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FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

IMPACT OF DESIGN FLAWS ON COST OVERRUNS IN ROAD CONSTRUCTION PROJECTS IN UGANDA

BY

ASUMAN KIRENZI

(BSc. Civ Eng. Mak.**)**

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

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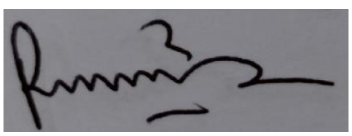
CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by Kyambogo University a dissertation titled "**Impact of Design Flaws on Cost Overruns in Road Construction Projects in Uganda**", in fulfilment of the requirements for the award of a Master of Science Degree in Construction Technology and Management of Kyambogo University.

Eng. Dr. Rodgers Mugume Bangi Date



22/11/2019

Dr. Muhwezi Lawrence Date

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DECLARATION

I, Asuman Kirenzi, 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.

Asuman Kirenzi	Date
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DEDICATION

This dissertation is dedicated to the engineering fraternity. It is intended to contribute knowledge for our institutions to the benefit of our beloved country Uganda.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANOVA	Analysis of Variance
BOQ	Bill of Quantities
CVI	Content Validity Index
CVR	Content Validity Ratio
IPC	Interim Payment Certificate
MS	Microsoft
FI	Frequency Index
I.I	Importance Index
MoFPED	Ministry of Finance, Planning and Economic Development
NDP I	National Development Plan I
SI	Severity Index
SPSS	Statistical Package for Social Scientists
SRB	Surveyors Registration Board
UACE	Uganda Association of Consulting Engineers
UGX	Uganda Shillings
UIPE	Uganda Institution of Professional Engineers
UNRA	Uganda National Roads Authority

LIST OF APPENDICES

ABSTRACT

The inability to complete projects within time and budget continues to be a chronic problem worldwide and it is worsening. Cost overruns have therefore remained a major setback in implementation of road construction projects. In Uganda, some projects have had cost overruns to a tune of 100% and are partly attributed to design flaws. There exists a need to understand the extent to which design flaws affect cost overruns. This research focused on identifying design flaws encountered during the construction phase of paved road projects and developed a model for predicting their impact on cost overruns.

A total of thirty-seven (37) design flaws encountered during construction were identified from literature. A questionnaire survey was conducted involving 120 professionals purposively selected from Uganda National Roads Authority, consulting firms and contractors and were requested to rate the design flaws frequency of occurrence and impact on cost using a five-point Likert scale basing on their experience. Using data from 16 completed paved road construction projects in Uganda, the effect of four of the major design flaws ranked according to importance index (II) was established. Using MS Excel, a regression model for predicting the contribution of the design flaws to cost overruns was developed. Results indicted the major design flaws to be: provision of less number of drainage culverts, inadequate quarries and earthen materials investigations, inadequate geotechnical investigations for road subgrade, under estimation of quantities of rock fill and provision of less volumes of cut and fill.

The contribution of the major design flaws to cost overrun on projects was established to be 33.3% on average. Increase in quantity of rock fill had the biggest effect on cost overruns with an average of 11.0% while increase in number of drainage culverts had the least effect with an average of 6.7%. The model for predicting impact of the major design flaws on cost overruns in paved road construction projects was developed and was found to explain the total variations in cost overruns by 82.4%. It was concluded that most of the design flaws which greatly affect cost overruns are attributed to non-comprehensive geotechnical and hydrological studies.

Key words: **Design Flaws, Cost overruns, Regression Model, Paved Road projects**

CHAPTER ONE

INTRODUCTION

1.1 Background

Infrastructure development is considered the backbone of economic growth and development world over (Calderon *et al*, 2008). Poor state of infrastructure is one of the impediments preventing African economies from leapfrogging from their current economic status into modern industrial economies (Foster *et al*, 2008). The development of infrastructure has a positive significant effect for developed and developing societies, predominantly road projects in the aspect of creating direct and indirect career opportunities, reducing cost of doing business, improving accessibility and general standards of the country locally and internationally (Garry *et al.*, 2010).

In Uganda, infrastructure development has been prioritised mainly to reduce the cost of doing business, increase country's global competitiveness, spar industrialization, and drive the country's economy to middle income status (NDP I, 2010). This is reflected by the increase in the funding of road development and maintenance over the last few years. Uganda National Roads Authority (UNRA), the national agency responsible for national roads, alone received UGX 2.3 and 3.8 trillion for road development and maintenance in the financial years 2015/2016 and 2017/2018 respectively (Kasaija, 2017).

Despite the increase in the funding for roads in Uganda, few roads are completed within budget and on time (Apolot, 2010). This has been attributed to variations that are very common in construction projects consequently causing cost overruns (Mfinanga, 2013). Cost overrun is the difference between forecasted and actual construction costs (Odeck, 2004). Pramen *et al* (2013) investigated the causes of cost overruns and highlighted design flaws such as inadequate scope definition and underestimation of quantities among others as key contributors to variations leading to cost overruns. A design flaw is defined as a fault, error, defect, mistake, imperfection or weakness found in any design (Oxford Advanced Learners' English Dictionary). Kaming *et. al.,* (1997) attributed cost overruns to designs issues (changes in design, poor estimation of quantities and inadequate geotechnical investigations), changes in material prices, poor site management and claims due to delayed payment by client as key contributors to cost overruns in road projects.

Chabota, (2008) investigated the major causes of cost escalation in Zambia's road construction sector. In his survey of 60 participants, 63% of the respondents indicated the cause as changes in scope while 61% attributed the cause to environmental protection and mitigation costs. Design flaws therefore, manifest themselves on projects in several forms leading to variations thus causing cost overruns in road construction projects beyond Uganda.

Though much attention has been devoted to establishing the major causes of cost overruns in road construction projects, little focus has been geared towards identifying the contribution of each factor on cost overruns.

Mfinanga (2013) investigated the causes of inadequate designs as well as the extent to which inadequate designs contribute to cost overruns in road construction projects in Tanzania, his investigation revealed that the total cost overrun rate was at 44% on average and 61% of the cost overruns were due to inadequate designs.

Vidalis *et. al*., (2002) investigated the causes for cost overruns in 708 highway projects for the Florida Department of Transportation and established that 39% of the project cost overruns were due to errors in designs and modifications in the project while 61% were due to other factors. However, both Mfinanga (2013) and Vidalis *et. al* (2002) did not critically analyse the extent to which each design issue affected the project cost, and no such study has been conducted in Uganda; in which findings may differ when different environments are considered.

When design flaws are not scrutinised, variations may continue blowing up the allocated budgets causing additional costs outside the budget allocation. Money spent on project change orders may necessitate supplementary budgets hence reducing the number and size of projects that can be completed during any fiscal year, and thus ultimately delaying service delivery in public sectors to the end users.

1.2 Problem Statement

The cost performance of a project is a key success criterion for project sponsors, managers and other key stakeholders. Ideally, successful projects are meant to be completed within budget, on schedule and to the satisfaction of the client and major project stakeholder

(PMI,2004). However, in Uganda, completing a major road construction project within budget and time has been a problem. According to the 2015 UNRA audit report, almost all paved road construction projects completed suffered a cost overrun. Kampala Northern Bypass Phase 1, for example, experienced more than 100% cost overrun (Ssepuuya, 2008); with most of the cost overruns attributed to design flaws that resulted into change orders, modifications and variations henceforth project cost overruns.

Without establishing the impact of critical design flaws on cost of road construction projects, significant variations might continue to occur on road projects. Significant variations consume the allocated budget and contingency then attract supplementary budgets reducing the number and size of projects that can be completed during any fiscal year hence ultimately delaying service delivery in public sectors to the end users.

This research, therefore, sought to establish the major design flaws, their contribution to cost overruns in paved road construction projects in Uganda, and to develop a regression model for predicting the contribution of the design flaws to cost overruns.

1.3 Research Objectives

1.3.1 Main objective

The main objective of this study was to establish the contribution of major design flaws to cost overruns in paved road construction projects in Uganda, and develop an associated predictive model.

1.3.2 Specific Objectives

The study was guided by the following specific objectives:

i. To identify the major design flaws encountered during construction of paved road projects in Uganda.
ii. To establish the impact of the major design flaws on cost overruns in paved road construction projects in Uganda.
iii. To develop a model for predicting the impact of the major design flaws on cost overruns of paved road construction projects in Uganda.

1.4 Research Questions

The research was guided by the following questions:

i. What are the major design flaws encountered during construction of paved road projects in Uganda?
ii. What is the impact of the major design flaws on cost overruns in paved road construction projects in Uganda?
iii. What is a reasonable predictive model for the impact of major design flaws on cost overruns in paved road construction projects in Uganda?

1.5 Justification

The road construction sector in Uganda is characterised by chronic cost overruns even when construction cost estimates with contingency are prepared (Alinaitwe *et al.,* 2008). Many road construction projects are completed above budget partly due to variations arising from design flaws (poor estimation of quantities, errors and omissions, inadequate geotechnical investigations etc.), delayed payment to contractor, inflation, unreliable material sources, changing climatic conditions, etc. The occurrence of these design flaws signifies dire consequences such as high costs of project implementation, poor safety of roads, delayed service delivery and financial loss inflicted to the taxpayers, clients and other stakeholders of projects.

The Government of Uganda in the Uganda Vision 2040, prioritised roads development projects to unlock the economic potential of the country and transform it from peasantry economy to middle income status. Therefore, more funds have been injected in infrastructure development. However, very few projects are being implemented and those completed experience cost overruns. Despite the fact that information is available on the causes of cost overruns, no study has been conducted in Uganda on the percentage contribution of each cause to the cost overruns. Therefore, general solutions like changing contracting mode, and improving contract management rather than specific solutions for minimising cost overruns have been suggested and this partly explains the continued occurrence of cost overruns in road construction projects in Uganda.

Without sufficient analysis of the impact of design flaws, projects might continuously experience large variations and cost overruns, financing challenges and have delayed infrastructure development due to financial losses as most of the major road projects are very expensive and often depend on either donor funds or loans from development banks which attract significant interest rates causing strain to the tax payers.

1.6 Significance

The performance of cost of a construction project is a key success criterion for project managers, clients, policy makers, and other key stakeholders (Baccarini, 2005). Therefore, minimising cost is key in any construction project.

This study sought to provide information to practitioners in the roads subsector and policy makers about the major design flaws which should be given critical attention during design and implementation stages consequently allowing for better planning and therefore, reducing the rate of project addenda and variations which cannot be absorbed by the construction contingency for the projects at planning and contract award.

The findings of this research and the regression model to be developed for prediction of the impact of design flaws on cost, are expected to enable construction managers, project engineers and paved road construction clients to better handle project costs issues. Ultimately, this study will provide a basis for other associated research studies concerning design flaws-based cost overruns in paved road construction projects in Uganda.

1.7 Scope

1.7.1 Content Scope

This research focused on identifying the most significant design flaws encountered during the construction phase of paved road projects in Uganda and their contribution to cost overruns with the intent of developing a model for predicting their impact on cost overruns, considering only completed paved road construction projects which experienced cost overruns.

Road Contractors, Client (UNRA), and design and supervision consultants provided the primary and secondary data.

1.7.2 Geographical Scope

Case study projects consisted of only paved road construction projects located country wide which were managed by UNRA.

The case study projects that were selected were located in all the major regions of the country. These projects were located in the major Eastern, Western, Northern, Southern and Central regions of Uganda. This helped to mitigate the effects of geographical location and climate on the objectives of this study.

1.7.3 Time Scope

The study focused on paved road construction projects completed between 2008 and 2017. Year 2008 was selected because it is when UNRA officially commenced its operations. This research was conducted from June 2018 to December 2018.

1.7.4 Conceptual Framework

The scheme of variables which the researcher operationalised to achieve the set of objectives is as shown in Figure 1.1. This entails the ultimate goal (research main objective), independent variables, processes/analysis methods, the dependent variable, and ultimate outcomes. It also spells out the exogenous factors which would influence the research outcomes. The independent variables are the identified major design flaws while the total project cost overruns are the dependent variable. The research outcome is the model which can be used to predict impact of the design flaws on cost overruns.

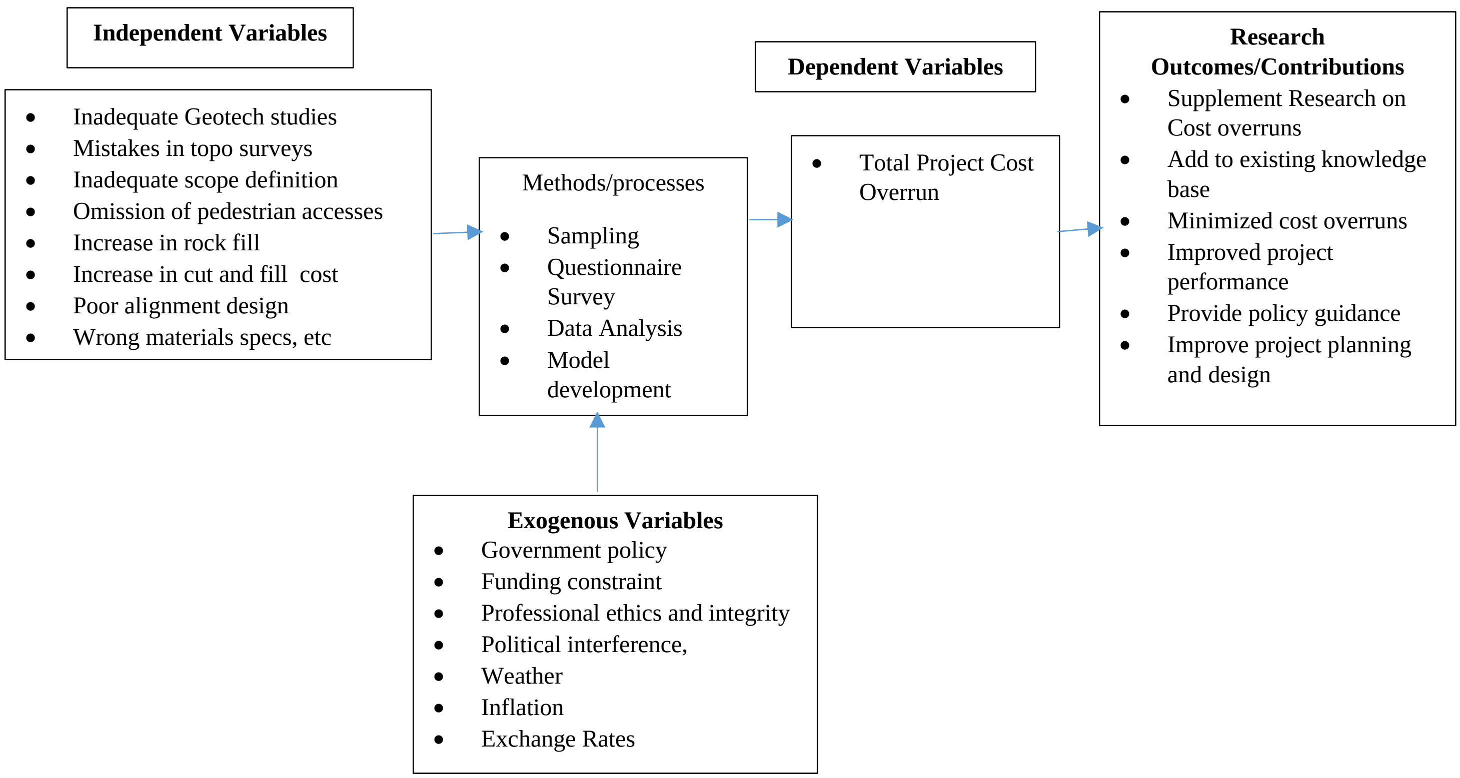

Figure 1.1: Conceptual Framework

1.8 Chapter Summary

Cost overruns are a major setback in implementation of road construction projects. In Uganda, some projects have had cost overruns to a tune of 100% and are partly attributed to design flaws. There exists a need to understand the extent to which design flaws affect cost overruns. This research focused on identifying design flaws encountered during the construction phase of paved road projects and develop a model for predicting their impact on cost overruns.

Chapter One introduces the problem, objectives, justification and significance of this research, the scope and the conceptual framework.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

This chapter reviews the engineering design process, literature about design flaws and cost overruns, and information about model development (validation, verification and selection of model parameters) it reviews empirical work done by different scholars in the subject area of design flaws and cost overruns, thereby identifying gaps in the existing studies.

