Improving costing in infrastructure projects to accommodate uncertainties

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Abstract

Determining a reliable estimate for a construction project based on scant information during the early stage is quite challenging. It is all too usual to make incorrect estimates based on vague client needs and desires. Early cost estimate reliability is vital to the success of construction project delivery. It is widely acknowledged that one of the major factors affecting a country's economy growing is the presence of adequate social and economic infrastructure. Construction projects delivery management team therefore needs adequate and robust improvement in cost estimation at the early stage. There is need for holistic view of how the present-day project control and management professionals manage and deliver infrastructure projects to make it viable economically. Early cost estimation used in providing key decision in financing these infrastructure projects are known to be flawed due to inadequate information. This is followed by the worry that industry mandated risk management principles are ineffective in managing uncertainty, especially in complex project environments. Construction projects therefore have routinely overrun their estimates. The research identified that there is no unanimity on the reference point from which contingency estimate is produced at the early stage. Another identified problem is that there is insufficient uncertainty management during the early stage of the project. This thesis advocates the use of system thinking in identifying uncertainty factors during the early stage of project to improve cost estimate. A mixed method approach was used to fulfil the objectives of the study. Initially, semi-structure interviews were conducted to identify uncertainty factors that impact early project cost estimate and the importance of using system thinking in identifying them. Twenty respondents were selected from UK project control and management professionals involved in infrastructure project delivery. 300 questionnaires were distributed to professionals in the UK infrastructure project industry, including client, contractors, and subcontractors and 76 respondents were received. A snow-balling sample technique was used to gather the respective respondents. Their responses were analysed using statistical techniques, and some of the results served as input for the regression model produced in establishing relationship amongst system thinking, need for cognition scale scores and years of experience. Another quantitative study was done using secondary data (cost information) obtained from 31 infrastructure projects in the UK. These costs date was analysed using Generalized linear model and Bayesian hierarchical regression Model to produce 12 predictive models that estimate cost overrun and final cost of a given infrastructure project during the early stage.6 case-study firms were used for the validation The models produced take cognisant of project level random effects to account for uncertainties in parameter estimation which reduces the level of biases in the models. Parameter estimation is based on Markov chain monte carlo (MCMC) algorithms implemented within the stan framework. Models were assessed for convergence and goodness of fit using a constellation of model diagnostics and fit indices. The findings from all the analysis showed that the covariates are independent of the project level random effects and there is inadequate uncertainty management at the early stage. Additionally, the year of experience is independent of the system thinking and need for cognition scale scores. High system thinking scale scores will enable project control and management professionals practice holism efficiently during project cost estimation process at the early stage. The predictive cost estimating model would estimate the final cost and cost overrun of an infrastructure project at the early stage which will be useful in producing an effective Should cost model (SCM) for UK project delivery team. If utilized properly, could be used at the output definition and feasibility stage (GRIP framework) to inform the first business case (strategic outline case for project departments).

Keywords: Early cost estimate, cost-overruns, uncertainty, risk, generalized linear model, Bayesian hierarchical regression model, System thinking & need for cognition

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List of Abbreviations

AACE Association for the Advancement of Cost Engineering

AAT Adaptation of Advance Technology

ACF Auto-correlation function

AcostE Association of Cost Engineers

AHP Analytical Hierarchy Process

ANNs- Artificial neural networks

APM Association of project management

AS Accelerated Schedule

BHRM Bayesian Hierarchical Regression Model

CAPEX Capital Expenditure

CC Contractual Cost

CCD Contractor Caused Delay

CCI Construction Coordination Issues

COR Cost Overrun

CPM Critical path method

DD Duration Delay

DO Designers Omission

ED Expected Duration

FC Final Cost

FOSM First order second moment

GLM Generalized Linear Model

GP Government Policies

HM Her Majesty

IPA Infrastructure Project Authority

LV Level

LTPPE Lack of thoroughness of Preconstruction Planning & Estimation

MBT Miscommunication between team

MCMC Markov Chain Monte-Carlo

NFCG Need for Cognition

NPV Net Present Value

OPEX Operating Expenditure

PC Project complexity

PDM Project Delivery Method

PERT Program Evaluation Review Technique

PMI Project management institute

QA Quality Assurance

RA Resources Availability

RIBA Royal Institute of Building Academy

RICS Royal Institute of Chartered Surveyor

ROM Rough-Order of Magnitude

ROW Right of Way

RPP Regulatory Permitting Process

SG Scope Gap

SEC Socio-Economic Condition

SI Stakeholders Issues

STSS System thinking Scale Score

TF Team Formation

TFL Transport For London

UUIS Underperforming Unqualified Inexperienced Staff

USC Unforeseen Site Condition

WBS Work break down structure

WC Weather Condition

Dedication

This thesis is dedicated to my late parent Mr.W.A. A Onalaja and Mrs.M.N.N. T Onalaja.

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I'd like to thank my supervisors Dr Victor Samwinga and Dr Wai Ming Cheung for their invaluable assistance during this research work. Their wisdom, experience, and knowledge are a constant source of inspiration. Also, their encouragement and motivation have been invaluable throughout. I'd also like to express my gratitude to Professor David Greenwood for his time and assistance at the annual progress meetings.

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Finally, I want to express my gratitude to God for providing me with the strength, energy, and drive to take on and complete this thesis.

Declaration

This thesis is being submitted to Northumbria University to meet the requirements for the Doctor of Philosophy degree. This thesis contains no material that has previously been submitted for a degree or diploma at this University or any other institution. This works fully acknowledges other people's perspectives, ideas, and contributions. The study presented in this thesis has received the necessary ethical approvals.

Name:

Signature:

Chapter 1 Introduction

This chapter introduces the research presented in this thesis. It outlines the research background and details the problem statement, aims, objectives and research questions it seeks to answer. This chapter also presents the methodology used in this study and closes with an overview of the structure of the thesis.

1.1 Research background

Infrastructure investment is critical to the success of the world's economy and high-quality infrastructures enhance the economic potential (Lees, 2019). Additionally, it provides the foundations for economies to develop and for lives to improve. For example, the transport infrastructure enhances mobility and promote agglomeration effects. Likewise, energy infrastructure provides economic security and delivers low-cost power to fuel wider industry (Lees, 2019). It is envisaged that by the year 2030, around $5.25trillion will be spent each year on infrastructure projects globally with US spending the lion's share of about $774bn by that date, India $432bn, Australia US$142bn while the UK will be spending $84bn (Lees, 2019). According to Lees (2019), the $5.25 trillion will be funded primarily by the taxpayers. (IPA, 2019b), stipulates that delivering major projects successfully is intrinsically tedious. Many of the major infrastructure projects handled by the government are large scale, and technically complex (IPA, 2019b). Most of these large-scale projects are often tasked to be delivered on an aggressive timescale established early in their lifecycle (IPA, 2019b). Typically, the key stakeholders expect these projects are to be delivered on an agreed schedule and budget respectively, and as taxpayers publicly fund them. This will invariably lead to informed or uninformed criticism from key stakeholders (public and government institutions) as well as the media (IPA, 2019b). Much of the past century has witnessed an increased tendency for large infrastructure projects to be funded by governments (Brealey et al., 2005). In the UK, the government is committed to improving and renewing existing infrastructure (HMTreasury, 2019a). The major Projects /Infrastructure Authority and National Infrastructure Commission created £37 billion national productivity investment fund to be spent on long-term infrastructure projects nationwide (HMTreasury, 2019). Lees (2019), claims that 80% of all large projects globally experience cost, or programme overruns.

