0	3,645,000.0	2,010,000.0	27,314,000.0	45,000,000	21,428,571
7	Jubi road.	1.8	8,193,800.0	4,065,000.0	1,973,700.0	17,767,500.0	32,000,000	17,777,778
8	Yusuf Adek road	1.8	8,193,800.0	4,065,000.0	1,926,200.0	22,815,000.0	37,000,000	20,555,556
9	Gulu-Gulu road	1.0	7,764,500.0	2,445,000.0	1,688,000.0	9,102,500.0	21,000,000	21,000,000
10	Ochan Ben road	1.5	7,844,000.0	2,950,000.0	1,740,000.0	16,466,000.0	29,000,000	19,333,333
11	Hassan lane & onono onweng road	3.0	11,925,000.0	2,150,000.0	1,700,000.0	23,168,000.0	38,943,000	12,981,000
12	Dorothy laker road	1.4	8,586,000.0	3,595,000.0	1,740,000.0	18,079,000.0	32,000,000	22,857,143
13	Patuda road	2.3	15,476,000.0	3,905,000.0	1,970,000.0	36,649,000.0	58,000,000	25,217,391
14	Obita Ludac road	1.0	7,764,500.0	2,445,000.0	1,768,000.0	16,009,000.0	27,986,500	27,986,500
15	Bunyoro road	0.3	4,550,000.0	1,550,000.0	696,000.0	3,200,000.0	9,996,000	33,320,000