2.2 Engineering Design and Design Process

Engineering is concerned with the creation of systems, devices, and processes useful to, and sought by, society. The process by which these goals are achieved is engineering design (McGraw, 2002).

The engineering design process is a methodical series of steps used in creating functional products and processes (Pahl & Beitz, 1988). It is a decision making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation (Ertas & Jones, 1996).

2.3 The Road Design Process

The road design is one of the stages involved in the overall highway development process. Historically, design has occurred in the middle of the process, linking the preceding phase of planning and project development with subsequent phases of right of way acquisition, construction and maintenance. This phase has several activities that differ from one country to another. However, major activities that cut across include; Feasibility study, preliminary design and detailed engineering design.

2.3.1 Feasibility Study and Preliminary Design

This involves analysing the possible solutions to the problem and recommendation of the best option to adopt. It is normally conducted to assist decision makers in determining whether to implement a particular project or not. Feasibility study of a road aims at determining the social economic needs necessary to implement the project, determine the most favourable alignment and to determine the most optimal structure and engineering solutions together with the possibilities of implementing them (Pahl & Beitz, 1988).

Preliminary design bridges the gap between design conception and detailed design especially where the level of conceptualization during ideation is not sufficient for full evaluation of the project. Therefore, at this stage, the project alignments, drawings, approximate quantities and specifications are provided to give early project configuration.

2.3.2 Detailed design and Design Review

At this stage, a review of the alternative proposed designs is done to select the most optimal one onto which detailing is done. The preliminary design activities are virtually repeated in a more meticulous way (Ertas & Jones, 1996). Detailed design, therefore, fixes the final road alignment and helps gathering additional physical data to prepare for construction phase such as quantities estimations, relocations required and actual volumes of earthworks required. Design review involves a team of specialists looking at the detailed design and providing comments on the design which may result in design changes or keeping the original design.

2.4 Design Flaws

A design flaw is a fault, omission, error, defect, mistake, imperfection or weakness found or introduced in any design and affects the appropriate functionality or constructability of the final design. In many construction projects, variation and scope changes result from design related factors and ultimately into cost changes (Chabota, 2008). Studies such as Josephson and Hammarlund (1999), that have examined design errors in construction have often interchangeably used the terms change, omissions, defects, quality deviations, non-conformances and failures.

A number of latent conditions reside within project systems that influence error-provoking activities to take place and, therefore, contribute to design errors occurring during construction (Love *et. al.*, 2012). For example, the use of competitive tendering can result in organizations committing to undertake work at a lowest price. This can result in opportunistic behaviour whereby design firms omit to undertake design audits, reviews, and verifications to maximize their fee. Moreover, when firms are placed under schedule pressure by clients to design and document, then a propensity exists for them to omit tasks to make work more efficient. This often result in errors in contract documentation, which has been identified as a major cause of disputes and cost variations during construction of projects (Love *et al.,* 2011a).

Once design errors are identified rework or design modification is inevitably required. The extent of the rework or modification that arises, however, is dependent upon when it is identified in a project's life cycle. Farrington (1987), in a study of nine construction projects established that that design inadequacies account for 19.7% of the total number of cost variations that arose in the projects. Farrington (1987) argued that design changes accounted for 79.1% of the total cost of quality deviations that arose in projects. Similarly, the engineering and review processes for an engineering project contributed 68% of rework costs with 78% of this total attributable to design errors and inadequacies. Barber *et. al*., (2000) established that design flaws accounted for 50% of quality failure costs in civil engineering projects.

The cost of design flaws has been reported to be lower in building projects with Love *et. al*., (2012) revealing that they accounted for 14% of rework costs. Cusack (1992) has revealed that design errors contained within contract documentation alone contributes at least 5% increase in a project's contract value.

2.5 Cost Overruns

A cost overrun is mainly described as a budget increase, cost increase or cost growth (Moris,1990). Cost overrun is the difference between forecasted and actual construction costs (Odeck, 2004). Chantal *et. al*., (2011), defines a cost overrun as the ratio of the actual final costs of the project to the estimate made at the full funds' authorisation measured in escalation-adjusted terms. In this instance, a cost overrun is treated as the margin between the initial project cost authorized and the real final costs incurred after adjusting for amounts spent due to escalation terms.

2.6 Studies on Cost Overruns and Gaps

Previous research has attempted to discover reasons for the disparity between tender sum and the final account (Ashworth,1999). Chabota *et. al.,* (2008) investigated the major causes of cost escalation in Zambia's road construction industry; their study showed that inclement weather due to heavy rains, scope changes, schedule delay, strikes, technical challenges, inflation and local government pressures were major causes of cost escalations. In the survey by Chabota *et. al.,* (2008), among 60 participants, (23%) of respondents attributed cost escalation to bad weather, (73%) indicated to changes in scope, while (4%) to environmental protection and mitigation cost. However, Chabota *et. al.,* (2008) they did not investigate the extent to which these causes contributed to the cost escalations and therefore general mitigation measures were provided not addressing the specific causes.

Morris., (1990) and Kaming *et. al.,* (2007) argue, in their studies for cost overruns, that design changes, inadequate planning, unpredictable weather conditions and fluctuation in the cost of construction materials were the major sources of cost overruns in projects. Morris., (1990) and Kaming *et. al.,* (2007) did not address the magnitude of the cost overruns that were experienced and how projects can be better planned to handle the eventual occurrence of cost overruns.

Moris (1990) studied cost overruns in large construction projects and established that cost overruns are a regular future of public sector projects. Detailed findings showed that cost overrun 82% on average. With respect to the causes, 20-25% were attributed to price variations and the remaining 75-80% were explained in terms of real factors such as delays in implementation. Poor project design and implementation, inadequate funding of projects, bureaucratic indecision, and lack of coordination between enterprises were the major causes of cost overruns. This study however focussed on identifying the magnitude of total project cost growth and causes but did not address the extent to which each causative factor contributed to the cost growth for the project and how each could be mitigated through prediction since they are expected to occur.

Ashebir *et. al*., (2017), investigated the causes of cost overruns in the Federal road projects of Ethiopia. In the analysis of 40 factors responsible for cost overruns, questionnaires were distributed to 54 practitioners who ranked the significance of these factors. Findings showed that materials price fluctuations, inadequate review of contract documents, lack of coordination at the design phase, cost under estimation, delay in supply of raw materials and lack of cost planning during pre and post contract stage were the six top ranked factors. The research also revealed that cost overruns among selected projects extended from 4.16% to 83.2% with an average of 21.52%.

Kikwasi (2012), studied the causes and effects of delays and disruptions in construction projects in Tanzania and revealed the main factors to be design changes, delays in payment to contractors, information delays, funding problems, poor project management, compensation issues and disagreement on the valuation of work done. On the other hand, time overrun, cost overrun, negative social impact, idling resources and disputes are the main effects of delays and disruptions. The study concludes that there still exist a number of causes of delays and disruptions and their effects put construction projects at great risk that has an effect on their performance. It is therefore recommended that adequate construction budget, timely issuing of information, finalization of design and project management skills should be the main focus of the parties in project procurement process

2.7 Identification of Design Inadequacies

Most of the previous research glaringly concentrate on a number of factors which influence cost overruns, such as design changes, which have been reported to account for 5-8% of the total project cost (Cox *et. al.,* 1999). These design changes are a symptom of inadequate or ineffective designs provided during the tender stage (Anguyo, 2017). Through the author's review of different research publications and project documents, a number of design related flaws which could influence cost overruns have been identified and grouped in categories as shown in Table 2.1 below.

Table 2.1: Design Flaws which influence Cost Overruns

Category	Design Issue	Reference
SURVEYING& GEOMETRIC DESIGN	• Use of wrongly established benchmarks. • Errors in centreline setting out data • Discrepancies in original ground levels from those on the drawings • Errors in vertical alignment/discrepancies in design levels • Wrong/inappropriate choice of route (poor alignment design).	• Mfinanga (2014) • Apolot (2010) • Love et al, (2011a) • Tucker et al, (2004) • Alinaitwe et al, (2008) • Lopez *et al*., (2006)
SCOPING	• Non comprehensive definition of scope of works • Incomplete definition of employer's facilities • Addition of extra works not in the original scope	• Apolot (2010) • Ochen (2010) • Mfinanga (2014) • Chabota *et al*., (2008)
QUANTITIES ESTIMATION	• Wrong take off/ computation of quantities • Application of wrong price indices during estimation • Under estimation of rock fill materials • Omission of costs for utilities relocation (Electricity and Water)	• Anguyo (2017) • Mfinanga (2014) • Flyvbjerg et al, (2003) • Hobbs et al,(2003)
HYDROLOGY	• Under sizing of drainage culverts • Provision of less number of drainage culverts. • Culverts proposed in wrong locations and require shifting • Culverts proposed in locations which require bridges • Pipe culverts instead of box culverts proposed • Inappropriate provision or omission of drainage ditches/side drains. • Improper investigation of soundness of existing drainage structures. • Omission of scour checks especially in hilly areas	• Mfinanga (2014) • Oladapo (2007) • Josephson (2002)
MATERIALS AND GEOTECHNICAL	• Inadequate Materials Investigations • Inadequate Geotechnical Investigations • Poor/wrong specifications for pavement layers construction materials. • Omission of slope protection works. • Change in specifications for surfacing materials	• Apolot (2013) • Mfinanga (2014) • Kaming *et al*., (2007) • Hefdhallah (2013)
PAVEMENT DESIGN	• Change in Traffic Projections leading to variation in pavement layer thickness specification • Change from flexible to rigid pavements where necessary e.g. market areas or border posts	• Moris (1990) • Mfinanga (2014) • Azhar et al (2008) • Farrington (1987) • Robinson (2003)
ANCILIARIES	• Omission of provision of utility service ducts • Omission of provision for road furniture • Omission of pavement edge protection kerbs	• Bubshait et al,(2002) • Mfinanga (2014)

Source: Candidate's Literature Review

2.8 Model Development

A model is a representation of an object or a system (Myung & Pitt, 2002). Models are used in science to help explain how something works or to describe how something is structured. Models can also be used to make predictions or to explain observations (Myung & Pitt, 2002). Models can be physical, mathematical or a conceptual model. Physical models provide an illustration of what the reality is. Mathematical models may be made up of numbers, equations, or other forms of data. Mathematical models are tools that assist in theory development and testing. Models are theories, or parts of theories, formalized mathematically. They complement theorizing but their ultimate goal is to promote understanding of the theory, and thus behavior, by taking advantage of the precision offered by mathematics (Fagarand *et al.*, 2008). Conceptual models represent systems of ideas, compare unfamiliar things with familiar things to explain unfamiliar ideas.

The model development process involves the steps of model estimation, model calibration, model validation and model application as shown in *Figure 2.1*.

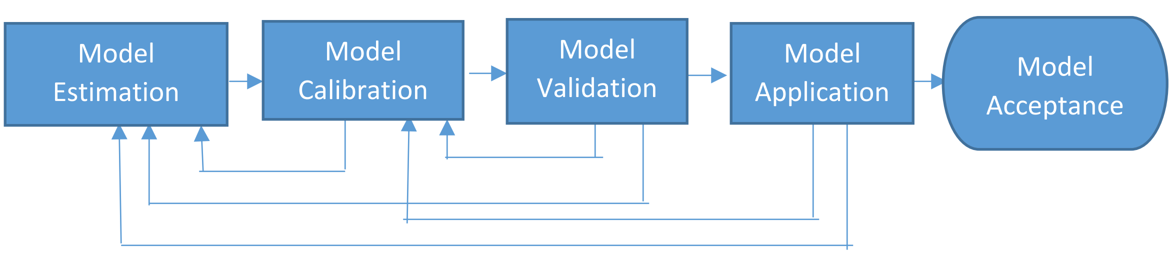

Figure 2.1: The Model Development process

(Source: http: tfresource.org)

2.8.1 Model Estimation

Model estimation is the use of statistical analysis techniques and observed data to determine model parameters or coefficients.

2.8.2 Model Calibration

Calibration on the other hand is a measure of how close the predicted values are to the observed values for any given configuration of the independent variables of the model (D'Agostino *et al.*, 1998). During model calibration, values of various relevant coefficients are adjusted in order to minimize the differences between model predictions and actual observed measurements in the field. Verification is performed to ensure that the model does what it is intended to do.

2.8.3 Model Validation

Model validation is the use of data to fit and test the model when demonstrating the generalizability of the model in order to use it to predict outcomes for future subjects (Hosmer & Lmeshow, 2000; Steven & Edwards, 1996). Ideally, validation is the task of demonstrating that the model is a reasonable representation of the actual system so that it reproduces system behavior with enough fidelity to satisfy analysis objectives. For most models, there are separate aspects to consider during model validation namely: assumptions, input parameter values and distributions, output values, and conclusions.

2.9 Literature Review Summary

Previous researches that attempted to discover reasons for the disparity between tender sum and the final account, such as Ashworth (1988) and Chabota *et al.,* (2008) did not investigate the extent to which causes such as variations in design and others contributed to the cost escalations and therefore general mitigation measures were provided not addressing the specific causes.

Morris *et al.,* (2006) and Kaming *et al.,* (2007) in their studies did not address the magnitude of the cost overruns that were experienced and how projects can be better planned to handle the eventual occurrence of cost overruns.

Moris (1990) studied cost overruns in large construction projects and established that cost overruns are a regular future of public sector projects. His study, however, focussed on identifying the magnitude of total project cost growth and causes, but did not address the extent to which each causative factor like design flaws contributed to the cost growth for the project and how each could be mitigated through prediction since they are expected to occur. Therefore, the next chapter three details a methodology for the research whose results are reported in Chapter 4.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the procedures and methods that were used to meet the objectives of the research.

3.2 Research Design and Approach

The research design was quantitative and the research approach involved two phases. Phase 1 involved a desk study to identify potential design flaws on projects. This was followed by a questionnaire survey to determine the severity and frequency of the design flaws. The design flaws were then ranked after computing their importance indices.

Phase 2 involved reviewing documents for completed paved road construction projects, as case study projects, to establish the existence of the five highly ranked design flaws and their contribution to the cost overrun on each project.

3.3 Questionnaire Development

Literature from previous research studies, articles, publications, design and construction reports as well as audit reports was reviewed, to identify and compile probable design flaws on paved road construction projects. From the review, thirty-seven (37) design flaws were identifed and categorised into seven (07) groups of surveying and geometric design, materials and geotechnical, hydrology, scoping, estimation of quantities, pavement design, and ancillaries based on the major professional specialities in highway engineering.

The design flaws identified in the literature review were used to generate a questionnaire. This questionnaire was administered to different road construction practitioners to determine the severity and frequency of design flaws on the projects they have implemented.

The questionnaire had two sections refer to appendix A, the first section capturing general information about the respondent (level of education, position, experience among others.) and their employing organization (Client, Consulting firm or Contractor) as well as the practitioner's work encounter with design flaws and cost overruns. The second section capturing how frequent the practitioner experienced design flaws and how the design flaws contribute to cost overruns.

3.4 Pretesting/Validity of the Questionnaire

The questionnaire was pretested before full scale survey. Five respondents with at least ten (10) years of experience were selected to study and answer the questionnaire and help in improving its wording, content and precision so as to increase the instruments' content validity. Five respondents were considered enough for pretesting so as to have more respondents available for a full-scale survey (Alinaitwe *et al*., 2008).

Content validity is the degree to which an instrument has an appropriate sample of items for the construct being measured (Mussio *et al*., 1973). The respondents were also asked to evaluate each question in the questionnaire and assign a score of either 1 or 0 for items they considered relevant and irrelevant respectively. The responses were tabulated and the number indicating relevant for each item was determined. The content validity ratio (CVR) for each question was calculated using Equation 3.1.

$$\mathrm{CVR} = {}^{\mathrm{Ne}}/_{\mathrm{N}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where: Ne is the number of experts indicating that the item is essential and N is the total number of experts.

The content validity index (CVI) for the questionnaire was then calculated using Equation 3.2 as the average of the content validity ratios for all items in the questionnaire.

$$\mathrm{CVI} = \sum_{1}^{\mathrm{N}} \mathrm{CVR}/\mathrm{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where: CVI is the content validity index, CVR is the content validity ratio for each question and N is the total number of questions in the tool. A question is considered valid when CVI is above 0.6 as the least recommended CVI in survey studies (Amin, 2004).