There is urgent need for the infrastructure project management professionals to be more proactive in delivering benefits at a reasonable cost to justify investment. Project objectives, time, quality, and cost are just a few of the factors that influence the success of any construction project (Yu Ann et al., 2005). One of the most effective variables in project success is an estimate of an accurate and dependable cost figure at various phases of the project lifecycle, notably at the early stage (briefing stage), to deliver good financial guidance (Jaggar et al., 2002). The early cost estimate that a construction project customer receives during the briefing stage has a significant impact on their decision-making (Trost et al., 2003). According to Sonmez and Rifat (2004), it is a crucial task, but the project scope has not been defined yet, and scant design information is accessible at this point. Understanding the interrelationship, interconnectedness of the external and internal variables (uncertainties) impacting on the early cost estimate will improve the reliability of the infrastructure project cost during the lifecycle. This study assumes that applying systems thinking in the identification of uncertainties during the project early stage of a project will assist in understanding the variables that will impact the cost estimation process thus improving its reliability.

1.2 Problem statement

Delivering infrastructure projects is seldom easy, nonetheless it is considerably more challenging in these unprecedented times. Early decisions typically decide whether a project succeeds or fails later, and if completed correctly guarantee that projects deliver genuine benefits to people and communities (Smallwood, 2019).

Establishing an accurate and timely cost estimate is critical to selecting the correct projects and completing them on time and on budget (Smallwood, 2019). Inaccurate early cost assessment can result in cost and time overruns, perhaps resulting in missed opportunities. Additionally, lower-than-expected returns and project delays may result in the abandonment and termination of a project, as well as possible insolvency (Ahiaga and Simon, 2014). However, there has been only a modicum of discussion concerning how to enhance the accuracy of initial cost estimates (Ahiaga and Simon, 2014). Numerous factors and limitations have been linked to this bad image. The lack of information on which to build an accurate early cost estimate at this point, as well as the time needed to completely understand project goals and requirements prior to beginning the estimation work, were two of the most significant reasons (Wang et al., 2022).

This dearth of required information at the early stage creates room for various uncertainties which may generate risks during the project lifecycle. According to Ayman and Khaled (2018), in order to obtain robust planning and estimation of project time, cost, and quality, there is another important factor to be considered, which relates to uncertainty. Several project factors, such as the duration of activities and the cost associated with them, are rarely understood precisely during the early stage, and can lead to estimating inaccuracies. Infrastructure project are executed in an uncertain environment contributing to a larger percentage of variability at the early stage (Amusan and Adeboye, 2013). A holistic approach in identifying and understanding the variability of these factors at the early stage is essential to regarding producing a robust initial project cost estimate. The common outcome of errors in the project early cost estimate is cost overruns. According to Akanbi and Zhang (2021), one of the many possible failures is unintentional mispricing, and inaccurate information is a recipe for disaster. Given the complex business environment, different projects would have different sets of variables and factors to consider, such as the type of project, location, complexity of the project design, site restrictions, the extent to which the design has been developed, along with the client and consultant team (Badawy et al., 2022). Understanding the interconnectedness, interrelationships amongst these variables and factors is crucial in improving the early cost information. Failure to understand the interplay between these variables and factors at the very beginning of the project serves a recipe for project cost estimate inaccuracy. Cost estimation process is also known to be erroneous because it is a method that depends on experience (Ahiaga-Dagbui et al., 2017). When estimating the costs of infrastructure projects, professionals in project control and management must think holistically to address the seemingly endless difficulties that are distinguished by uncertainty, ambiguity, and conflicting objectives (Ahiaga-Dagbui et al., 2017).

On the subject of cost estimating accuracy, a significant amount of literature has been written, covering topics including determining the variables that influence cost estimation, creating a cost model, and creating a framework to deal with the issue (Herszon and Keraminiyage, 2014). Cost overruns are frequently caused by inaccurate cost projections. Cost overruns in infrastructure projects can be devastating to investors and taxpayers, jeopardising senior executives and their companies, and even resulting in bankruptcy (Flyvbjerg et al., 2018). Ammar et al. (2022) state that insufficient preliminary information during the early phase, a lack of a work cost database, a lack of proper cost estimation procedures, in addition to the presence of multiple uncertainties, are the causes of inaccurate first cost estimates. Kwon and Kang (2018) emphasised the significance of creating a model with a "rigorous language" that enables the project control and management team to evaluate the accuracy of project data from the outset. Different projects would have different sets of variables and hazards to take into account given the complex business environment, such as the type of project, location, complexity of the project design, site restrictions, and the extent to which the design has been developed in collaboration with the client and consultant team (Mahmoodzadeh et al., 2022). To arrive at robust early cost estimate, there is need to analyse the interrelationships amongst the variables and factors prior to the production of definite estimate. Failure to understand the interplay between these variables and factors at the very beginning of the project serves a recipe for project cost estimate inaccuracy. In these circumstances, a project's ability to successfully manage risk and uncertainty appears to be crucial (Shibani et al., 2022).

1.3 Research aims and objectives

The aim of this research is to develop a cost predictive model for infrastructure projects that, takes cognizance of the factors related to uncertainty and soft data, can forecast the final cost and cost overrun at the very beginning (conceptual stage) of the project life cycle. This will assist the project control and management professionals to produce a robust contingency estimate that will mitigate the impact of cost overruns to an acceptable level for the main stakeholders.

To attain the aim, the following objectives have been set:

- To review the traditional infrastructure project cost estimation and identify/explore major factors concerning uncertainty that impact on infrastructure project's early cost estimate.
- To review the literature related to the system thinking holistic approach to enhance infrastructure project cost estimate reliability.

- To develop a robust cost predictive model that forecasts the final cost/cost overrun of an infrastructure project by being aware of uncertainty factors.
- To determine the system thinking scale scores of project control and management professionals.
- To validate the infrastructure cost model using predictive diagnostics and project case studies.

These objectives were used to create a set of research questions, which led the research design. The research questions that were answered are listed below:

- To what extent are cost overruns in infrastructure project caused by uncertainty factors during initiation stage?
- Can system thinking approaches capture uncertainties adequately during the initiation stage?
- What criteria are employed to determine the most significant uncertainties and risk regarding cost information?
- Is uncertainty management in an infrastructure project delivery inadequate?

1.4 Research scope

This research focuses on the early cost estimate of UK rail infrastructure projects in the UK. The early-stage cost estimate focus is at the strategic definition and preparation/brief (RIBA/GRIP framework). The rail infrastructure projects utilized in this research are rail-track, Over-Head Line Equipment (OLE), stations and the construction of bridges.