3.5 Reliability of the Questionnaire

Reliability refers to the quality of a measurement procedure that provides repeatability and accuracy. In this study, the Cronbach’s alpha was used as a measure of reliability. According to Santos (1999), alpha greater than 0.7 is required for the instrument to be acceptable. All questions in the questionnaire were coded and entered into the Statistical Package for Social Scientists (SPSS). Each response was entered using the numerical number assigned as required by SPSS. The Cronbach’s alpha value for the questionnaire was determined in SPSS.

3.6 Questionnaire Survey

The updated questionnaire was then administered to selected practitioners in the road construction sector. The survey package comprised of an introduction letter and a set of questionnaires as shown in Appendix A.

The respondents were asked to rate on a five-point Likert scale (1-5) both the frequency of occurrence and severity in terms of impact each of the identified design flaws has on cost. On frequency, 5 represented that the practitioner always experienced design flaws whereas 1 represented that the practitioner has never experienced a design flaw. On impact, 5 represented that the design flaw very significantly contributed to cost variation whereas 1 represented that the design flaw has no effect on cost variation. The questionnaires were distributed both physically in hard copy and electronically via mail.

3.7 Population of the Study

The questionnaires were administered selectively to engineers, construction managers, land surveyors and quantity surveyors who had been involved in at least two road projects while working with either road contractors, consulting firms or Uganda National Roads Authority (Client). This population was considered because it is these professions which deal with road construction works. The experience of at least two road projects was preferred in order to enable the practitioner give a comparison of the projects.

3.8 Sampling of Respondents

Experts (experienced members registered with their professional bodies) in the roads sector with experience in design, construction and for supervision of paved road projects were sampled from different engineering companies. Due to the need to get expert information concerning design flaws and cost overruns in road construction projects, the method that was adopted for sampling was purposive sampling. In Purposive sampling (also known as judgment, selective or subjective sampling), the researcher relies on personal judgment when choosing respondents to participate in the study basing on established requirements such as years of experience for this particular study.

3.9 Sample size

The average size of samples from previous similar studies guided in determining the sample size (Babatunde *et. al*., 2010; Barasa, 2014; Kikwasi, 2012; Saida Abbass & Okibo, 2014). A representative sample size constituting at least 10% of the population was taken which is consistent with Kothari (2004).

Selecting a sample that is representative of the population was guided by lists of members from Uganda Institution of Professional Engineers (UIPE) and Surveyors Registration Board (SRB). The membership numbers were 1035 UIPE corporate members, 44 registered quantity surveyors and 72 registered land surveyors, corresponding to a total population of 1151 all working for either client/UNRA, contractors or consulting firms. From this population, ten percent gave about 115 which was rounded upwards to a target number of one hundred and twenty (120) respondents. Thus, the target number of respondents to whom questionnaires were administered was 120 distributed amongst Contractors, Consultants and Clients.

3.10 Data Analysis

The data was manually processed to eliminate any omissions and errors that might have occurred in the process of data collection. This involved summarizing, comparing and generalizing. The questionnaire responses were input into the computer and analysed using SPSS software as well as MS Excel software.

The methods described hereafter were used to compute parameters namely Frequency Index (FI), Severity Index (SI) and Importance Index (II) required for establishing the major design flaws based on the respondents' responses.

3.10.1 Frequency Index

This represented how regularly the identified design flaws were encountered on projects. It was calculated using Equation (3.3) as adopted from (Al-Khalil & Al-Ghafly, 1999).

$$FI = \sum_{1}^{5} a_i f_i / N \qquad (3.3)$$

Where;

a_i = Constant expressing the weight assigned to each of the responses (range from 1 for never-5 for always);

f_i= frequency of each response and;

N= total number of responses.

3.10.2 Severity Index

This represented the effect that the identified design flaw had on the project cost. It was calculated using *Equation (3.4)* as adopted from (Al-Khalil & Al-Ghafly, 1999).

$$SI = \sum_{1}^{5} a_i s_i / N \ldots\ldots (3.4)$$

Where;

a_i = Constant expressing the weight assigned to each of the responses (range from 1 for no impact- 5 for very significantly);

s_i= frequency of each response on impact and;

N= total number of responses.

3.10.3 Importance Index

This was adopted for selecting the most significant (major) design flaws after rating. The Importance Index for each design flaw was calculated using *Equation (3.5)* (Al-Khalil & Al-Ghafly, 1999).

Importance Index (I.I) = $(FI \times SI) \times 100\%/25$ ………………………………….. (3.5)

The rationale for importance index was that the importance or significance of a design flaw is the combined effect of frequency and severity. The higher the Importance index value, the more significant the design flaw. Thus, two design flaws of the same frequency of occurrence would have the same significance if their score on the severity is equal. However, if one of the flaws had a more severe impact, then it would be considered more significant. Major design flaws were taken as those with II greater than 25. However, the five top ranked design flaws were selected for further study.

3.11 Case Study Projects

Documentation of completed paved road projects was reviewed to get more detailed information about the existence of the five highly ranked design flaws and their contribution to the cost overrun on each project. The projects whose documents were reviewed were those implemented and completed by UNRA in the period between 2008 and 2017 of minimum contract sum UGX 25 billion. A desk study of UNRA together with a discussion with the UNRA network development officials revealed that only 40 paved road projects had been completed by UNRA in the same period. However, documents on only sixteen (16) road reconstruction and upgrading projects could be found. The projects whose documentation could be traced are shown in *Appendix F*.

The documents reviewed included project report cards, original and revised bills of quantities, variation orders, final payment certificates, final account statements and project completion reports from supervising consultants.Due to the sensitivity of the information obtained, confidentiality of the projects' identity was ensured by coding with alphabetical letters from A-P.

Effect of Design Flaws on Project Cost Overrun

The original bill of quantities was reviewed to identify bill items associated with each of the five highly ranked design flaws identified in the questionnaire responses (See Table 3.1). Project report cards, final payment certificates, consultants' final account statements and project completion reports for all the projects were also reviewed to establish the original project cost, final project cost and any approved variations and claims associated with each of the design flaws.

From the original project cost and the final project cost established, the total project cost overrun was calculated as the difference between the original cost and the final cost. The effect of each design flaw in a particular project was then calculated as the ratio of the cost variation due to each of the design flaw to the total project cost overrun expressed as a percentage. The descriptive statistics (Mean, variance and standard deviations) for the data from all the case study projects were computed.

Table 3.1: Design Flaws and their related Cost Implications

SN	Design Flaws	Cost Implications
11	Provision of less number of drainage culverts	• Increase in cost for pipe culverts purchase/fabrication • Increase Excavation costs for culvert installation • Increase Backfilling costs • Increase in Cost of construction of box culverts and associated structures
19	Inadequate Geotechnical Investigations for road subgrade	• Increase in cost of common excavation to spoil • Increases cost due to Increase in volume of excavation in swamps and wetlands to spoil • Increased cost due to increase in quantity of geotextile materials • Increase in cost due to increase in quantity of rock excavation • Additional costs sanctioned for further geotechnical investigations.
33	Under estimation of quantities for Earthworks like rock fill	• Increase in cost due to rock fill for swamps and wetlands • Increase in cost due to rock fill for foundation of structures (culverts and bridges) • Increased cost due to introduction of pioneered layers
5	Less volumes of cut and fill provided	• Increase in cost due to increase volume of pavement layers cut and fill material (G3, G7 and G15 material)
18	Inadequate Quarries and Earthen Materials Investigations	

The effect of inadequate quarries and earthen materials investigations on project cost overrun could not be studied and modelled. This is because there was no documentation filed on this design flaw. Therefore, only four design flaws were studied and modelled.

3.12 Model Development

3.12.1 Determination of Model Parameters

The model parameters contained the cost variations for each of the four highly ranked design flaws as the independent variables. The four design flaws were; 1) provision of less number of drainage culverts, 2) inadequate geotechnical investigations for road subgrade, 3) under estimation of quantities for rock fill and 4) estimation of less volumes of cut and fill. These were coded D_c, G_s, R_f and V_{cf} respectively. The total project cost overruns as obtained from the case study projects were the dependent variables and these were coded P_{co}.

3.12.2 Regression Analysis

The values of the independent and the dependent variables were entered into Microsoft excel for analysis. Using the analysis tool pack, a multiple linear regression was run at 0.05 level of significance. Multiple regression analysis was selected to enable the researcher to assess the association between two or more of independent variables (overrun from each design flaws) and a single continuous dependent variable (total project cost overrun in this case).

A regression model for predicting the total project cost overrun was developed using the regression coefficients from the regression analysis.

This predictive model is a regression equation in which the total project cost overrun (P_{co}) is expressed in terms of the effect of significant major design flaws (D_c, G_s, R_f and V_{cf}) and a constant representing other factors which cause cost overruns including other design issues which are not among the evaluated.

3.12.3 Checking for Overall significance of the model

After running the regression, the overall significance (F) from the ANOVA for the model variables was checked. Significance F represents the acceptability of the model and its ability to reliably predict the dependent variable (total cost overrun) from the independent variables. Where the significance F is less than or equal to 0.05, the model is considered significant with a better predictive power. This means that there is a probability of up to 5% of having no relationship between the cost overruns due to the evaluated design flaws and total project cost overruns.

3.12.4 Checking significance of the Independent Variables (Design flaws)

The significance value (P-Value) of each design flaw in the model was examined. The P-Value indicates the influence which a particular design flaw has in predicting the total project cost overruns when considered alone by keeping others constant. Design flaws with P-values of less than or equal to 0.05 were considered significant predictors, those with P-values between 0.05 and 0.1 were considered to have a marginal impact while those with P-Values greater than 0.1were considered to have negligible impact in predicting cost overruns when considered alone. This P-value for each design flaw indicates whether that design flaw is a significant predictor of the total project cost overrun over and above the other design flaws being considered in the model.

3.12.5 Checking Coefficient of Determination and Correlation Coefficient

The coefficient of determination (R-square) was checked after running the regression analysis. R-square value gives an indication of how the variance in the total project cost overruns are accounted for by the joint predictive power of the design flaws.

An R^2 value of 0 means that the dependent variable cannot be predicted using the evaluated independent variables while R^2 of 1 means the dependent variable can perfectly be predicted from the independent variable.

The correlation coefficient (R) was checked to examine the correlation between the independent variables (Overruns due to design flaws under evaluation) and the total project cost overrun. Where R is equal to 1, the model is highly correlated and where R is equal to -1, the model is negatively correlated and therefore, no positive relationship can be obtained between the variables.

3.12.6 Checking Regression Coefficients

Regression coefficients indicate the direction and magnitude by which the total project cost overrun is affected by a unit change in the amount resulting from each of the design flaws under study. Two kinds of coefficients were used, that is, the un- standardised β and the standardised β. The unstandardized β weight associated with each variable is in terms of the units of measure for that variable while the standardized β is a standard unit of measure, which the same for all variables used in the model. Therefore, the standardised β was used in the model.

3.12.7 Model Calibration and Validation

Model calibration involved adjustment of constants and other model parameters in estimated model to make the model replicate observed data or otherwise produce more reasonable results. Model validation involved use of fresh data to test the predictive ability of the model under investigation.

The use of data to fit and test the model is preferable when demonstrating the generalizability of the model in order to use it to predict outcomes for future subjects (Hosmer & Lmeshow, 2000; Steven & Edwards, 1996). This type of assessment is called Model validation. Calibration on the other hand is a measure of how close the predicted values are to the observed values for any given configuration of the independent variables of the model (D'Agostino *et al*., 1998).

For a given configuration **X** of the independent variables, perfect calibration results in a prediction of the positive outcome that numerically agrees with the observed frequency of the event when that configuration occurs. Model validation can be externally or internally although the most reliable, stringent and unbiased test for model and for the entire data collection process is external validation (Giancristofaro & Salmaso, 2003; Arlot & Celisse, 2010). The most common credited methods for obtaining a good validation of a model's performance are: data-splitting, repeated data splitting, jack-knifing technique and bootstrapping etc. The current study used the external validation and was based on fresh data collected from five completed paved road projects shown in Table F.3 in the appendix.

3.13 Ethical Considerations

Informed consent of relevant organisations and persons was sought to access information from them. This was after obtaining an introduction letter from the university.

Strict confidentiality was ensured of the information which was used for research purposes only. This involved concealing the identities of the projects studied by giving them hypothetical names such as Project A, B, C and so on (i.e. coding).

In addition, the identities of the respondents were kept anonymous and all the information from them was strictly kept confidential and used only for the purpose of the research.

The letter of ethical consideration is shown in *Appendix C*.

3.14 Chapter Summary

A total of 37 design flaws encountered during construction were identified from literature. A survey was conducted using a structured questionnaire involving 120 professionals' who were requested to rate the design flaws frequency of occurrence and impact on cost using a five-point Likert scale basing on experience. Using data from 16 completed paved road projects, the effect of the major design flaws was established. Using Ms Excel, a regression model for predicting impact of the design flaws was developed and validated using external data validation based on newly collected data from five projects.

CHAPTER FOUR

PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

The results from the questionnaire survey, the case study projects and the process of developing a regression model for predicting impact of the design flaws have been presented in this chapter. Analysis and discussions of findings have been presented based on generally agreed engineering principles and in relation with other scholars.

4.2 Validity of the Questionnaire

Validity of the questionnaire evaluated based on the content validity index. Results from the analysis are shown in appendix E, Table E-1. From the assessment of five respondents, a content validity index of 0.883 was obtained. This content validity index is greater than the 0.78 recommended for items in the questionnaires to be included in the tool (Mussio *et al*., 1973). This content validity index indicates a significant agreement between the five respondents who pretested the questionnaire on the items retained.

4.3 Questionnaire Response Rate

A total of 120 questionnaires were distributed amongst consultant, contractor and UNRA staff, out of which 74 were returned. As shown in Table 4.1, the response rate of the questionnaire survey was 61.7%. This indicates a non-response bias of 38.3 %. According to Richardson (2005), a response rate greater that 50% is considered acceptable, and therefore the obtained response rate of 61.7% shows that the information obtained is acceptable and representative enough.

Table 4.1: Distribution of Questionnaires and Response Rate

Respondents Category	Distributed	Received	Response Rate
Client	35	22	62.9%
Consultant	40	27	67.5%
Contractor	45	25	55.6%
Total	**120**	**74**	**61.7%**

4.4 Reliability Analysis

The results for the analysis of the reliability of the questionnaire based on the Cronbach's Alpha value for all the variables (37 items) are shown in *Table 4.2*.

Table 4.2: Results of Reliability Analysis

Variables	Cronbach's Alpha
Frequency of Design Flaws/Inadequacies	0.728
Impact on Cost of Projects	0.961

The Alpha Cronbach values obtained were 0.728 and 0.961 for the frequency of design flaws and impact on cost of projects respectively. These values were greater than the minimum of 0.7 required for results to have significant reliability as per Nunnally (1978) and Santos *et al*., (1999). Therefore, the data from frequency and severity rating of the design flaws was reliable and capable of generating similar results when used more than once.

4.5 Respondents' Profiles

The characteristics of the respondents which included nature of employing organisation, profession, level of education, years of experience and experience on design flaws in projects they implemented are presented in the subsequent sub-sections. These characteristics helped to ensure quality of the responses obtained.

4.5.1 Nature of Employing Organisation

The distribution of responses as per the nature of employing organization that is UNRA, Consulting firm or Contractor is as shown in *Figure 4.1*. The biggest portion of respondents was 36.5% followed by 33.8% from consultants and contractors, respectively. This response provides better reliability for the data obtained since it is the consultants and contractors who implement road works on project sites on behalf of the client, facing these design issues from time to time so they could easily explain how they were addressed.

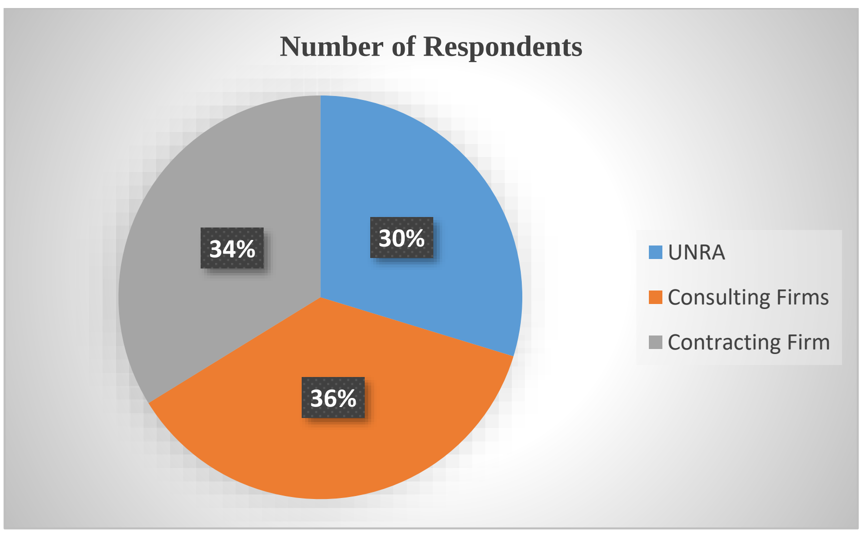

Figure 4.1: Nature of Respondents' Employing Organization

4.5.2 Respondents' professions

The professions of the respondents are as shown *Table 4.3*. As indicated in the table, the largest portion of responses were received from civil engineers followed by construction managers. This large number of responses (75.7%) from civil engineers is probably an indication of interest in the research topic and also provided more confidence in the results obtained since the civil engineers are principal in the design and construction of roads and therefore, they understand the subject matter well.

Table 4.3: Respondents' profession

Profession	Frequency	Percentage (%)
Civil Engineering	56	75.7
Construction Management	8	10.8
Quantity Surveying	5	6.8
Others	5	6.8
Total	**74**	**100**

4.5.3 Respondents' levels of Education

The respondents' level of education is as shown in *Table 4.4*. Results indicate that the largest portion of respondents (75%) had degree while 18.9% possessed postgraduate qualifications. This shows that the respondents have had at least the basic training required to comprehend engineering design and project management aspects, and therefore were knowledgeable enough in the subject area of this research.

Table 4.4: Respondents' level of education

Level of Education	Percentage (%)
Diploma	5.4
Degree	75.7
Postgraduate	18.9
Total	**100**

4.5.4 Years of Experience in road works

Results shown in *Table 4.5* indicate that 39.2% of the respondents had experience between 10 – 15 years while 32.4% had experience of between 15-20 years. This implies that the respondents had experience in either the design, construction or supervision of at least one road project and therefore could probably provide insight and comparison into their experience with design flaws and costs on the different projects which they implemented.

Table 4.5: Respondents level of experience

Years of Experience	Frequency	Percent (%)
5-9	20	27.0
10-15	29	39.2
16-20	24	32.4
21 and above	1	1.4
Total	**74**	**100**

4.5.5 Respondents' positions

Of the respondents, 28% have been resident engineers or deputy resident engineers, 16% project managers, 14% project engineers while 14% held other positions which include among others materials engineers, work inspectors and structural engineers as shown in Figure 4.2.

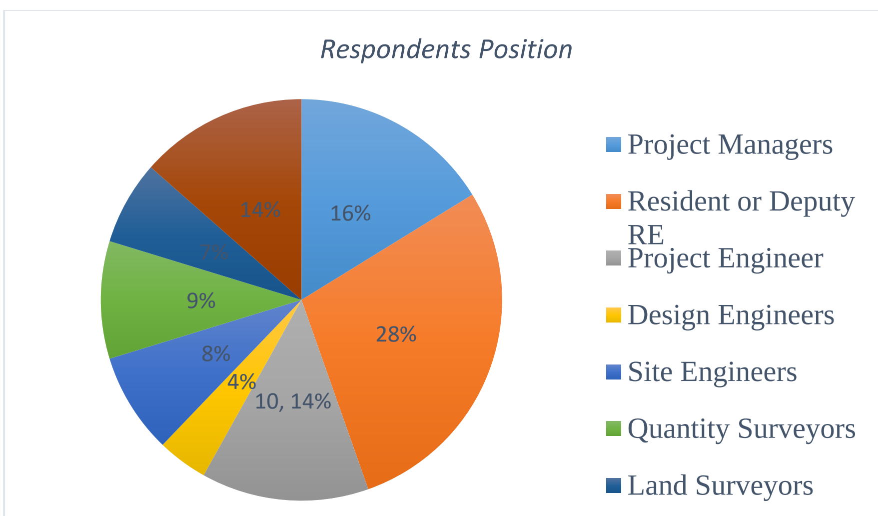

Figure 4.2: Respondents Position

This high number of responses from resident and deputy resident engineers provides more reliability for the data collected because on most projects, it is the resident engineers who are responsible for reviewing and making a determination on some of the design changes identified, advising on the cost implication and recommending approval of the design changes.

4.5.6 Experience with Cost Overruns

The results for respondents' experience with cost overruns on projects are shown in *Table 4.6*. On this, 98.6% of the respondents acknowledged that the road projects they implemented suffered cost overruns while only 1 respondent was on a project which had no cost overrun.

Table 4.6: Experience with Cost Overruns

Response	Frequency	Percentage (%)
Yes	73	98.6%
No	1	1.4%
Total	**74**	**100%**

4.5.7 Average Cost Overruns on Projects

Results for responses on average cost overruns on projects implemented are shown in *Figure 4.3*. Results indicate that the majority of the respondents had projects with average cost overrun ranging between 10% and 25%.

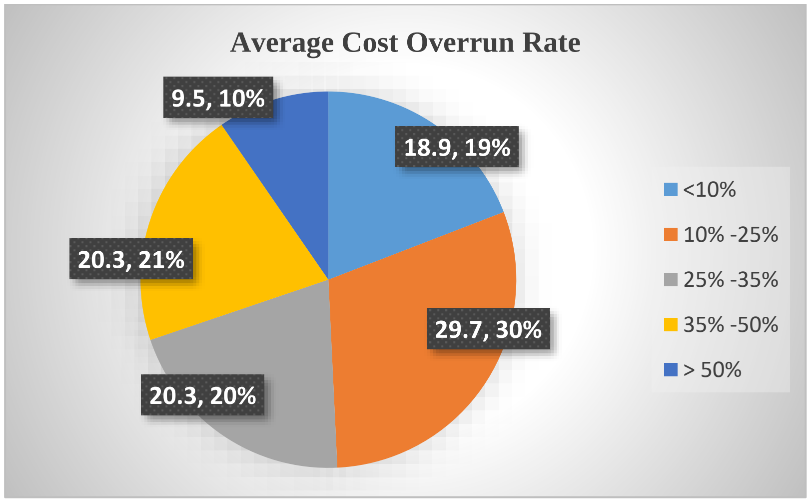

Figure 4.3: Average Cost Overrun Rate Experienced

Results indicate that projects experienced cost overruns between 10% and 50% on average as consented by 70.3% of the respondents. This is lies within the findings of Mfinanga (2013) which studied the effect of inadequate designs on both schedule and cost overruns in Tanzania and established the average cost overrun on road construction projects ranged between 9% and 97%.

4.5.8 Experience with Design Flaws

Responses on whether any design issues that affected project cost were encountered during construction are shown in Table 4.7. Results indicate that for 97.3% of the respondents, their projects had design flaws which affected the project cost while only 2.7% were on projects without design flaws.

Table 4.7: Experience with Design Flaws/Inadequacies

Response	Frequency	Percentage (%)
No	2	2.7%
Yes	72	97.3%
Total	**74**	**100.0%**

On the category of design flaws mostly experienced and affected cost, responses were as summarised in *Table 4.8*.

Table 4.8: Design Flaw Categories

Category	**Not Encountered (%)**	**Encountered (%)**
Survey and Geometric Design	86.5	13.5
Materials &Geotechnical Investigations	58.1	41.9
Hydrology	81.1	18.9
Scoping	64.9	35.1
Estimation	86.5	13.5
Pavement design	82.4	17.6
Others	98.6	1.4

Of the respondents, 41.9% indicate that design flaws relating to materials and geotechnical investigations are mostly experienced and affect project cost. Meanwhile, 35.1% of the respondents experienced issues related to project scoping and 18.9 % of the respondents acknowledge that issues were connected with hydrology.

This result implies that while designing, materials and geotechnical investigations, project scoping and hydrological assessments greatly influence cost variations on projects and therefore should be handled meticulously, accorded ample time and budget to avoid their occurrence during construction. This revelation is in agreement with results presented by

Kirby., (1988) and Lutz., (1989) in which respondents indicated that a significant portion of cost overruns (30%) originate from defective designs.

4.6 Ranking of Design Flaws

Ranking was based on the importance index obtained from the respondents rating of the 37 design flaws identified. *Tables 4.9* and *Table 4.10* summarise the results obtained showing the Frequency Index (FI), Severity Index (SI), Importance Index (II) and the ranking of the design flaws per design category and overall ranking respectively.

4.6.1 Ranking Based on Design Category

The 37 design flaws identified and ranked were organised into seven (07) design categories namely: Surveying and geometric design, Hydrology, Materials and geotechnical, Pavement design, Scoping, Quantities estimation and Ancillaries. The results of the rankings per category are as shown in *Table 4.9*.

Table 4.9: Ranking of Design Flaws per Design Category

Design Category	SN	Identified Design Flaws	FI (Max 5)	SI (Max 5)	II (Max 100)	Rank
Surveying and Geometric Design	**1**	**Use of wrongly established benchmarks**	**1.84**	**2.12**	**15.6**	**9**
	2	**Error in Centreline Setting out Data**	**2.00**	**2.13**	**17.0**	**8**
	3	Discrepancies in original ground levels from those on drawings	2.69	2.24	24.1	4
	4	Errors in vertical alignment/Discrepancies in design levels	2.54	2.24	22.7	5
	5	**Less volumes of cut and fill provided**	**3.27**	**2.25**	**29.4**	**1**
	6	Omission of parking facilities (Bus bays and Urban Parking Lanes).	2.78	2.32	25.9	3
	7	Omission of climbing lanes where necessary	2.26	2.19	19.8	6
	8	Inappropriate choice of route/changes in horizontal alignment	2.27	2.06	18.7	7
	9	**Omission of vehicular and pedestrian accesses**	**3.10**	**2.26**	**28.0**	**2**
Hydrology	10	Under sizing of drainage culverts	2.42	2.17	21.0	5
	11	**Provision of less number of drainage culverts**	**3.81**	**2.49**	**37.9**	**1**
	12	**Culverts proposed in wrong locations and require shifting**	**2.80**	**2.25**	**25.2**	**2**
	13	Culverts proposed in locations which require bridges necessitating change	2.28	2.11	19.3	6
	14	**Pipe culvert proposed instead of box culvert**	**2.26**	**2.08**	**18.8**	**7**
	15	Omission of drainage ditches/side drains	2.65	2.28	24.2	3
	16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)	2.85	2.00	22.8	4
	17	**Omission of scour checks especially in steep areas**	**2.24**	**1.81**	**16.2**	**8**
Materials and Geotechinical	**18**	**Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances**	**3.32**	**2.72**	**36.1**	**1**
	19	**Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties**	**3.23**	**2.72**	**35.1**	**2**
	20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations	2.37	2.00	19.0	7
	21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks	3.34	1.85	24.7	3
	22	**Poor/wrong specifications for pavement layers construction materials**	**2.39**	**1.86**	**17.8**	**8**
	23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)	2.85	2.07	23.6	5
	24	**Changes in specifications for surfacing materials**	**2.49**	**1.70**	**17.0**	**9**
	25	Omission of culvert backfill concrete surrounding	2.40	2.00	19.2	6
	26	Change in specifications for concrete works	2.72	2.24	24.4	4
Pavement Design	27	Change in Traffic Projections leading to variation in pavement layer thickness specification	2.92	2.07	24.1	1
	28	Change flexible to rigid pavements where necessary e.g. market areas or border posts	2.18	2.11	18.3	2
Scoping	29	Incomplete/Inadequate definition of employers facilities	2.36	1.65	15.6	2
	30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc	3.62	2.03	29.4	1
Estimation	31	Wrong take off / computation of quantities	2.64	1.82	19.2	4
	32	**Application of wrong prices during estimation (wrong application of price indices)**	**3.46**	**1.89**	**26.2**	**2**
	33	**Under estimation of quantities for Earthworks like rock fill**	**3.15**	**2.41**	**30.3**	**1**
	34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)	3.35	1.88	25.2	3
Ancillary	**35**	**Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)**	**3.00**	**2.11**	**25.3**	**2**
	36	Omission of provisions for road furniture like mark posts, sign posts, marking	1.93	1.88	14.5	3
	37	**Omission of pavement edge protection Kerbs**	**2.76**	**2.35**	**26.0**	**1**

Results show that within the surveying and geometric design category, Provision of less volumes of cut and fill was the highest ranked with an Importance Index of 29.4%. The second ranked was omission of vehicular and pedestrian accesses which had an Importance Index of 28.0%. The least ranked design flaw under this category was use of wrongly established benchmarks and had an II of 15.6%. Experts argued that they rarely encountered situations where wrong benchmarks are used but, in the event, that this happened, the impact on cost would be exhibited through resurveying.

In the category for hydrology, provision of a smaller number of drainage culverts was the highest ranked design flaw experienced during construction and had an II of 37.9%. This result is probably attributed to the fact that during detailed design for the projects, more concentration is put on the locations with already existing culverts and introduction of new culvert locations to increase hydraulic capacity for the roads is often ignored. In addition, the need for specialist hydrologists in projects is often ignored. Interactions in the various organizations during data collection, hydrologists employed were either very scares or not there. The second ranked design flaw in this category was proposing culverts in wrong locations i.e. at chainages which do not require culverts hence the need for shifting with an II of 25.2%. This is probably attributed to the additional costs incurred in transfer and installation of the culverts. The least ranked design flaw in this category was omission of scour checks especially in steep areas. It had FI of 2.24, SI of 1.81 and II of 16.2%. This is probably because most of the roads that have been constructed in Uganda are not located in areas with hilly terrain, therefore a low frequency index. Where the scour checks are introduced, their cost is not always significant because they are incorporated in the cost for constructing side drains, hence a very low severity index.

Under the materials and geotechnical investigations category, inadequate materials investigations especially provision of locations with less quantities, sources with inferior quality materials and long haulage distances was the highest ranked and had an II of 36.1%. This response is probably due to the fact that there is no comprehensive investigation of material sources and only those along the designed alignment are considered and the depths investigated were not sufficient to validate the availability of significant quantities of good quality materials. The second ranked design flaw in the category was inadequate geotechnical investigations for the road subgrade e.g. shallow depth of test pits and large spacing between test points and had an II of 35.1%. This subgrade investigation mainly affects the earthworks for the road works such as determining the extent of common excavation to spoil and proposals for ground treatment among others. This finding is in agreement with Amadi *et.al*., (2016) who established that latent pathogens such as heterogenous ground condition and non-adherence to geotechnical best practices account for the majority of the recorded variance between initial cost estimates and project final accounts.

The least ranked in the materials and geotechnical investigations category were wrong specifications for pavement layer construction materials and change in specifications for surfacing materials, with FI of 2.39 and 2.49, SI of 1.86 and 1.70, and II of 17.8 and 17.0

respectively. This is attributed to the fact that the nature of pavement materials is mainly informed by the traffic loading classes which are determined during design and can be predicted more accurately. Though studies on cost overruns in infrastructure projects (Chantal *et. al*., 2010 & Fouracre *et. al*., 1990) identified change in specifications among the top five causes of cost overruns, they are not explicit on the specific change that affects the project cost.

Under scoping, the most important factor was addition of extra works which were not part of the original contract. It had an FI of 3.62, SI of 2.03 and II of 29.4%. Professionals attributed this to poor planning/prioritization and incomplete definition of the terms of reference and political pressures. This finding is in strong agreement with Cho *et. al*., (2001) who indicated poor scope as one of the leading causes of project failure through introduction of extra works and can result in around a 20% financial loss if not well defined at inception.

In the estimation category, underestimation of the volumes of rock fill was the highest ranked followed by wrong application of price indices. Underestimation of volumes of rock fill is attributed to the inadequate geotechnical investigations especially in the swamps and low-lying areas which often require provision of rock fill as pioneer layers and as foundations for drainage structures. This establishment is in agreement with Karunakaran *et.al*., (2018) study on categorization of potential project cost overrun factors in which established underestimation of quantities as one of the major causes of cost overruns in projects. A study conducted by Mansfield *et. al*., (1994) on the causes of cost overruns in highway projects is also in tandem with these results by acknowledging that inaccurate estimation of materials quantities is among the major variables that lead to excessive project cost overruns.