1.5 Research methodology

The research methodology used to achieve the research goals was a combination of qualitative and quantitative methods. He methods and practises of project cost estimation are system thinking, whilst the infrastructure project risks and uncertainties are the subject of this study. The research design began with the formation of a theoretical background and understanding of the issue as a foundation for justifying the research challenge and selecting the most appropriate ways for conducting the study efficiently and effectively. Moreover, the study used a combination of qualitative and quantitative research methodologies to answer the research question. Therefore, the study issue and the methods used to tackle it are pragmatic in nature, incorporating tools from both pragmatic and interpretivist paradigms. The objectives that were addressed to attain the research aim were accomplished in stages. The first section of the literature study identifies and examines the many theories, aspects, and practices of infrastructure project cost estimating, system thinking, uncertainty, risk, combined with cost overrun in general, as well as UK rail projects. The qualitative interviews were then conducted to support the findings of the literature review. The subsequent step was to conduct a survey to determine the various levels of risk/uncertainty management practices as well as the identification of uncertainty factors that impact on project early cost estimates. Likewise, to determine the system thinking scale score and the need for cognition of the project control/management professionals. The modelling step was completed by completing a second quantitative questionnaire with the goal of determining the impacts of uncertainty factors on cost data and producing a predictive cost model. The last stage was the test diagnostic and validation of the produced cost predictive models. The surveys were conducted using Bristol-online survey and the statistical analysis was completed.

1.6 Thesis structure

The structure of the thesis consists of the following seven chapters:

- **Chapter-One**

The research background and the entire thesis content are presented in this introductory Chapter. This chapter contains the research's principal goal and objectives of the research, as well as an explanation of the technique used.

- **Chapter-Two**

The first part of the literature reviews the infrastructure project industry, explores different types of projects and cost management. The second stage explores the infrastructure project uncertainties, risks, cost overruns, system thinking approaches/theories, psychology of cost estimation, etc.

- **Chapter-Three**

The research work employs a mixed-methods approach, combining qualitative and quantitative research methods. A cyclic and iterative connection between these methods is provided by the research strategy. It also provides a summary of the epistemology of how the study's data identification and data collecting were performed to meet the research work aim and objectives.

- **Chapter-Four**

The statistical analysis of the data was presented here. To begin, descriptive statistics are used to describe the data, describing the sample's characteristics and applicability, then providing a univariate description of the major study variables.

- **Chapter-Five**

Model development and validation were presented in this chapter. It explains the model framework and validation.

- **Chapter-Six**

This chapter discusses the findings of the data analysis, developed models and the validation, respectively.

- **Chapter-Seven**

This chapter also discusses the contribution of the research to knowledge, impact, limits, and recommendations for future research. Similarly, it shows how the research answers the research questions and meets the respective objectives.

1.7 Publication

- **Conference paper**

ONALAJA, A., CHUNG, W. & SAMWINGA, V. 2018. *Identifying Infrastructure project uncertainties during project initiation using system thinking*. Creative Construction Conference 2018, CCC 2018, 30 June - 3 July 2018, Ljubljana, Slovenia

Chapter 2 Literature review

2.1 Introduction

Construction projects often make the headlines for being financial disaster, rather than the benefits of the contribution to infrastructural development. In the mid-1990s, government investigation showed that more than one quarter of construction schemes finished over their capital cost limit (Doloi, 2013). A proper consultation survey was made within the construction industry and revealed that almost one third complained about their project budget which overran the planned estimation (APM, 2006). This problem lingered till the later part of the decade with the construction client forum reporting that only sixty percent of clients said that cost was over budget. However, the subject of poor cost performance has been a key issue in the mainstream project and construction management hemisphere. It has also been widely accepted that the underlying responsibilities of the key stakeholders (clients, consultant & contractors) cannot be overemphasized. Based on a thorough and widely researched literature review as well as relevant industry inputs almost 73 attributes (Australia construction industry case study) associated with cost performance were identified for investigation (Doloi, 2013). Planning and scheduling deficiencies have the highest impact on cost performance from clients, consultant, and contractor's perspectives. Accurate cost estimation at an early stage of the project is quite crucial and essential because this will avoid cost overrun within the project. The reputation of construction project has fallen drastically recently but with keen attention to proper cost estimation improvement in the long run will be noticed (Doloi, 2013).

It is known that projects have phases that start with a concept and finish with utilization. These phases are also known as the life cycle. The timing and period of the Lifecycle varies which is a factor of resource availability and the degree of complexity (Saad, 2013). These phases may occur in sequence or overlap which can be treated as mini-project as an outright mini-project.

In general, there are major performance drivers that most project teams keep track of which are cost, time, and scope of work. Managing these triple constraints within the specified interval is the responsibility of all participants of the project directly or indirectly. This enables the quality level of the deliverables to be accomplished. In the monitoring and controlling of a project, cost upsurge is always a major area of concern for the construction project team or stakeholders. Cost upsurge does not only affect the overall project performance but also jeopardizes the upcoming project that the client can undertake in a fiscal year. Therefore, the project owner becomes curious and pays utmost attention on cost control and monitoring keenly to execute the project within the stipulated budget. In most of the projects, cost upsurge is a major factor in determining whether the project is performing satisfactorily or not. This varies according to the project size and complexities (Shield, 2010). The project lifecycle is concerned with all stages of a lifecycle from inception to retirement. During the life of a project, various cost estimate and associated aspects are essential in supporting the critical decision process, the project review process, and the annual budget formulation as well as the execution process document (Shield, 2010). Effective costing of the construction project lifecycle becomes inevitable to be able to achieve a better or improved cost performance. The best antidote is to be more proactive in managing cost effectively by producing a robust initial cost estimate that will mitigate or reduce the impact of cost overruns.

2.1.1 Global Construction industry overview

The construction industry generally is fast becoming a profitable sector like any other business although it fluctuates according to the law of demand and supply. According to the research carried out, construction activity amount to 6-9% of the GDP of some countries, and approximately 9% GDP of the world. It is about the largest industrial employer in the world and accounts for almost 7% of the total employment worldwide. This forms more than half of the fixed capital formation as infrastructure and public utilities capital works essential for economic advancement (Chitkara, 2014). According to the survey carried out by *Engineering News Record* (ENR) the total construction industry spending in 2004 amounts to $4 trillion dollars. The role of the construction industry in a nation's economic development cannot be overemphasised as indicated by Crosthwaite in the year 2000 (Horta et al., 2013). The Construction industry produces facilities that aids production of other goods and services needed for daily activities. It is becoming highly competitive and cyclically sensitive. Most of the reputable players within this sector are adopting strategies that will make them highly competitive on the global stage. Due to this strategy some of the western construction companies are moving to a cheaper location where the running cost can be well optimized. Indirectly trying to improve overhead cost to be globally competitive and thrive more in the sector. In Europe, the construction industry sector contributes to about 7% of total employment with about 20 million operatives estimated to be directly engaged in this sector. The Construction Industry Federation stipulated that construction output in Europe came to about €1241billion in 2015 which is expected to increase to €1290 billion in 2017 (DBIS, 2013). Almost 44 million workers are directly or indirectly involved in the European construction sector contributing more than 10% of the GDP and 50% gross fixed capital formation which represents about €1.36 trillion in 2011 (Enquirer, 2017). The UK will be considered to be Europe's booming market, overtaking Germany to be the sixth largest construction market in the world (OxfordEconomics, 2015). In the UK, the construction industry contributes immensely to the economy, when it was an integral part of the EU it accounts to about 7% of the GDP with €110 billion in expenditure (Potts, 2013). At the moment the UK government is planning to invest £500bn on both infrastructural project and innovation by 2021. According to *Construction Enquirer*, there is a plan by the government to build 1 million homes in the year 2020 (Enquirer, 2017). The global construction market is to grow up to $8 trillion by the year 2030 which will be driven solely by the US, China, and India. It is also expected that the rate of growth will be rapid compared to the overall economy making it more viable for future investments as forecasted (OxfordEconomics, 2015).