The last category was ancillary; in this category, omission of pavement edge protection kerbs was the most important design issue encountered followed by omission of provisions for services and utility ducts (water, power, cables, etc). Fouracre *et. al*., (1990) in his investigation of cost overruns in metro projects worldwide revealed that most cost overruns were attributed to additional costs of unforeseen services and utility diversions. However, his finding is quite divergent with this study in which the impact of omission of these utilities is considered not significant in terms of project cost variation.

4.6.2 Overall Ranking of Design Flaws

The results of the overall ranking of design flaws irrespective of respondents' groups or design category are shown in *Appendix 6*. The five top ranked design flaws with the highest importance index based on the questionnaire responses were identified as summarised in *Table 4.10*.

Table 4.10: Overall Rank of Design Flaws

CATEGORY	DESIGN FLAWS	FI	SI	II (%)	Rank
Hydrology	Provision of less number of drainage culverts	3.81	2.49	37.92	1
Materials and Geotechnical	Inadequate Quarries and earthen materials Investigations	3.32	2.72	36.08	2
Materials and Geotechnical	Inadequate geotechnical Investigations for road subgrade	3.23	2.72	35.08	3
Estimation	Under estimation of quantities for Earthworks like rock fill	3.15	2.41	30.36	4
Surveying and Geometric	Less volumes of cut and fill provided	3.27	2.25	29.4	5

Results indicate that provision of less number of drainage culverts was the highest ranked design flaw experienced during construction of road projects with an importance index of 37.92%. This could be probably due to non-comprehensive hydrological design culminated by lack of meticulous assessment of the drainage locations during detailed engineering design and design review stages. This design flaw could be solved probably by requiring consultants to assign specialist hydrologists on all road projects. This will enable provision on well informed and factual designs for the roads intended for construction. This is consistent with the findings of the study conducted by Mfinanga (2013) on design inadequacies in Tanzania road construction industry where it was established that inadequate hydrological investigations existed in all projects and fewer culverts were always provided than actually required.

The second ranked design flaw was inadequate quarries and earthen material sources investigations and had importance index 36.08%. It was highlighted that the sources identified during detailed design always have limited quantities of good quality materials while those with sufficient quantities are always located far from the project alignment. The existence of this design flaw could be because of the time provided to the materials and geotechnical team during the design of the road projects which lead to un comprehensive and detailed investigations to establish the extents and locations of good quality materials. This has a cumulative effect on the cost of investigation for new sources, over haul transportation cost and cost of purchasing a number of earthen material sources. Existence of this design flaw could be addressed probably through the creation of an independent geotechnical and materials department in all road implementing agencies so that detailed material sources investigations are conducted in house prior to the construction phase.

The third and fourth ranked design flaws were inadequate investigation of road subgrade (shallow depth of test pits, large intervals between test points, etc.) and under estimation of volumes of rock fill with importance index of 35.08% and 30.36% respectively. This is because less time and attention is given to detailed and meticulous geotechnical investigations during the project design phase. Investigations of the road subgrade especially in swamps and wetlands are done at larger intervals. This implies that these design flaws significantly affect the project cost once encountered on the project. This result is in agreement with the findings of Hefdhallah *et. al., (*2013) on the effect of inadequate soil investigations on the cost and time in a construction project which established that inadequate investigation of subsurface layers significantly affect project cost.

The three least ranked design flaws were omission of provision of road furniture, use of wrongly established bench marks and incomplete definition of employer's facilities which had importance indices of 14.5,15.6 and 15.6 respectively. Omission of provision of road furniture is least ranked probably because road furniture is linked to the geometric design and the road design criteria which incorporates and caters for this furniture. Benchmarks are referenced on the national grid and normally surveyors can easily crosscheck the coordinates against the national and universal grid. Therefore, it was very rare to find wrongly established benchmarks on projects. Fouracre *et. al*., (1990) in his investigation of cost overruns in metro projects worldwide revealed that most cost overruns were attributed to additional costs of unforeseen services and utility diversions; their finding is quite divergent with this study in which the impact of omission of these utilities is considered insignificant in terms of project cost variation.

4.7 Case Study Projects

Paved road projects that had a cost overrun of at least 10% were considered as case study projects. This was selected based on the questionnaire survey in which 79.8% of the respondents had projects with average cost overrun of at least 10%. The results are discussed in the subsequent sub-sections.

4.7.1 Occurrence of the Major Design Flaws on Projects

Findings on the existence of the most highly ranked design flaws on projects are shown in *Table 4.11*.

Table 4.11: Occurrence of Design Flaws in Projects

Project ID.	Design Flaw/Inadequacy			
	Provision of less number of drainage culverts (11)	Inadequate Geotechnical investigations for road subgrade (19)	Underestimation of rock fill quantities (33)	Provision of less volume of cut and fill (5)
A	√	√	√	√
B	√	√	√	√
C	√	√	√	√
D	√	√	√	√
E	√	√	√	√
F	√	√	√	√
G	√	√	√	√
H	√	√	√	√
I	√	√	√	√
J	√	√	√	√
K	√	√	√	√
L	√	√	√	√
M	√	√	√	√
N	√	√	√	√
O	√	√	√	√
P	√	√	√	√
Total Frequency of Occurrence	16	16	16	16

Results indicate that provision of less number of drainage culverts, inadequate geotechnical investigations for road subgrade, underestimation of rock fill quantities, and provision of less volume of cut and fill, occurred in all the case study projects reviewed. This finding is in affirmation with the Uganda Auditor General technical audit reports of 2010, 2014, 2015 and 2017 on selected UNRA projects; which reported that there were significant increases in quantities of works mainly culvert installations, rock fill and fill quantities for pavement layers (Muwanga, 2010,2014,2015,2017)

These design flaws occurred on all projects probably because there is very little time and budget allocated to their detailed examination during the design phase so as to enable proper scrutiny of these design aspects.

These design flaws should be critically addressed by probably providing ample time for design, dedicating personnel to handle each specific item separately, increasing the quality control levels during design and by providing a provisional sum to cater for any uncertainties. These interventions will probably provide better design output and reduce emerging changes during construction which affect the project cost performance.

4.7.2 Project Cost Overruns

All projects reviewed experienced a cost overrun ranging between 9.8% and 74.5% with the average cost overrun being 33.5% as shown in *Table 4.12*. This implies that on average, the project cost will go beyond the original planned value by 33.5%. This indicates that projects without adequate budget over and above the tendered price will probably be delayed in completion pending availability of funds or lead to reallocation of funds from other projects leading to delayed service delivery to the end users.

Table 4.12: Project Cost Overruns and Overruns due to the Four Design Flaws

PROJECT ID	Project Contract Sum (Billion UGX)	Total Project Cost (Billion UGX)	Project Cost Overrun (Billion UGX)	Cost Overrun Rate (%)	Overrun due to the four design flaws (Billion UGX)	Overrun Rate due to the four design flaws (%)
A	211.69	272.19	60.50	28.58	20.03	24.10
B	242.64	273.26	30.62	12.62	17.55	49.11
C	221.37	243.02	21.65	9.78	8.72	40.30
D	134.39	199.01	64.62	48.09	27.91	19.90
E	97.48	112.72	15.24	15.64	3.99	21.20
F	168.21	233.07	64.85	38.55	23.48	28.70
G	134.68	168.25	33.57	24.92	9.63	28.70
H	147.07	189.95	42.89	29.16	23.89	48.70
I	165.15	239.66	74.51	45.12	22.13	29.70
J	34.87	42.38	7.50	21.51	2.44	32.47
K	184.38	207.68	23.30	12.64	5.85	25.10
L	132.12	145.60	13.48	10.20	10.66	29.10
M	30.29	57.14	26.85	88.66	10.23	13.10
N	46.08	60.83	14.75	32.00	4.79	15.50
O	25.10	41.77	16.67	66.40	12.09	72.57
P	92.00	140.56	48.56	52.78	31.18	55.15
Average			**34.97**	**33.54**	**11.41**	**33.34**
Standard deviation			**21.58**	**22.25**	**7.78**	**9.75**

The cost overrun rate due to the four design flaws studied ranged between 13.1% and 72.6% with average of 33.3% and standard deviation of 9.8%. This result implies that in every project, 33.3% of the cost overrun can be explained by the four study design flaws while the 66.7% of the cost overruns are accounted for by the 33 identified design flaws and other causative factors for cost overruns. The result shows that though the studied four design flaws contribute to the cost overruns, the majority of the cost overruns are not from these major four, but rather from the remaining 33 design flaws combined with other non-design issues coherent in projects management. Therefore, addressing the four design flaws only reduces the extent of cost overrun by 33.3% and these should be addressed together with other cost overrun factors for better results.

The results are in agreement with the findings of the study conducted by Vidalis *et al*., (2014) on the causes of cost overruns in 708 highway projects for the Florida Department of transportation where it was established that 39% of the cost overruns were due to errors in designs and modifications while 61% were due to other factors. The results are also in tandem with the findings of a study by Andi and Takayuki, (2002) on the impact of design document quality on the construction process which established that 30% of total rework and cost overruns were caused by defective designs.

4.7.3 Effect of each Design Flaw on Cost Overrun

Results for effect of each design flaw in terms of contribution to the total project cost overrun are presented in *Table 4.13*. The biggest effect is from increase in quantity of rock fill with average of 11.0%, followed by increase in volume of cut and fill (8%), and inadequate geotechnical investigations for the road subgrade (7.6%). The design flaw with the least effect was increase in costs due to increase in number of drainage culvers with an average contribution of 6.7%. These results imply that increasing the quantity of rock fill should as much as possible be minimised as it greatly increases the project cost.

Table 4.13: Effect of Each Design Flaw on Cost Overruns

Design Flaw ID		**11**	**19**	**33**	**5**
Description		Increase in number of culverts	Inadequate Geotechnical Investigations for road subgrade	Increase in Quantity of Rock fill	Increase in volumes of cut and fill
PROJECT ID	Total Project Overrun Rate (%)	**Contribution to Project Cost Overrun (%)**			
A	28.6	3.3	6.9	7.4	6.5
B	12.6	17.8	9.2	12.2	9.9
C	9.8	12.1	7.8	9.1	11.3
D	48.1	4.2	6.9	7.2	1.6
E	15.6	6.3	5.1	7.2	2.6
F	38.6	8.2	7.4	8.0	5.1
G	24.9	5.2	6.3	10.1	7.1
H	29.2	3.5	12.2	15.0	18.0
I	45.1	4.7	7.5	10.2	7.3
J	21.5	4.6	12.1	7.5	8.2
K	12.6	3.1	6.3	12.4	3.3
L	10.2	7.1	8.1	6.4	7.5
M	88.7	8.0	2.0	3.0	0.1
N	32.0	4.0	1.5	9.0	1.0
O	66.4	0.3	21.9	30.1	20.2
P	52.8	15.4	0.4	20.4	18.9
Average (%)	**33.5**	**6.7**	**7.6**	**11.0**	**8.0**
Standard Deviation (%)	**22.3**	**4.7**	**5.0**	**6.5**	**6.3**

4.8 Predictive Model for Cost Overruns

A multiple linear regression analysis was run in Microsoft excel using the analysis tool pack and a multiple linear regression-based model was developed. *Table 4.14* shows the regression statistics for the model while *Figure 4.4* shows a plot of the input cost overrun (Pco) versus the cost overrun predicted by the developed model. The inputs to the model were; overrun due to increase in volume of cut and fill materials, overrun due to

Inadequate investigation of road subgrade, overrun due to increase in number of culverts and associated costs, and overrun due to increase in quantities of rock fill as independent variables and the total project cost overrun was the independent variable. All inputs were expressed in billion shillings (Billion UGX).

Table 4.14: Regression Statistics for the Cost Overrun Model

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.907	0.824	0.761	10.558	16

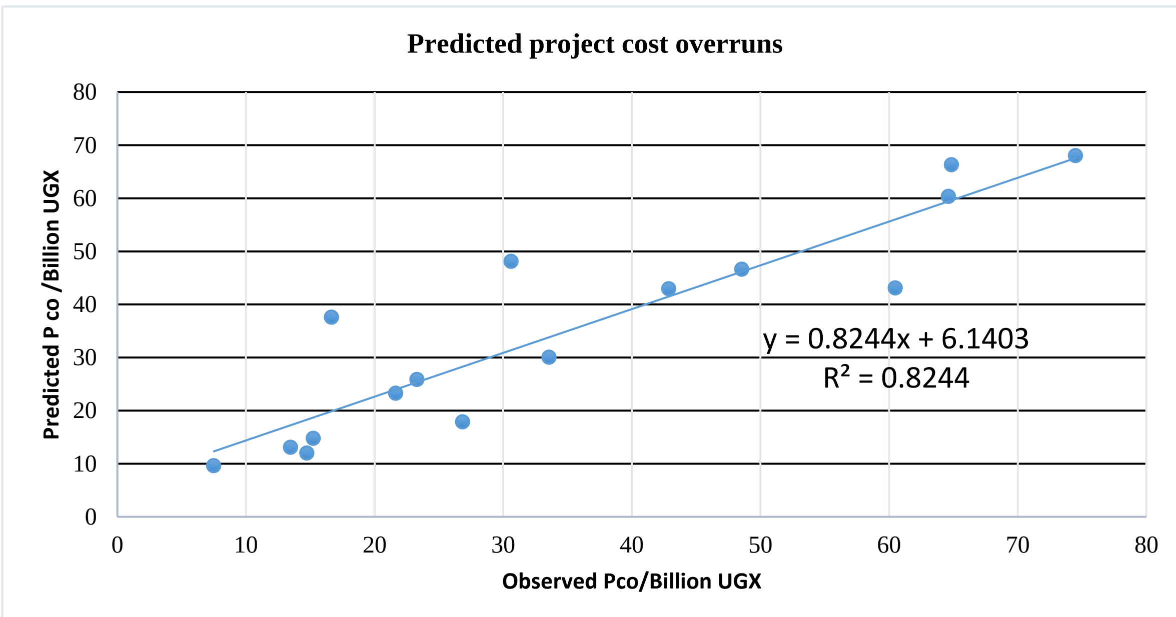

Figure 4.4: Predicted cost Overrun with Estimated Model

From the Figure 4.4 above, the R-square value indicates that 82.4% of the total variation of cost overrun in the projects studied can be predicted by increase in volume of cut and fill, Inadequate investigation of road subgrade, increase in number of culverts and associated costs, and increase in quantities of rock fill when considered together in the model.

The results for the correlation coefficient (R) indicate a strong correlation between the entered independent variables [increase in volume of cut and fill (**V_{cf}**), inadequate investigation of road subgrade(**G_s**), increase in number of culverts and associated costs (**D_c**), and increase in quantities of rock fill (**R_f**)] when considered as a set and the project cost overruns (**P_{co}**) with very less amount of data loss since the R value (0.908) is very close to 1. Statistically, if the value of R=1, the model independent and dependent variables are is highly correlated, if R=-1, then the model parameters are negatively correlated and therefore no positive relationship can be obtained within the variables.

4.8.1 Significance of Model

Results from the analysis of variance (ANOVA) are shown in *Table 4.15*. The significance F for the model represents the acceptability of the model from a statistical perspective.

Table 4.15: ANOVA Statistics

	df	**SS**	**MS**	**F**	**Significance F**
Regression	4	5758.099	1439.524	12.913	0.000386
Residual	11	1226.309	111.483		
Total	15	6984.408			

As shown in the table, the statistical significance value is less than 0.01, the acceptable level of significance, implying that the model developed can predict the cost overrun significantly well when all the independent variables are considered as a set.

4.8.2 Significance of Independent Variables (Design Flaws) in the Model

As shown in the *Table 4.16*, overruns due to inadequate geotechnical investigations of the road subgrade is the most statistically significant (P=0.005) while cost overrun due to increase in volume of cut and fill is the least significant (P=0.125) design flaw in the model when analysed at 95% confidence level. This implies that inadequate geotechnical investigations can significantly predict the amount of cost overrun when considered alone in the model while cut and fill has a minimal effect on the cost overrun value.

4.8.3 Model Coefficients

The coefficients for the variables in the model are as shown in *Table 4.16*. The coefficients indicate the effect which a unit change in each design flaw has on the project cost overrun when all the four design flaws are considered as a set.

Table 4.16: Model Coefficients for the Variables

Variables	Unstandardized Coefficients		Standardized Coefficients	t test	P-Value
	B	Std. Error	Beta		
(Constant)	2.119	5.286		.401	.696
Overrun due to increase in Number of culverts and associated costs (Billion UGX)	3.898	1.790	.380	2.178	.052
Overrun due to Inadequate investigation of Road Subgrade (Billion UGX)	6.264	1.810	.550	3.462	.005
Overrun due to increase in Quantities of Rock fill (Billion UGX)	5.118	2.855	.640	1.793	.101
Overrun Due to Increase in Volume of Cut and fill materials (Billion UGX)	-3.979	2.399	-.500	-1.659	.125

From the above data, the model obtained is:

$$\mathbf{Pco = 2.119 + 0.380\, D_c + 0.550 G_s + 0.640 R_f - 0.500 V_{cf}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Where: $\mathbf{P_{co}}$ represents the total project cost overrun, $\mathbf{D_c}$ represents the Overrun due to increase in number of culverts and associated costs, $\mathbf{G_s}$ represents the Overrun due to inadequate investigation of Road Subgrade, $\mathbf{R_f}$ represents the overrun due to increase in Quantities of Rock fill, $\mathbf{V_{cf}}$ represents the overrun due to increase in volume of cut and fill and the constant represents the change in cost overrun caused by other factors and other design flaws which are not part of the model.

From the Equation 4.1, $\mathbf{D_c}$, $\mathbf{G_s}$ and $\mathbf{R_f}$ have positive coefficients implying that a unit increase in any of them increases the project cost overrun by 0.380, 0.550 and 0.640 units respectively. Increase in quantities of rock fill has the greatest impact on project cost overrun and this implies that among the design flaws in the model, rockfill should be controlled during design by thoroughly investigating sections where rockfill can required and properly estimating its quantities to avoid its increase during construction to minimize the magnitude of the expected overrun.

The coefficient for $\mathbf{V_{cf}}$ is negative (-0.5) implying that a unit increase in the volumes of cut and fill decreases the project cost overrun by 0.5 units. Statistically, the negative coefficient exists because there exists a negative correlation between $\mathbf{V_{cf}}$ and $\mathbf{R_f}$ within the same model and therefore increase in one negatively affects the other.

This therefore implies that in any design good material suitable for cut and fill should be encouraged so as to reduce on the quantity of borrowed materials from outside the road alignment. In fact, from the model, to reduce the magnitude of cost overruns, cut and fill of suitable materials should be optimised to reduce on the volume required rock fill which greatly increases the cost overrun.

The constant (2.119) represents the change in cost overrun caused by other factors and other design flaws which are not part of the model. The constant shows that with the four design flaws absent on the project, there will still be a project cost overrun increase by 2.119 units. Therefore, project cost overruns are not solely dependent on the four design flaws in the model but there are other design flaws and project management issues which affect project cost which ought to be addressed together with the major design flaws shown in the model.

4.8.4 Model Calibration and Validation

External model validation was conducted using data from other completed projects not part of that used in the model estimation. Data for the model parameters from five (05) new completed paved road projects was input into the estimated model during calibration and validation process to check the predictive ability of the estimated model. A plot of observed cost overruns against the cost overruns estimated using the already developed model in 4.8.3 is shown in *Figure 4.5.*

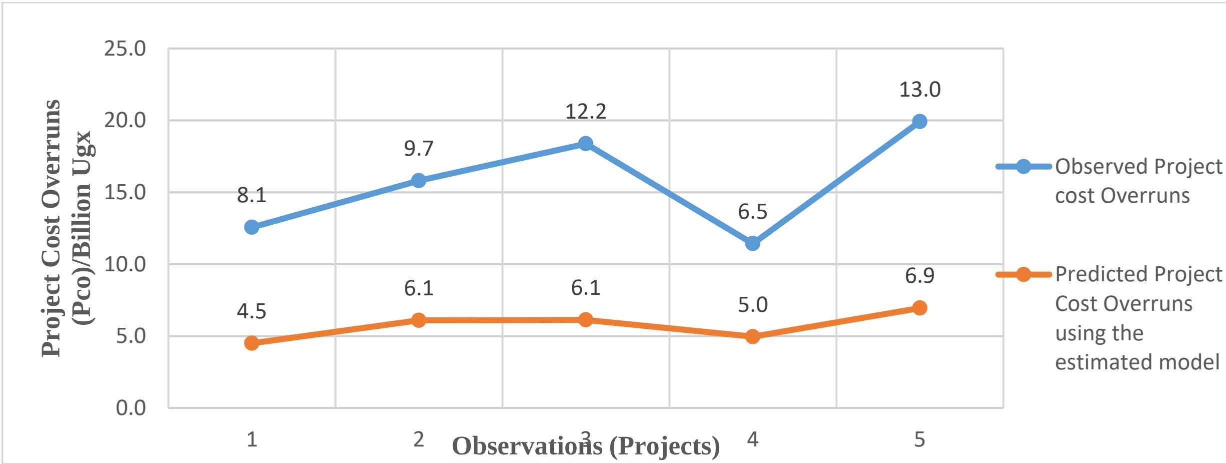

Figure 4.5: Comparison of Observed and Predicted cost Overruns

The Figure 4.5 shows the comparison between the project cost overruns observed from the additional projects with the cost overrun values calculated by incorporating the extracted values of the four design flaws into the developed model.

From Figure 4.5, it is evident that the predicted cost overrun values were generally lower than the observed cost overrun values by 40.1% on average. This justifies the fact that the four design flaws studied do not account for 100% of the design flaws on the project. The high observed project cost overruns could be attributed to other factors which cause cost overruns in addition to the four design flaws assessed. Results imply that to be able to use the developed model to predict cost overruns, the predicted value of cost overrun should be increased by 40% to reflect the true expectation.

To further check the predictive ability of the model, a plot of observed cost overruns against estimated cost overruns was made as shown in *Figure 4.6* overleaf. From the figure

4.6, the coefficient of determination (R-square) of 0.772 indicates 77.2% of the observed cost overruns can be predicated using the developed model with the four design flaws as the inputs Comparing the coefficients of determination of the original model.

The closeness of the coefficient of determination for the developed model (82.44%) and the calibration data (77.2%) that is 5.2% shows a narrow distance between the observed cost overrun and the predicted cost overrun, which is a sign of good fit and predictive ability of the developed model.

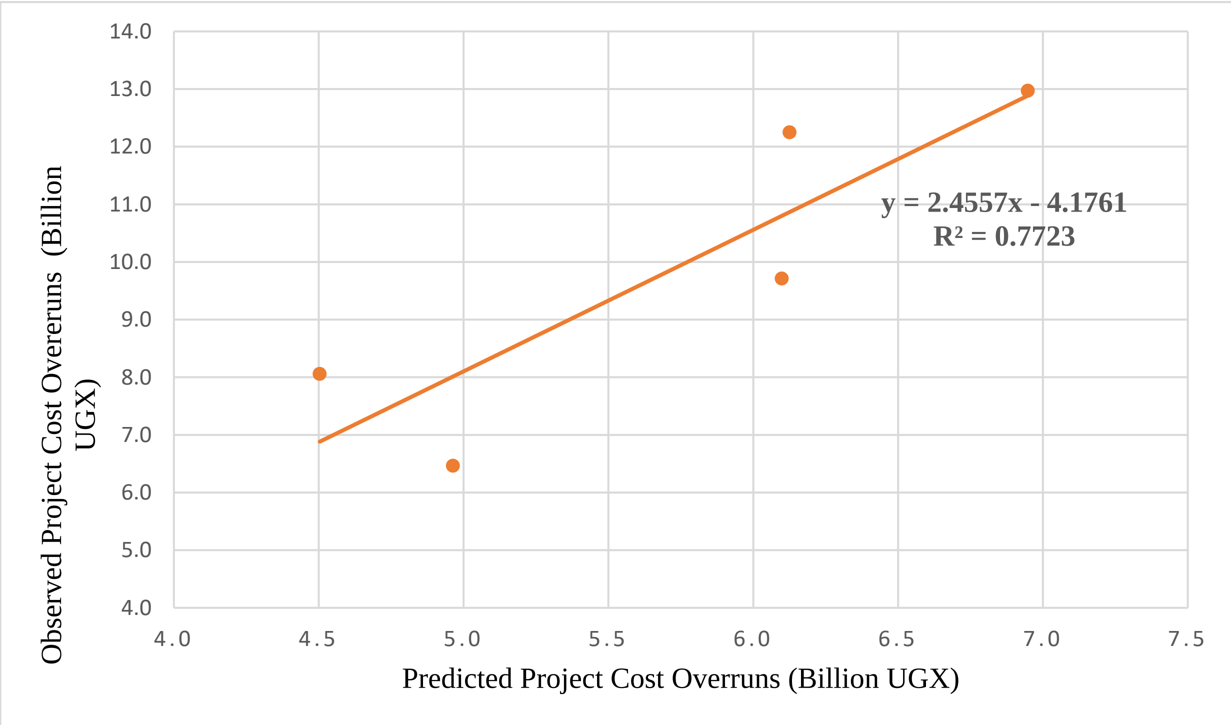

Figure 4.6: Observed Verses Predicted Cost Overruns using the developed Model

4.9 Summary of Results

The top five ranked design flaws encountered during construction of paved road projects were provision of less number of drainage culverts, inadequate quarries and earthen materials investigations, Inadequate Geotechnical Investigations for road subgrade, under estimation of quantities for Earthworks like rock fill and provision of less volumes of cut and fill provided.

The cost overrun rate due to the design flaws ranged between 13.1% and 72.6% with average of 33.3%. Therefore 33.3% of the cost overrun in the studied projects can be explained by the four design flaws studied while 66.7% was due to other factors and design flaws. Increase in quantity of rock fill had the biggest effect on cost overrun in projects with average of 11.0% and the least effect was from increase in number of drainage culvers with average of 6.7%.

The linear regression model developed for predicting cost overruns based the collected data set was: $\mathbf{Pco = 2.119 + 0.380\ D_c + 0.550 G_s + 0.640 R_f - 0.500 V_{cf}}$. The model was found significant at 0.01 level of significance with significant F of 0.0004 and coefficient of determination (R square) of 0.824 implying that the total variations in total cost overrun defined by the design flaws are 82.4% that the model is feasible from the data point of view with only 17.6% data loss. The model was calibrated and validated using fresh data from other completed paved road projects and results showed good fitness in predicting cost overruns in future projects.

The developed model is applicable to projects with a minimum contract sum of Ugx. 25 billion and in which there are provisions for design modifications during construction. The model can be applied in countries with conditions similar to those in Uganda.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This research investigated the impact of design flaws on project cost overruns in road construction projects in Uganda with a focus on paved road projects and design flaws only encountered during the construction phase. This was through identifying the top five ranked design flaws basing on the questionnaire responses from construction practitioners, establishing the contribution of the highest ranked design flaws on the total cost overrun and developing a model to predict the effect of the design flaws on cost overruns in road construction projects.

5.2 Conclusions

5.2.1 Major Design Flaws Identified during Construction of Paved Roads

According to the practitioners' opinions, the five highest ranking design flaws in order were; provision of less number of drainage culverts, inadequate quarries and earthen materials investigations, Inadequate geotechnical investigations for road subgrade, under estimation of quantities for earthworks like rock fill and provision of less volumes of cut and fill. Therefore, the research concludes that the above design flaws are prominent on all the construction projects studied and should be given critical attention during design to alleviate their impact on project cost when addressed during construction.

5.2.2 Impact of Major Design Flaws to Cost Overruns in Paved Road Construction Projects in Uganda

The cost overrun rate due to the design flaws ranged between 13.1% and 72.6% with average of 33.3%. Therefore 33.3% of the cost overrun in the studied projects can be explained by the four design flaws studied. The research concluded that rock fill has the biggest effect (11.0%) on cost overrun in the studied.

5.2.3 Predictive Model for Impact of Major Design Flaws on Cost Overruns in Paved Road Construction Projects in Uganda.

The linear regression model developed for predicting cost overruns based the collected data set was:

$$\mathbf{Pco = 2.119 + 0.380\, D_c + 0.550 G_s + 0.640 R_f - 0.500 V_{cf}.}$$

The model was found significant at 0.01 level of significance with significant F of 0.0004 and R square of 0.824 implying that the total variations in total cost overrun defined by the design flaws are 82.4% that the model is feasible from the data point of view with only 17.6% data loss. Therefore, the research concluded that where design was not comprehensive, the project cost overruns in road construction projects could be predicted using the developed model to 82.4%.

5.3 Recommendations

Most of the critical design issues ranked appear related to field investigations. Therefore, the following are recommended;

There be instituted clearly document specific guidelines for Uganda with respect to conducting geotechnical and materials investigations within the Uganda Road Design Manuals.

The design reviews for road construction projects be considered for all projects by third party consultants at stages sufficient prior to design formalisation and/or consideration of value engineering especially as far as geotechnical engineering and alignment design are concerned.

The model to be improved through research that considers a wider/large paved roads database

There should be adequate considerations for design flaw issues in design and construction bidding documentation and/or contract documents.

Further research should be conducted on the different factors causing cost overruns and establish the extent to which the major contributors affect the cost overruns.

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APPENDICES

Appendix A: Questionnaire

Dear Sir/Madam/Eng/Dr/Prof,

I am ASUMAN KIRENZI conducting a study on the impact of design flaws/inadequacies on cost overruns in road construction projects in Uganda as part of my study program for Master of Science Construction Technology and Management at Kyambogo University. Your opinion and experience is of great importance to this study and the information you will provide will only be used for academic purposes. I therefore kindly request that based on your experience and knowledge, you help me complete this questionnaire.

SECTION 1: GENERAL INFORMATION

1.1. About Your Organization (*Please select/tick as appropriate*)

1.1.1. Nature of the employing Organisation.

(a) Client (b) Consulting Firm (c) Contractor

1.2 About the Respondent (*Please select the most appropriate*)

1.2.1. Please kindly indicate your profession

(a) Civil Engineering (b) Construction Management (c) Surveying (d) Quantity Surveying (e) Others

1.2.2. Please indicate your current position in the organization.

(a) Project Manager (b) Resident/Deputy Engineer (c) Project Engineer (d) Design Engineer (e) Site Engineer (f) Quantity Surveyor (g) Land surveyor (f) other

1.2.3. Please kindly indicate your level of education?

(a) Certificate (b) Diploma (c) Degree (d) Post Graduate (e) Other

1.2.4. Years of experience in roads subsector in Uganda?

(a) 5-9 yrs (b) 10-15yrs (c) 15-20 yrs (d) Over 20 yrs

1.2.5. Have you ever implemented a project which experienced a cost overrun? Yes / No

1.2.6. If yes, give an indication of the average cost overrun in percentage?

1.2.7. Were there any design issues that significantly contributed to the cost overrun? Yes/No

1.2.8. If yes, which of the following design section significantly contributed to the cost overrun?
(a) Surveying and Geometric design (b) Materials and Geotechnical (c) Hydrology (d) Scoping (e) Estimation (f) Pavement Design (g) others

SECTION 2: FREQUENCY OF OCCURANCE OF DESIGN FLAWS AND THEIR IMPACT ON PROJECT COST

2.1 Frequency of Occurrence of Identified Design Issues on Projects

Please basing on your experience in construction, supervision or management of paved road projects in Uganda, how frequently have you experience the following design issues during construction. Please mark most appropriate response under the frequency column in Table 1 using the scale below:

1. Never (In none of the projects)

2. Rarely (In ≤25% the number of projects done)

3. Averagely (About half the number of projects)

4. Often (More than half (50-75%) of the projects)

5. Always (In all project)

2.2 Impact of identified design issues on project cost.

How did the design flaws identified contribute to cost variation in the projects when rectified during construction? Please mark most appropriate response in the impacts column in Table 1 using the scale below:

1. Had No effect (Did not affect cost)

2. Less Significantly (Caused ≤2% increase in cost)

3. Moderately Significant (Caused 2-5% increase in cost)

4. Significant (Caused 5-10% increase in cost)

5. Very Significantly (Caused more than 10% increase in cost)

Table 1: Frequency and Impact (Severity) of identified Design Issues

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
A	**SURVEYING AND GEOMETRIC DESIGN** (For this section, consider the ultimate impact of rectifying on construction quantities and cost)										
1	Use of wrongly established benchmarks										
2	Error in Centreline Setting out Data										
3	Discrepancies in original ground levels from those on drawings										
4	Errors in vertical alignment/Discrepancies in design levels										
5	Less volumes of cut and fill provided										
6	Omission of parking facilities (Bus bays and Urban Parking Lanes).										