In Africa, according to the Deloitte research carried out in West-Africa over $116 billion was channelled into large scale infrastructural development projects (Enquirer, 2017). This amounts to 26% of all projects in Africa. Nigeria and Ghana respectively have both 19 & 15 projects which represents 24% & 19% of the West-African region. An Influx of infrastructural projects into the Economy will drastically improve the GDP and cognizant effort needs to be put in place to ensure the projects meet their aims and objectives (Labuschagne, 2015).

In Northern America (US), the government spent upto $305 billion on highway projects which connects road in the country thus making access to basic amenities possible. Also Housing and Urban development received a boost by investing close to $48.9 billion in social housing projects between 2016-2017 (Oxford Economics, 2017).

Investmentincleanenergy projects (Renewable energy) will eventually boost the construction industry sector in the country (Reportbuyer, 2016). In the far East (China) constructionactivity remains alarge percentage of the country's GDP. The market for these activities is quite enormous more than one-third of all the buildings in the world are being built there. A total of €12 trillion was invested into the construction industry in the year 2012 (Sector, 2013). A series of construction projects are going on globally which has a tremendous impact on the economy so the need to pay more attention on cost improvement,cost performance and reduce cost overruns becomes inevitable. In this present era the survival of this key economic sector relies mainly on effective infrastructure project management.

Many factors affect the effective delivery of the goals and objectives of carrying out an infrastructureproject one of which is the reliability of cost estimation. The main focus of this research will be the construction (Infrastructure) cost management and how improvement will be made by accommodating uncertainties.

2.1.2 UK Construction Industry overview

The UK construction market is quite promising despite the economy uncertainty surrounding Brexit but considerable amount of investments in infrastructural project such as High-speed rail, green energy, high rise buildings and nuclear power station project has been observed (McGuckin, 2017). This is a boost to major regional centres in the country thus providing the jobs needed for the populace. Currently, the construction industry sector in the UK can stimulate both employment and economic growth concurrently due to its reliance on massive supply chain contributing immensely to the economy. The Confederation of British industry reported that the construction industry relies solely on materials manufactured locally (UK) leading to reinvestment in other sector thus augmenting economic activities within the (Enquirer, 2017). There is no doubt that a great interconnectivity is observed within the construction industry with respect to other sector of the economy. Financing infrastructure project is capital intensive which requires strategic planning from the onset. The ability for construction firms to access the appropriate funds to finance infrastructure project is quite important for their growth and operation (DBIS, 2013).

2.1.3 Infrastructure project management global overview (Construction)

The term infrastructure refers to all physical assets, equipment, and facilities of interconnected transportation and energy systems, as well as the necessary service providers, as well as the underlying structures, organisations, business models, rules, and regulations that are used to provide specific commodities and services (Demirel et al., 2021).

Infrastructure investment is critical to the success of the world economy. Good infrastructures enhance the economic potential (Lee, 2019). It provides the foundations for economies to grow and lives to improve. For example, the transport infrastructure enhances mobility and promote agglomeration effects. Also, energy infrastructure provides economic security and deliver low-cost power to fuel wider industry (Lee, 2019).

It is envisaged that by the year 2030, around $5.25 trillion will be spent a year on infrastructure projects globally with the US spending the lion's share of about $774bn by that date, India $432bn, Australia US$142bn while the UK will be spending $84bn respectively (Lee, 2019). According to Lee (2019) the $5.25 trillion will be funded mostly by the taxpayers.

IPA (2019a) stipulates that delivering major projects successfully is intrinsically tedious. Many of the major infrastructure projects handled by the government are of large scale, and technically complex (IPA, 2019a). Most of these large-scale projects are often tasked to be delivered on an aggressive timescale set early in their lifecycle. Typically, the key stakeholders expect these projects to be delivered on agreed schedule and budget respectively, especially as taxpayers publicly fund them. This invariably leads to informed or uninformed criticism from key stakeholders (public and government institutions) as well as the media (IPA, 2019a). Much of the past century has witnessed an increased tendency for large infrastructure projects to be funded by government. In the UK, the government is committed to improving and renewing existing infrastructure. The Major projects infrastructure authority and National infrastructure Commission created a £37 billion National Productivity investment fund to be spent on long-term infrastructure projects nationwide (HMTreasury, 2019b). According to Lee (2019), it states that 80% of all large projects globally experiences cost or programmes overrun. There is an urgent need for the infrastructure project management professionals to be more proactive in delivering benefits at a reasonable cost to justify investment. The UK government is funding large projects such as HS2, Crossrail and other Railway infrastructure enhancement projects which are digging deep into the treasury. These projects are delayed and experiencing cost overruns which is making politicians as well as the public furious.

Plimmer (2018) of the *Financial Times* reported that the Crossrail-project is presently overrunning by the amount of £600M, which the public are seriously furious about. Some of the professionals in the infrastructure Project management and delivery sector are complacent on the issue, insinuating that for a project of that magnitude, it is naturally expected. It is about time to start thinking differently on infrastructure project delivery and taking cost and time overrun seriously but not as a norm in the project control and management world. Irrespective of why a project has been initiated the timeline and budget are always constrained. An infrastructure project like Crossrail (one of Europe's largest infrastructure projects) is made up of professionals who are savvy in project control and management approaches, still went over budget in time and budget consecutively. Another similar capitally intensive project, HS2 (High speed rail) with a budget of £55.7B is going through a cost and time overrun ordeal like the cross-rail project and despite being handled with brilliant project control and management. Plimmer (2018), of the *Financial Times* states that one of the causes of delay in the Crossrail project was due to the engineering challenges faced in burrowing tunnels underneath the heritage buildings in London. The biggest ordeal was due to a software integration delay experienced at the signalling system between a split of TFL (Transport for London), Crossrail & Network Rail. This was due to software testing that was not fully developed when needed (Plimmer, 2018). One could not have imagined that a project with brilliant project control and management professionals of that magnitude wouldn't have envisaged a potential risk like software testing would eventually lead to massive cost overrun in the project and resulting to revenue loss for TFL (Transport for London).