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
7	Omission of climbing lanes where necessary										
8	Inappropriate choice of route/changes in horizontal alignment										
9	Omission of vehicular and pedestrian accesses										
B	**HYDROLOGY**										
10	Under sizing of drainage culverts										
11	Provision of less number of drainage culverts										
12	Culverts proposed in wrong locations and require shifting										
13	Culverts proposed in locations which require bridges necessitating change										
14	Pipe culvert proposed instead of box culvert										

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
15	Omission of drainage ditches/side drains										
16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)										
17	Omission of scour checks especially in steep areas										
C	**MATERIALS AND GEOTECHNICAL**										
18	Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances.										

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
19	Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties.										
20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations										
21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks.										

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
22	Poor/wrong specifications for pavement layers construction materials										
23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)										
24	Changes in specifications for surfacing materials										
25	Omission of culvert backfill concrete surrounding										
26	Change in specifications for concrete works										
D	**PAVEMENT DESIGN**										
27	Change in Traffic Projections leading to variation in pavement layer thickness specification										
28	Change flexible to rigid pavements where necessary e.g. market areas or border posts										

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
E	**SCOPING**										
29	Incomplete/Inadequate definition of employers facilities										
30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc										
G	**QUANTITIES ESTIMATION**										
31	Wrong take off / computation of quantities										
32	Application of wrong prices during estimation (wrong application of price indices)										
33	Under estimation of quantities for Earthworks like rock fill										
34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)										

Sn	Design Issue	Frequency					Impact				
		1 *Never*	***2*** *Rarely*	***3*** *Averagely*	***4*** *Often*	***5*** *Always*	***5*** *Very Significantly*	***4*** *Significant*	***3*** *Moderately Significant*	***2*** *Less Significant*	***1*** *No effect*
H	**ANCILIARIES**										
35	Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)										
36	Omission of provisions for road furniture like mark posts, sign posts, marking										
37	Omission of pavement edge protection Kerbs										

2.3. Kindly provide any other information you feel could be vital in completing this research.

……………………………………………….

Thank you for your effort and Time

Appendix B: Secondary Data Collection Tool - Case Study Projects

1. Project
Name:……………………………………………………………………………….

2. Type of construction

(a) Rehabilitation:

(b) Reconstruction

(c) New Construction

(d) Upgrading

3. Surface type:

a. Asphalt concrete

b. Stone chippings

4. Cost Performance

(i) Original Contract Sum ……………………

…………………………………...

(ii) Actual/Final Contract
Sum…………………………………………………...

(iii) Contingency Sum

…………………………………………………………..

7. Variations approved and Respective Causes

Sn	**Cause of Variation**	**Original Value (USD)**	**Variation approved (USD)**

Appendix C: University Introduction Letter

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

19th February 2018

The Executive Director
Uganda National Roads Authority
P.O. Box 28487,
Kampala.

Dear Sir/Madam,

RE: INTRODUCTION LETTER FOR MR. ASUMAN KIRENZI REG.NO. 16/U/13485/GMET/PE

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 Building Engineering, Kyambogo University. Mr. Kirenzi is undertaking a research study on the topic titled **"Investigating the impact of design flaws on cost overruns in road construction projects in Uganda".** It 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 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,

Dr. Jacob Nyende
Head of Department

THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

Appendix D: Correspondences on Request for Data on Completed Projects

Asuman Kirenzi
C/o Standard Gauge Railway Project
P.O.Box 27756
Nakawa Business Park-Kampala
Tel: 0775314743/0704919564

19th February, 2018

The Executive Director
Uganda National Roads Authority
Plot 3-5 New Port Bell Road
UAP Nakawa Business Park
P.O. Box 28487
KAMPALA

UGANDA NATIONAL ROADS AUTHORITY
RECEIVED
NAME: Halin mena
22 FEB 2018
TIME: 1543 hrs
MAIN RECEPTION

Dear Sir/Madam

RE: REQUEST FOR ACCESS TO INFORMATION ON COMPLETED ROAD PROJECTS

Iam Asuman Kirenzi, a Civil Engineer working with the Standard Gauge Railway Project (SGRP). Iam currently pursuing a Master of Science degree in construction technology and management of Kyambogo University. I am in my second year of study and conducting a research in the roads sector titled*: **Investigating the impact of design flaws on cost overruns in road construction projects in Uganda.*** The main focus of this research is on design issues which arise during construction. The main objectives of my research include;

i. To identify the major design flaws encountered during implementation of road projects in Uganda.
ii. To establish the impact of the major design flaws on cost overruns in road construction projects in Uganda.
iii. To develop a predictive model for estimating the impact of the major design flaws on cost of road construction projects in Uganda.

Your organization is the only authentic source of information which can help me in completing this research.

This is to, therefore, kindly request for information like ***final account reports***, ***project correspondences especially on variations***, ***final revised bills of quantities*** and ***design review comments*** for different projects. Find attached the list of projects under consideration and an introduction letter from the University.

I look forward for your timely assistance

Yours Faithfully

Asuman Kirenzi
Civil Engineer-Researcher

Uganda National Roads Authority
Plot 3-5 New Port Bell Road, Nakawa
UAP Business Park
P.O. Box 28487
Kampala Uganda
In any correspondence on this subject
Please quote No UNRA/DLS/GN/18

9th May, 2018

Asuman Kirenzi
C/O Standard Gauge Railway Project
Nakawa Business Park
P.O. Box 27756
Kampala.

RE: REQUEST FOR ACCESS TO INFORMATION ON COMPLETED ROAD PROJECTS

Reference is made to your letter attached on the above subject and the research you indicated to be conducting in the Roads Sector titled, 'Investigating the impact of design flaws on cost overruns in road construction projects in Uganda'.

We note your request for information such as final accounts, project correspondences especially on variations, final released bills of quantity and design review comments for 30 projects.

Please note that Uganda National Roads Authority (UNRA) is only able to avail you information on Total Project Costs. We also note that your sample space is too wide. The total project costs can only be availed for three projects. In the event that you are interested in the information for Total Project Costs for three of the completed road projects, the same will be availed to you subject to the terms and conditions below;

i. **Conducting the Research**
You will interface with UNRA's Acting Manager Network Planning for provision of the information.

ii. **Financing of the Research**
You will be responsible for any monetary expenses that may arise during the course of your research.

iii. **Declaration of Conflict of Interest and Potential Conflict of Interest**
You will sign and return to the undersigned prior to the commencement of research, the attached Declaration of Conflict of Interest and or Potential Conflict of Interest Form.

iv. **Intellectual Property Rights**
Intellectual property rights that may arise during the course of the research with contribution from UNRA the evidence of which shall be proven, shall be shared in accordance to the proportionate contribution of the parties (yourself and UNRA).

v. **Confidentiality**

You shall not in any fashion, form or manner unless specifically consented to in writing by UNRA either directly or indirectly use, divulge or transmit or otherwise disclose or cause to be disclosed or cause to be used, divulged, transmitted or otherwise disclose to any person information received during the course of his research and for a period of up to 3 (three) years after the end of his research.

vi. **Termination by UNRA**

UNRA reserves the right to terminate the above approval at any stage for reasons including, but not limited to prevailing conditions making it impossible to continue with the research or breach of Terms and Conditions by yourself or Kyambogo University.

Eng. Joseph Otim
Ag.EXECUTIVE DIRECTOR

Copy:

- Director Legal Services (UNRA)
- Director Network Planning and Engineering (UNRA)
- Director Human Resource (UNRA)

MKK/WT/ARMB/DLS

Uganda National Roads Authority
Plot 3-5 New Port Bell Road, Nakawa
UAP Business Park
P.O. Box 28487
Kampala Uganda
In any correspondence on this subject
Please quote No UNRA/DLS/GN/18

14th June 2018

Asuman Kirenzi
C/O Standard Gauge Railway Project
Nakawa Business Park
P.O. Box 27756
Kampala.

RE: REQUEST FOR ACCESS TO INFORMATION ON COMPLETED ROAD PROJECTS

Reference is made to your letter attached on the above subject matter.

We note your acceptance of the Terms and Conditions of the Research on '*Investigating the impact of design flaws on cost overruns in road construction projects in Uganda*'.

Please find attached for your signature the Declaration of Conflict of Interest form. Please return the same to the undersigned thereafter as a condition prior to release of information.

Allen C. Kagina
EXECUTIVE DIRECTOR

Copy:

- Director Legal Services (UNRA)
- Director Network Planning and Engineering (UNRA)
- Director Human Resource (UNRA)

TSK/WT/ARMB/DLS

Tel: +256 31 2233100▪ 256 414 318000▪ Fax: +256 414 232807, 347616▪E-mail: executive@unra.go.ug▪Website: http://www.unra.go.ug

Appendix E: Results from Questionnaire Analysis

Table E- 1: Results of Content Validity Assessment

No.	Item	Experts					Total	Content Validity Rating (CVR)
		1	2	3	4	5		
1	Nature of Organization	1	1	1	1	1	5	1.00
2	Respondents Proffession	0	1	1	1	1	4	0.80
3	Respondents Position in Organization	1	1	1	1	1	5	1.00
4	Level of Education	0	1	1	1	0	3	0.60
5	Respondents Years of Experience	1	1	1	1	1	5	1.00
6	Project with Cost overrun	1	0	1	0	0	2	0.40
7	Average cost overrun experienced on projects	1	1	1	1	1	5	1.00
8	Any design issues that let to Cost overrun	1	0	1	1	1	4	0.80
9	Design Section which significantly affected cost	1	1	1	1	1	5	1.00
10	Rating of Impact of Design flaws on cost of projects	1	1	1	1	1	5	1.00
11	Rating of frequency of occurance of design flaws on projects	1	1	1	1	1	5	1.00
	Total							**9.60**
	Content Validity Index (CVI)							**0.873**

Table E-2: Ranking of Design Flaws per Design Category

Design Category	SN	Identified Design Flaws	FI (Max 5)	SI (Max 5)	II (Max 100)	Rank
Surveying and Geometric Design	**1**	**Use of wrongly established benchmarks**	**1.84**	**2.12**	**15.6**	**9**
	2	**Error in Centreline Setting out Data**	**2.00**	**2.13**	**17.0**	**8**
	3	Discrepancies in original ground levels from those on drawings	2.69	2.24	24.1	4
	4	Errors in vertical alignment/Discrepancies in design levels	2.54	2.24	22.7	5
	5	**Less volumes of cut and fill provided**	**3.27**	**2.25**	**29.4**	**1**
	6	Omission of parking facilities (Bus bays and Urban Parking Lanes).	2.78	2.32	25.9	3
	7	Omission of climbing lanes where necessary	2.26	2.19	19.8	6
	8	Inappropriate choice of route/changes in horizontal alignment	2.27	2.06	18.7	7
	9	**Omission of vehicular and pedestrian accesses**	**3.10**	**2.26**	**28.0**	**2**
Hydrology	10	Under sizing of drainage culverts	2.42	2.17	21.0	5
	11	**Provision of less number of drainage culverts**	**3.81**	**2.49**	**37.9**	**1**
	12	**Culverts proposed in wrong locations and require shifting**	**2.80**	**2.25**	**25.2**	**2**
	13	Culverts proposed in locations which require bridges necessitating change	2.28	2.11	19.3	6
	14	**Pipe culvert proposed instead of box culvert**	**2.26**	**2.08**	**18.8**	**7**
	15	Omission of drainage ditches/side drains	2.65	2.28	24.2	3
	16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)	2.85	2.00	22.8	4
	17	**Omission of scour checks especially in steep areas**	**2.24**	**1.81**	**16.2**	**8**
Materials and Geotechnical	**18**	**Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances**	**3.32**	**2.72**	**36.1**	**1**
	19	**Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties**	**3.23**	**2.72**	**35.1**	**2**
	20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations	2.37	2.00	19.0	7
	21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks	3.34	1.85	24.7	3

Design Category	SN	Identified Design Flaws	FI (Max 5)	SI (Max 5)	II (Max 100)	Rank
	22	**Poor/wrong specifications for pavement layers construction materials**	**2.39**	**1.86**	**17.8**	**8**
	23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)	2.85	2.07	23.6	5
	24	**Changes in specifications for surfacing materials**	**2.49**	**1.70**	**17.0**	**9**
	25	Omission of culvert backfill concrete surrounding	2.40	2.00	19.2	6
	26	Change in specifications for concrete works	2.72	2.24	24.4	4
Pavement Design	27	Change in Traffic Projections leading to variation in pavement layer thickness specification	2.92	2.07	24.1	1
	28	Change flexible to rigid pavements where necessary e.g. market areas or border posts	2.18	2.11	18.3	2
Scoping	29	Incomplete/Inadequate definition of employers facilities	2.36	1.65	15.6	2
	30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc	3.62	2.03	29.4	1
Estimation	31	Wrong take off / computation of quantities	2.64	1.82	19.2	4
	32	**Application of wrong prices during estimation (wrong application of price indices)**	**3.46**	**1.89**	**26.2**	**2**
	33	**Under estimation of quantities for Earthworks like rock fill**	**3.15**	**2.41**	**30.3**	**1**
	34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)	3.35	1.88	25.2	3
Ancillary	**35**	**Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)**	**3.00**	**2.11**	**25.3**	**2**
	36	Omission of provisions for road furniture like mark posts, sign posts, marking	1.93	1.88	14.5	3
	37	**Omission of pavement edge protection Kerbs**	**2.76**	**2.35**	**26.0**	**1**

Table E-3: Ranking of Design Flaws per Respondents Group

A) Consultant's Perspective

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Hydrology	11	Provision of less number of drainage culverts	3.93	3.74	58.7	1
Materials and Geotechinical	18	Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances	3.07	2.44	30.1	17
Materials and Geotechinical	19	Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties	3.22	3.00	38.7	5
Estimation	33	Under estimation of quantities for Earthworks like rock fill	2.37	3.63	34.4	9
Surveying and Geometric Design	5	Less volumes of cut and fill provided	3.00	2.81	33.8	10
Scoping	30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc	3.78	3.85	58.2	2
Surveying and Geometric	9	Omission of vehicular and pedestrian accesses	2.56	2.56	26.1	23
Estimation	32	Application of wrong prices during estimation (wrong application of price indices)	2.56	3.44	35.2	7
Ancillary	37	Omission of pavement edge protection Kerbs	2.70	2.33	25.2	27
Surveying and Geometric Design	6	Omission of parking facilities (Bus bays and Urban Parking Lanes).	3.07	2.48	30.5	15

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Ancillary	35	Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)	2.63	2.11	22.2	30
Hydrology	12	Culverts proposed in wrong locations and require shifting	3.56	2.96	42.1	4
Estimation	34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)	3.33	2.48	33.1	12
Materials and Geotechinical	21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks	2.81	2.93	32.9	13
Materials and Geotechinical	26	Change in specifications for concrete works	3.00	2.22	26.7	21
Hydrology	15	Omission of drainage ditches/side drains	1.85	2.44	18.1	35
pavement Design	27	Change in Traffic Projections leading to variation in pavement layer thickness specification	2.89	3.07	35.5	6
Surveying and Geometric Design	3	Discrepancies in original ground levels from those on drawings	2.89	3.04	35.1	8
Materials and Geotechinical	23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)	2.96	2.19	25.9	24
Hydrology	16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)	2.33	2.70	25.2	26
Surveying and Geometric Design	4	Errors in vertical alignment/Discrepancies in design levels	2.07	2.81	23.4	28
Hydrology	10	Under sizing of drainage culverts	2.85	2.67	30.4	16

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Surveying and Geometric Design	7	Omission of climbing lanes where necessary	2.52	2.56	25.7	25
Hydrology	13	Culverts proposed in locations which require bridges necessitating change	3.44	3.70	51.0	3
Estimation	31	Wrong take off / computation of quantities	2.41	2.85	27.5	19
Hydrology	25	Omission of culvert backfill concrete surrounding	2.89	2.37	27.4	20
Materials and Geotechinical	20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations	2.56	3.04	31.0	14
Hydrology	14	Pipe culvert proposed instead of box culvert	2.33	2.81	26.3	22
Surveying and Geometric Design	8	Inappropriate choice of route/changes in horizontal alignment	2.37	2.41	22.8	29
Materials and Geotechinical	28	Change flexible to rigid pavements where necessary e.g. market areas or border posts	2.30	2.00	18.4	34
Materials and Geotechinical	22	Poor/wrong specifications for pavement layers construction materials	2.81	2.48	27.9	18
Surveying and Geometric	2	Error in Centreline Setting out Data	1.96	2.37	18.6	33
Materials and Geotechinical	24	Changes in specifications for surfacing materials	3.11	2.67	33.2	11
Hydrology	17	Omission of scour checks especially in steep areas	2.07	1.78	14.7	36
Scoping	29	Incomplete/Inadequate definition of employer’s facilities	2.30	2.04	18.7	32
Surveying and Geometric Design	1	Use of wrongly established benchmarks	1.93	2.56	19.7	31