Another similar project situated in California (USA) named the California High Speed-Rail project is running over budget as well. Nagourney (2018) of the *New York Times* reported that California High Speed initiated in the year 2008 on a budget of $32B has doubled its budget over a decade and may likely skyrocket to $100B with an estimate delivery date of 2033. One of the major issues cited was a delay in acquiring enough Right of Way (R.O.W) before embarking on actual construction. A project of that magnitude with experienced professionals should have envisaged a potential risk like Wight of way (R.O.W) acquisition during high level risk and uncertainty identification at the initiation stage and put appropriate measures in place to manage or mitigate it to an acceptable level. Proctor (2018) from *Power magazine* reported about a nuclear project in Australia executed by EDF (Electricity de France) that announced a cost overrun which has tripled from the initial cost of $3.4B to $12. 75B. This project was initiated in 2007 and was scheduled to be delivered in 2017 but due to unforeseen issues, the delivery date has shifted several times. One of the latest cost of delays was due to faulty weld joints. Another major cause of the delay was due to the problem involved in the design of the reactor's digital instrumentation and control system (Proctor, 2018). These issues also should have been robustly identified as either high level risk or uncertainty before them becoming substantial issues for key stakeholders. These infrastructure project issues witnessed across different geographical locations is not a coincidence but a common trend that has persisted for years with no clear-cut resolution. Infrastructure projects are becoming more complex and complicated than envisaged (Clegg et al., 2002). The scope of this thesis work is focussed on UK infrastructure projects but for learning purpose it is appropriate to compare it briefly with some similar projects overseas. There should be a paradigm shift in managing infrastructure project. A new approach is needed in delivering infrastructure projects of these kinds.

Hoverstadt et al. (2019) states that the pressing need to shift the approach utilised towards managing project was due to complexity and uncertainty. He further postulated that in an uncertain and complex environment you can't fix these variables (requirement, time, and cost) and expect it to hold. Most of the project management approaches utilised in the present day are not completely designed to cope with complexities and the uncertain environment in which infrastructure project is being carried out. A need to understand the relationship between complexities and uncertainties become inevitable to deliver project successfully. Dunovic et al. (2014) suggests that due to the complexity, interests, role, significance, and level of uncertainty in large-scale projects, alternative management approaches are required a times specifically modelled for a type of project. Some of the large-scale infrastructure projects are characterised as uncertain, complex, politically sensitive, and also involving multiple partners (Clegg et al., 2002). Most of the time they are carried out under particular conditions which are of high uncertainty, ambiguity, and complexity with massively tight budget, and also managed in the context of very complex operation (Marrewijk et al., 2008). The adequate understanding of complexity of the project is paramount for project management due to the association with difficulties in decision making as well as goal attainment (Remington et al., 2009). In most cases it has been found in complex project failures that key stakeholders are unable to discern the level of project complexity faced. It has been noticed that they often recognise these complexities far too deep into the project then it becomes cumbersome to regain control to keep it in check (Leroy, 2005). It is advisable for the project key stakeholders to be aware of the level of complexity right from the beginning (Initiation stage) to develop an appropriate strategy and assign key competent resources to it (Dunovic et al., 2014). According to Williams (2002) complexity is compounded by uncertainty. Danilovic and Browning (2007) further argue that project complexity is the source of uncertainty in project. To reduce the level of complexities of a project a robust understanding of uncertainties is quite crucial in managing infrastructure project. Krane et al. (2014), back this assertion by stating that uncertainty analyses are utilised to get answers to questions about the expected cost estimate and expected final delivery date, respectively.

The scope of the research work is focused on infrastructure project uncertainties and risk identification using system thinking approaches during the initiation stage but since most complexities are associated with infrastructure project, it is advisable to understand the construction projects concepts, processes, and stages, respectively.

2.1.3.1 UK Rail infrastructure project

The infrastructure sector is at an exciting and pivotal point in its development. The situation of infrastructure in many wealthy countries throughout the world is becoming increasingly urgent, with costs rising as time goes on. Transportation infrastructure investments account for 31% of global capital expenditures (Abeysekara et al., 2021). Transportation is one of the most significant components of infrastructure since it touches millions of people on a daily basis and is a requirement for most forms of labour and trade, from the daily commute to freight transit. The urban rail network is especially important in today's rapidly urbanising world because infrastructure failures can have significant economic ramifications for both the operator's finances and customer time expenses (Xuto et al., 2021). In today's rapidly urbanising globe, one mode of transportation stands out in particular: the urban rail network. Indeed, in the twenty-first century, when the most important world cities, such as London, New York, and Tokyo, generate a disproportionate share of not only economic output but also cultural and political influence within their respective countries, it is only natural to pay special attention to their infrastructure (Anupriya et al., 2020). Furthermore, compared to other modes of transportation in large cities, rail is one of the most important transportation components of a city because it can provide large volumes of movement at relatively high speeds, allowing workers to get to their workplaces at relatively low economic (Legaspi et al., 2015). Due to the effectiveness of this means of transportation there are lots of investment in this particular sector of transportation. For example, in China, more than US$84 billion has been set aside to build and modernise rail systems in a number of cities, including Guangzhou, Guiyang, and Wuhan (Li et al., 2022). According to NEWS (2021), the European Commission has unveiled a significant infrastructure investment strategy that aims to raise up to €300 billion in global development investments by 2027. The American counterpart spends about $400 billion annually on public infrastructure projects (Schwartz, 2021). In the UK precisely, £650 billion will be spent on infrastructure project in the next decade (Authority, 2019). It is very clear that there are many infrastructure projects activities going on in the world. Despite the benefits of public infrastructure projects, the limited cash available from public tax coffers and the large number of potential projects make infrastructure investment selections both difficult and consequential (Sobieralski, 2021). According to Smallwood (2021), infrastructure and public services that we rely on every day are important to our country's success, economy, and well-being.

Over the next year, contracts worth between £21 billion and £31 billion in economic and social infrastructure will be placed to market, with a total value of £650 billion expected over the next ten years (Smallwood, 2021). Many capital project investments are planned in the UK which requires careful and adequate management. To achieve the UK government target objective, there is need for project delivery team to be able produce robust early cost estimate. This research work focuses on the improvement of UK's rail infrastructure project early cost estimation.

2.1.3.2 UK Rail Infrastructure project investment

The railway network is a vital national economic asset that requires significant and ongoing investment. Because much of the core network was built in the nineteenth century, a balance must be achieved between maintaining an ageing system through operations, maintenance, and renewals while also investing in innovations and new projects (Shapps, 2021). Enhancements have been a major focus during the current rail control period (CP5, 2014–2019), with an ambitious programme of highly specified railway electrification, major station rebuilding, and line capacity and speed improvements. The full electrification programme could not be completed within the revised CP5 upgrade profile, so spending had to be cut. This resulted in the abandonment of three electrification schemes in July 2017 on the Midland Mainline (MML), the Great Western Mainline (GWML) in south Wales, and the Lakes Line (LL) from Oxenholme to Windermere (Shapps, 2021). Most of the planned railway infrastructure projects have been fraught with many uncertainties with should have been adequately identified prior to project execution commencement. According to HMTreasury (2021) the UK government is still committed to improving infrastructure in the UK in order to boost economic growth and provide opportunities for people across the country. Excellent progress has already been made to improve the UK's infrastructure. Since 2010, the UK has invested more than a quarter of a trillion pounds in infrastructure. On the ground, this funding has resulted in significant activity. Thousands of major road and local transportation projects, as well as enhancements to hundreds of rail stations and more than 20GW of new energy generation capacity, have now been completed across the country (HMTreasury, 2021). It is imperative to ensure that UK rail infrastructure projects deliver the cost-benefits as planned in the business case.

The Network rail is the main management of UK rail infrastructure projects and asset via the department of transport. Network Rail is a non-profit organisation that manages, maintains, and improves Britain's rail infrastructure, which includes track, signalling, bridges, tunnels, level crossings, and several important stations. Network Rail was classed as a public sector organisation in September 2014, which means it is now accountable to Parliament for its operations and finances (Networkrail, 2021b). Network Rail is supported by a combination of public and private investment, with revenue coming from three sources: direct government subsidies, rail access charges paid by train Operating firms and freight companies, and commercial property (Enquiries, 2020). Network Rail previously raised debt finance for capital spending by issuing government-backed bonds, but following reclassification, it now borrows directly from the government (Enquiries, 2020). According to Morse (2014), the production of quantitative benefit–cost ratios is at the heart of economic analysis. However, because these ratios are based on estimations for several decades ahead of time, they are naturally vulnerable to change as time goes on and new data becomes available. This depicts that there is dearth of required information at the beginning of the project to produce robust early cost estimate that will take cognizance of uncertainties. Many of the UK infrastructure projects cost have been estimated wrongly due to lack of adequate early information. This has led to cost and time overrun. Below are some of the troubled infrastructure projects that has caused the UK government huge amount of loss.

According to Graham et al. (2017), Government and project delivery team rush to choose preferred initiatives, devoting less than a third of project development time to the essential early stages of options analysis. If you don't pay enough attention to the early stages of the process, you can miss out on superior possibilities. This may have been the case with the Thames Tideway project, where viable options were dismissed too soon and not examined even after estimated prices skyrocketed. In some cases, uncertain long-term forecasting could be used to approve projects that are costly and difficult to implement, as some have claimed was the case with Heathrow's third runway and Hinkley Point C (Morse, 2017). Battersea power station happens to be another conundrum for the London authorities is an extension to the Northern line to the landmark redevelopment at Battersea Power station which ran a year late due to project complexities (Sabah, 2019). This issue would have been envisaged earlier if adequate information about the early stage was known. Another known project that was delayed drastically was Crossrail project. The project was delayed because of signalling and civil problems. This was costing taxpayers £30m a week in cash as it struggles to reach completion (Gardiner, 2019). The civils issue would have been envisaged early enough if adequate or holistic view was carried out during the initiation stage. According to Varun et al. (2020) underground construction is always fraught with dangers due to a lack of information of the current geological conditions at the job site, as well as other unknowns. It is pertinent now to properly understand the early-stage information so as to forestall any surprises during the project lifecycle.

2.1.3.3 Construction project early cost information

Budget, timing, and quality are three interdependent limitations that must be met for a successful construction project. During the building phase, project quality can be reviewed and enhanced, although budget and time must adhere to the contracts' agreed-upon estimates (Wang et al., 2022). These estimations have piqued the interest of both contractors and stakeholders (Azman et al., 2013). Accurate cost estimating allows stakeholders and decision-makers to undertake more logical feasibility studies prior to project start-up, decide the financial scale at the bidding stage, and regulate and monitor cash flows during the project's building phase (Shehu et al., 2014). Cost overruns and/or financial losses for stakeholders and/or contractors are common outcomes of projects with underestimated costs (Wang et al., 2022). Several ways to effectively estimate construction costs have been used in practise and advocated in the research to avoid losses and satisfy project profitability goals, (Shutian et al., 2017). The most common methodologies for cost estimation are qualitative and quantitative assessments. Qualitative methods depending on expert assessments may be skewed and result in erroneous estimates (Asghari et al., 2020). As a result, a growing body of work has employed classic statistical approaches (such as regression analysis) and machine learning (ML) methods (such as support vector machine (SVM), decision tree (DT), and random forest) to solve cost estimation issues (Wang et al., 2022). These methods are completely based on hard information used in cost estimation. Few literatures have dealt with soft information required in cost estimation process. Since most of the qualitative method of cost estimation is based on expert knowledge/judgement of the estimators which is bound to be biased in nature. These elusive features have received little attention, despite their importance in shaping project cost management decisions(Abidin and Azizi, 2021). It is high time that studies on the impact of soft information on cost estimation should be taken into consideration by project management team. Understanding the impact of soft information in cost estimation process will aid in producing a robust early cost estimate. There is dearth of required information to produce a robust estimate at the early stage, the estimation procedure provides a conclusion with a high degree of uncertainty (Azzeh et al., 2022). Wiebe (2010) explains that soft information is subjective and it is based on feelings and perceptions. Ability of the project delivery team to indulge in holism during early cost estimation process will mitigate the impact of biases. There are a lot of information transfers (Hard and soft) during the early stage of an infrastructure project estimate process. Below is a diagram showing the information transfer during the early-stage estimation process.