Design Category	**SN**	**Identified Design Flaws**	**Results of Analysis**			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Ancillary	36	Omission of provisions for road furniture like mark posts, sign posts, marking	1.67	1.93	12.8	37

B) Ranking from the Contractors' Perspective

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Hydrology	11	Provision of less number of drainage culverts	4.04	3.20	51.7	5
Materials and Geotechinical	18	Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances	3.60	2.32	33.4	9
Materials and Geotechinical	19	Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties	3.64	2.92	42.5	6
Estimation	33	Under estimation of quantities for Earthworks like rock fill	4.04	4.16	67.2	1
Surveying and Geometric Design	5	Less volumes of cut and fill provided	3.20	2.84	36.4	7
Scoping	30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc	4.00	3.84	61.4	2
Surveying and Geometric	9	Omission of vehicular and pedestrian accesses	3.60	2.20	31.7	10
Estimation	32	Application of wrong prices during estimation (wrong application of price indices)	4.00	3.76	60.2	3
Ancillary	37	Omission of pavement edge protection Kerbs	2.64	2.08	22.0	21
Surveying and Geometric Design	6	Omission of parking facilities (Bus bays and Urban Parking Lanes).	2.64	2.32	24.5	19
Ancillary	35	Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)	3.28	2.20	28.9	13
Hydrology	12	Culverts proposed in wrong locations and require shifting	2.00	2.04	16.3	30

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Estimation	34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)	2.72	2.36	25.7	17
Materials and Geotechinical	21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks	3.72	3.48	51.8	4
Materials and Geotechinical	26	Change in specifications for concrete works	2.72	2.44	26.5	16
Hydrology	15	Omission of drainage ditches/side drains	3.12	2.36	29.5	11
pavement Design	27	Change in Traffic Projections leading to variation in pavement layer thickness specification	2.88	2.52	29.0	12
Surveying and Geometric Design	3	Discrepancies in original ground levels from those on drawings	1.88	1.68	12.6	34
Materials and Geotechinical	23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)	2.84	2.20	25.0	18
Hydrology	16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)	3.24	2.76	35.8	8
Surveying and Geometric Design	4	Errors in vertical alignment/Discrepancies in design levels	1.96	2.52	19.8	25
Hydrology	10	Under sizing of drainage culverts	2.32	2.24	20.8	23
Surveying and Geometric Design	7	Omission of climbing lanes where necessary	2.04	2.72	22.2	20
Hydrology	13	Culverts proposed in locations which require bridges necessitating change	1.52	2.80	17.0	29
Estimation	31	Wrong take off / computation of quantities	2.48	2.68	26.6	15

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Hydrology	25	Omission of culvert backfill concrete surrounding	1.64	1.80	11.8	35
Materials and Geotechinical	20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations	1.92	2.52	19.4	26
Hydrology	14	Pipe culvert proposed instead of box culvert	2.64	2.68	28.3	14
Surveying and Geometric Design	8	Inappropriate choice of route/changes in horizontal alignment	2.04	2.32	18.9	27
Materials and Geotechinical	28	Change flexible to rigid pavements where necessary e.g. market areas or border posts	1.76	2.96	20.8	22
Materials and Geotechinical	22	Poor/wrong specifications for pavement layers construction materials	1.84	2.04	15.0	32
Surveying and Geometric	2	Error in Centreline Setting out Data	1.84	1.60	11.8	37
Materials and Geotechinical	24	Changes in specifications for surfacing materials	1.64	2.36	15.5	31
Hydrology	17	Omission of scour checks especially in steep areas	1.88	2.76	20.8	24
Scoping	29	Incomplete/Inadequate definition of employers facilities	2.16	2.16	18.7	28
Surveying and Geometric Design	1	Use of wrongly established benchmarks	1.80	1.64	11.8	36
Ancillary	36	Omission of provisions for road furniture like mark posts, sign posts, marking	1.88	1.76	13.2	33

C) Rankings from the Clients' Perspective

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Hydrology	11	Provision of less number of drainage culverts	3.41	3.77	51.4	6
Materials and Geotechinical	18	Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances	3.00	3.55	42.5	10
Materials and Geotechinical	19	Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties	2.77	3.50	38.8	12
Estimation	33	Under estimation of quantities for Earthworks like rock fill	3.68	4.36	64.3	2
Surveying and Geometric Design	5	Less volumes of cut and fill provided	3.68	3.73	54.9	4
Scoping	30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc	3.00	4.32	51.8	5
Surveying and Geometric	9	Omission of vehicular and pedestrian accesses	3.05	2.77	33.8	18
Estimation	32	Application of wrong prices during estimation (wrong application of price indices)	3.95	3.55	56.1	3
Ancillary	37	Omission of pavement edge protection Kerbs	2.73	2.36	25.8	30
Surveying and Geometric Design	6	Omission of parking facilities (Bus bays and Urban Parking Lanes).	2.59	2.59	26.9	27
Ancillary	35	Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)	3.14	2.91	36.5	16
Hydrology	12	Culverts proposed in wrong locations and require shifting	2.77	2.45	27.2	26

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Estimation	34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)	4.09	4.00	65.5	1
Materials and Geotechinical	21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks	3.09	3.91	48.3	7
Materials and Geotechinical	26	Change in specifications for concrete works	2.36	2.73	25.8	28
Hydrology	15	Omission of drainage ditches/side drains	3.09	3.36	41.6	11
pavement Design	27	Change in Traffic Projections leading to variation in pavement layer thickness specification	3.00	3.95	47.5	8
Surveying and Geometric Design	3	Discrepancies in original ground levels from those on drawings	3.36	3.23	43.4	9
Materials and Geotechinical	23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)	2.73	2.68	29.3	23
Hydrology	16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)	3.05	3.00	36.5	15
Surveying and Geometric Design	4	Errors in vertical alignment/Discrepancies in design levels	3.18	2.95	37.6	14
Hydrology	10	Under sizing of drainage culverts	2.00	2.36	18.9	37
Surveying and Geometric Design	7	Omission of climbing lanes where necessary	2.18	2.95	25.8	29
Hydrology	13	Culverts proposed in locations which require bridges necessitating change	1.73	3.23	22.3	32
Estimation	31	Wrong take off / computation of quantities	3.09	3.14	38.8	13

Design Category	SN	Identified Design Flaws	Results of Analysis			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Hydrology	25	Omission of culvert backfill concrete surrounding	2.55	2.45	25.0	31
Materials and Geotechinical	20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations	2.55	3.09	31.5	19
Hydrology	14	Pipe culvert proposed instead of box culvert	1.73	2.77	19.2	35
Surveying and Geometric Design	8	Inappropriate choice of route/changes in horizontal alignment	2.41	2.86	27.6	25
Materials and Geotechinical	28	Change flexible to rigid pavements where necessary e.g. market areas or border posts	2.50	3.09	30.9	20
Materials and Geotechinical	22	Poor/wrong specifications for pavement layers construction materials	2.50	3.41	34.1	17
Surveying and Geometric	2	Error in Centreline Setting out Data	2.23	2.41	21.5	34
Materials and Geotechinical	24	Changes in specifications for surfacing materials	2.59	2.95	30.6	22
Hydrology	17	Omission of scour checks especially in steep areas	2.86	2.55	29.2	24
Scoping	29	Incomplete/Inadequate definition of employers facilities	2.68	2.86	30.7	21
Surveying and Geometric Design	1	Use of wrongly established benchmarks	1.77	2.68	19.0	36
Ancillary	36	Omission of provisions for road furniture like mark posts, sign posts, marking	2.32	2.32	21.5	33

Table E-3: General Ranking of Design Flaws

Design Category	SN	Identified Design Flaws	Analysis Result			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Hydrology	11	Provision of less number of drainage culverts	3.81	2.49	**37.9**	**1**
Materials and Geotechinical	18	Inadequate Materials (Quarries and earthen materials) Investigations e.g. Provision of locations with less quantities, sources of inferior quality materials proposed, long haulage distances	3.32	2.72	**36.1**	**2**
Materials and Geotechinical	19	Inadequate Geotechnical Investigations for road subgrade e.g. Shallow depth of test pits, large spacing of test points etc. hence inadequate definition of alignment soil properties	3.23	2.72	**35.1**	**3**
Estimation	33	Under estimation of quantities for Earthworks like rock fill	3.15	2.41	**30.3**	**4**
Surveying and Geometric Design	5	Less volumes of cut and fill provided	3.27	2.25	**29.4**	**5**
Scoping	30	Addition of extra works not in the original scope for example paving a link to the main road, inclusion of grade separations, etc	3.62	2.03	**29.4**	**6**
Surveying and Geometric	9	Omission of vehicular and pedestrian accesses	3.10	2.26	**28.0**	**7**
Estimation	32	Application of wrong prices during estimation (wrong application of price indices)	3.46	1.89	**26.2**	**8**
Ancillary	37	Omission of pavement edge protection Kerbs	2.76	2.35	**26.0**	**9**
Surveying and Geometric Design	6	Omission of parking facilities (Bus bays and Urban Parking Lanes).	2.78	2.32	**25.9**	**10**
Ancillary	35	Omission of provisions for services and utility ducts (Water, Power, Cables, etc.)	3.00	2.11	**25.3**	**11**
Hydrology	12	Culverts proposed in wrong locations and require shifting	2.80	2.25	**25.2**	**12**

Design Category	SN	Identified Design Flaws	Analysis Result			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Estimation	34	Omission of costs for utilities relocation (Electricity, Water, internet cables, etc.)	3.35	1.88	**25.2**	**13**
Materials and geotechnical	21	Inadequate Geotechnical Investigations for swamps and low lands leading to wrong specifications for treatment method and less quantities of earthworks	3.34	1.85	**24.7**	**14**
Materials and geotechnical	26	Change in specifications for concrete works	2.72	2.24	**24.4**	**15**
Hydrology	15	Omission of drainage ditches/side drains	2.65	2.28	**24.2**	**16**
pavement Design	27	Change in Traffic Projections leading to variation in pavement layer thickness specification	2.92	2.07	**24.1**	**17**
Surveying and Geometric Design	3	Discrepancies in original ground levels from those on drawings	2.69	2.24	**24.1**	**18**
Materials and geotechnical	23	Omission of embankment/slope protection works (e.g. Omission of gabion boxes, grassing, etc.)	2.85	2.07	**23.6**	**19**
Hydrology	16	Improper investigation of soundness of existing drainage structures necessitating replacement (e.g. remove and replace structure proposed to be left in place)	2.85	2.00	**22.8**	**20**
Surveying and Geometric Design	4	Errors in vertical alignment/Discrepancies in design levels	2.54	2.24	**22.7**	**21**
Hydrology	10	Under sizing of drainage culverts	2.42	2.17	**21.0**	**22**
Surveying and Geometric Design	7	Omission of climbing lanes where necessary	2.26	2.19	**19.8**	**23**
Hydrology	13	Culverts proposed in locations which require bridges necessitating change	2.28	2.11	**19.3**	**24**

Design Category	**SN**	**Identified Design Flaws**	**Analysis Result**			
			FI (Max 5)	SI (Max 5)	II (Max 100)	Rank (37)
Estimation	31	Wrong take off / computation of quantities	2.64	1.82	**19.2**	**25**
Hydrology	25	Omission of culvert backfill concrete surrounding	2.40	2.00	**19.2**	**26**
Materials and Geotechinical	20	Inadequate Geotechnical Investigations for bridge abutments necessitating fresh investigations	2.37	2.00	**19.0**	**27**
Hydrology	14	Pipe culvert proposed instead of box culvert	2.26	2.08	**18.8**	**28**
Surveying and Geometric Design	8	Inappropriate choice of route/changes in horizontal alignment	2.27	2.06	**18.7**	**29**
Materials and Geotechinical	28	Change flexible to rigid pavements where necessary e.g. market areas or border posts	2.18	2.11	**18.3**	**30**
Materials and Geotechinical	22	Poor/wrong specifications for pavement layers construction materials	2.39	1.86	**17.8**	**31**
Surveying and Geometric	2	Error in Centreline Setting out Data	2.00	2.13	**17.0**	**32**
Materials and Geotechinical	24	Changes in specifications for surfacing materials	2.49	1.70	**17.0**	**33**
Hydrology	17	Omission of scour checks especially in steep areas	2.24	1.81	**16.2**	**34**
Scoping	29	Incomplete/Inadequate definition of employers facilities	2.36	1.65	**15.6**	**35**
Surveying and Geometric Design	1	Use of wrongly established benchmarks	1.84	2.12	**15.6**	**36**
Ancillary	36	Omission of provisions for road furniture like mark posts, sign posts, marking	1.93	1.88	**14.5**	**37**

Appendix F: Details of Secondary Data Findings

Table F-1: Case Study Projects Cost Characteristics

PROJECT CODE	*Initial Contract Sum (UGX)*	*Final Contract sum (UGX)*	*Total Project Overrun(UGX)*	*Project Cost Overrun Rate (%)*
A	211,691,110,703.30	272,187,973,254	60,496,862,550.70	28.6
B	242,636,153,677.83	273,255,713,945.64	30,619,560,267.81	12.6
C	221,374,628,395.90	2.43025E+11	21,650,000,000.00	9.8
D	134,385,576,794.65	199,006,533,437	64,620,956,642.35	48.1
E	97,476,095,241	112,718,570,492	15,242,475,251.00	15.6
F	168,214,943,915.54	2.33069E+11	64,854,544,296.46	38.6
G	1.34679E+11	1.68247E+11	33,567,223,214.00	24.9
H	147,067,121,956	189,953,416,930	42,886,294,974.00	29.2
I	165,146,577,582	239,655,000,000	74,508,422,418.00	45.1
J	34874876268	42377662483	7,502,786,215.00	21.5
K	1.84379E+11	2.0768E+11	23,301,115,576.00	12.6
L	132,123,510,816	145,599,405,874	13,475,895,058.00	10.2
M	30,285,508,100	57,138,091,380.0	26,852,583,280.00	88.7
N	46,083,277,750	60,829,926,630.00	14,746,648,880.00	32.0
O	25,100,987,800	41,768,003,793	16,667,015,993.00	66.4
P	92,000,000,000	140,556,490,385	48,556,490,385.00	52.8
	Averages		34,971,804,687.6	33.5
	Standard deviation		21,578,396,241.37	22.25

Table F-2: Inputs to the Predictive model

Project Code	Dependent Variable (Billion UGX)	Independent Variables (Billion UGX)			
	Pco	Dc	Gs	Rf	Vcf
A	60.497	1.995	4.152	4.481	3.955
B	30.620	5.460	2.826	3.723	3.028
C	21.650	2.620	1.689	1.970	2.446
D	64.621	2.714	4.459	4.653	1.034
E	15.242	0.960	0.777	1.097	0.396
F	64.855	5.318	4.799	5.188	3.308
G	33.567	1.745	2.115	3.390	2.383
H	42.886	1.501	5.232	6.433	7.720
I	74.508	3.502	5.588	7.600	5.439
J	7.503	0.345	0.909	0.566	0.616
K	23.301	0.722	1.468	2.889	0.769
L	13.476	0.957	1.092	0.862	1.011
M	26.853	2.148	0.537	0.806	0.027
N	14.747	0.590	0.221	1.327	0.147
O	16.667	0.054	3.657	5.023	3.362
P	48.556	7.454	0.216	9.907	9.201

Table F-3: Model calibration/ Validation Data

Project Code	**Observed Cost Overrun (Billion UGX)**	**Independent Variables (Billion UGX)**			
	Pco	Dc	Gs	Rf	Vcf
1	8.1	1.074	0.806	2.417	0.027
2	9.7	3.727	0.216	3.963	0.184
3	12.2	0.382	2.826	3.723	0.151
4	6.5	0.136	0.134	4.653	0.517
5	13.0	3.191	1.440	5.188	0.992