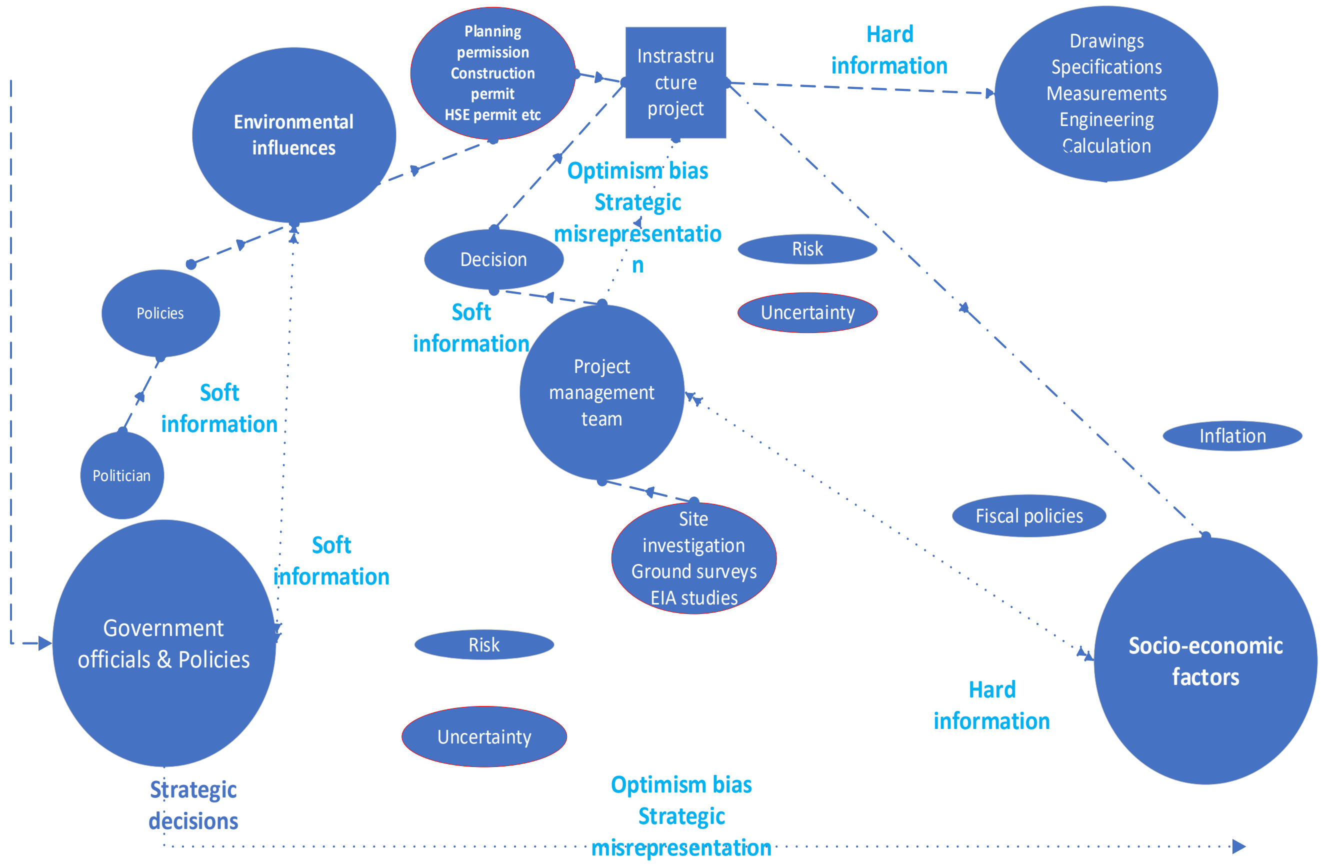


Fig 2.1 Early estimation process stage information transfer

At the early stage of an infrastructure project, much information is unknown to the project management team and the stakeholders. Construction cost prediction has traditionally been a procedure that heavily relies on the expertise of professionals. Large agencies or corporations may have adequate facilities and information on previous construction projects to build an in-house cost database (Hatamleh et al., 2018). Many others, who lack professional knowledge or resources, may be forced to rely on a commercially available construction cost index. Most of these databases or sources of information solely analyse past prices, neglecting the trend and value of stock market indices and other market indices. Then, based on specialists' expertise, cost estimates are produced and updated, perhaps leading to even lower accuracy (Su Zhang et al., 2017). All these information at the early stage required to make a robust estimate are solely based on hard information. Infrastructure projects are driven by societal demand and political biases, there are a large number of stakeholders involved a result, subjective, soft informational inputs will be flowing in from all angles. As a result, an estimate will always be a mixture of both soft and hard information respectively (Input and output). Liberti and Petersen (2017), argues that if any of the data is qualitative, it cannot all be represented by a single numerical figure; instead, an experienced person must make a decision. This means that an estimate should be regarded or viewed as both hard and soft data that requires human interpretation rather than absolute figure for project cost. These soft information stems from decision making, expert knowledge/judgment from both stakeholders, clients and subcontractor which are susceptible to biases or optimism biases. This eventually makes the cost estimate inaccurate at the early stage. As shown above in Fig-2.1, there are many information transfer interplay between soft and hard information which needs to be properly understood and can easily subject the output of an estimate to error. It will be appropriate for the project management team to be involved in holism and take cognizance of all internal and external factors that may impact on the early cost estimate. An average to high system thinking capability of the project management will be readily beneficial to produce early cost estimate that will take cognizance of uncertainties (Unknown/Unknown). This research assesses the system thinking capabilities (soft information) of infrastructure project delivery team in chapter 3.6.6 & 3.6.7.

2.1.4 Construction project lifecycle.

The key aspect of the uncertainties identification in infrastructure project is the adequate understanding of the construction project lifecycle. Each stage of a construction project is quite distinctive and for the purpose of this research work, the focus is on the initiation stage. At this stage, there is vague knowledge of the infrastructure project, and it is quite prone to error or misjudgement of the estimate.

Construction projects are a specialized form of project which can be capital intensive due to the purpose and skills involved. Due to the nature of the process involved in actualizing the objectives a need for adequate management and technical expertise is quite essential. Construction in the real term means the art and science to create or form an object, system, or organization (Potts, 2008). To adequately understand the mechanism (Interrelationship, interdependencies & interconnectedness) of project processes/stages/groups, project lifecycle study becomes inevitable. A description of the project lifecycle was done but with the focus on the early stage of the project.

According to Fewings (2005) the project lifecycle commences where there is a formal recognition of project objectives, also known as inception and through to the formal delivery of these objectives. In construction project, the inception stage is where resources are acquired for the project work. This is where vague information about the project is acquired, and the project budget is being produced. At this stage of the construction project, the level of uncertainties is quite high. Many different approaches are being utilized in describing the various construction stages/phases depending on the viewpoints of participants involved. There is a need to be more flexible in the view of the construction project lifecycle due to the various procurement strategies used in sourcing for resources (Fewings, 2005). The Design, Build, Operate and Finance procurement route has a higher representation of the contractor throughout the construction project lifecycle compared to the traditional route. This research work utilizes RIBA (Royal Institute of British Architect) plan of work to adequately describe the construction project. The stages of the RIBA construction project lifecycle are described below as follows:

2.1.4.1 RIBA Plan of work

0-Strategic definition

This is the first stage of the construction project lifecycle according to the RIBA document. This is an ongoing process document utilized to define the client's project requirements. It describes the project requirements in detail to allow the employment or acquisition of consultants. It is further expatiated to accommodate the comments made by consultants to allow for feasibility studies (Designingbuildings, 2019a). According to RIBA (2013), a strategic brief is prepared to enable strategic definition of the project. This may include site consideration, project outcome and assembling of project team. The key elements of the strategic definition stage are listed as follows:

- Strategic brief
- Business identification
- Core requirements (RIBA, 2013).

The key task at this stage is the establishment of the programme by noting the time frame.

At this stage of the construction project there is only vague information to produce budget. The level of uncertainty on the project is very high and a robust strategy is required to identify core uncertainty factors that may impact on the project adversely.

1-Preparation and Brief

This stage elaborates more on the strategic definition and develop the project objectives to include quality objectives as well. This stage is very important to the commercial success of the project due to the production of a budget. The initial project budget production is quite vital and may determine the overall commercial success or failure of the project, respectively. The main consideration to produce this budget is quite important and it should be robust enough to mitigate the impact of cost overrun to an acceptable level to the key stakeholder. The focus of this research is at both stage 0 &1 due to the production of an initial project budget where the cost estimate is being done. Listed below are the activities done in this stage according to RIBA work plan document of 2013:

- Embarking on comprehensive feasibility studies.
- Business case development.
- Sustainability objectives.
- Project budgets.
- Constraint parameters (Risk assessment).
- Site information (RIBA, 2013).

The listed activities below are the key events done at the stage, but other sub-activities are being done as well.

2-Concept design

This stage consists of the development of the concept design generated from the project brief. Initial drawings from the designers are developed gradually. Preliminary cost information is generated from this stage as well a final project review. The key activities at this stage are the final production of the project brief and strategies that will be utilised for the designed programme, respectively. Most of the uncertainties that may affect the project cost estimate are gradually known to some extent therefore the research work wouldn't entail this stage but just the stage 0 & 1.

3-Developed design

The concept design is developed at this stage appropriately to generate further cost information to produce a project cost estimate. Structural and building services systems for the project are produced and outline specifications are updated as well. The level of uncertainty at this stage is reduced drastically due to additional information known to produce a realistic estimate for the project. Listed below are the key activities done at this stage.

- Completed project brief
- Developed design
- Update cost information.

4-Technical design

A detailed design for the construction project is developed in accordance with the design responsibility matrix and project strategies, respectively. This includes all structural and architectural works. Updated design specifications and drawings are done at this stage in preparation for actual construction work (Execution).

5-Construction

The mobilization of all contractors to the work site to begin construction is done at this stage. The administration of all building contracts to completion are being done at this stage as well to ensure contractual requirements are met. The activities done at the stage listed as follows:

- Offsite manufacturing and onsite construction according to construction programme.
- Contract administration to deal with any design queries

6-Handover and Closeout

This stage involves completion of all construction contractual requirements to specification and handed over to the final user.

7-In-use

Post construction activities are done at this stage by reviewing performance of the project. The end-user uses the product delivered according to specification. In this research work, the focus is on stages 0 & 1, respectively. In respect of the RIBA plan not all construction projects follow these processes or stages. It all depends on the type of procurement route utilized for the execution of the project. It is of the best interest of the research to utilize the RIBA plan since the case-study information will be derived from UK infrastructure projects. Based on the UK rail infrastructure project, Governance for Rail investment projects (GRIP) is used for the project lifecycle which is explained below in Fig 2.1.5

2.1.5 Governance for Railway Investment Projects (GRIP).

GRIP (Governance for Railway Investment Projects) is a critical Network Rail process for effective ```project control (Ozonzeadi, 2018). It gives a structure to the life cycle of Network rail projects, similar to the RIBA Plan of Work, TFL Pathway, Prince2, APM, and PMI frameworks, and consists of eight stages from determination of necessary outputs to handover for operational usage and project closure. Each stage is intended to produce a pre-determined set of outputs that demonstrate the project's preparedness to move on to the next stage, or not (Ozonzeadi, 2018). There are eight stages involved in the GRIP which are explained below as follows:

- Output definition
- Feasibility
- Option selection
- Single option development
- Detailed design
- Construction test and commission
- Scheme hand back
- Project closeout (Networkrail, 2021a)
- **Output-definition**: This involves defining the project's outcome, requirement, needs and opportunity.

- **Feasibility section**: Define the investment's scope as well as its limits. Confirm that the outputs are both cost-effective and consistent with the network plan. Solution-finding in response to the needs. Prior to the option selection section an approach (Office of Government Commerce) is followed to produce an initial project cost estimate. This is discussed separately in Chapter 2.1.6.
- **Open selection section:** It deals with the creation of choices for dealing with restrictions. Assesses and chooses the best solution for meeting the needs of the stakeholders, as well as confirming that the products can be supplied cheaply.
- **Detailed design section**: It deals with the production of a thorough, reliable engineering design that serves as the foundation for accurate cost, time, resource, and risk estimations.
- **Construction test and commission section:** It involves delivering in compliance with the specification, as well as testing to ensure that the system is operating as intended.
- **Scheme hand back section**: This is the stage where asset management are handed over to the operator and maintainer from the project team.
- **Project closeout section**: This section involves completing the task in a timely manner. Accounts are resolved, and any contingencies or warranties are in place. A benefit assessment is carried out (Networkrail, 2021a). This research focuses on the early cost estimate produced at the output- definition and feasibility study stage by taken cognizance of all uncertainty factors.

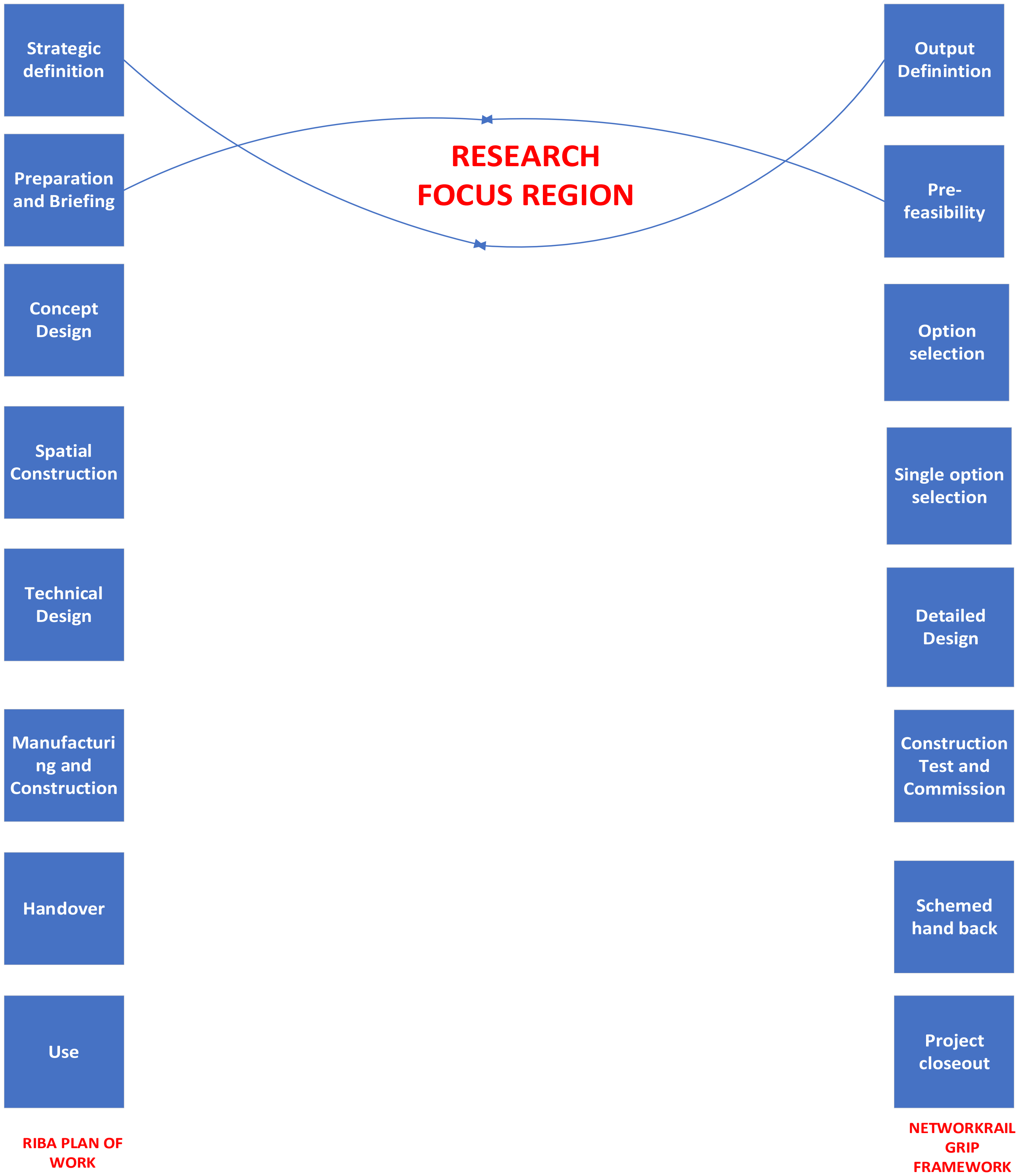


Fig-2.2 Diagrammatical illustration of the research focus area using the RIBA plan of work & Network rail Grip framework (Project lifecycle)

At the (Strategic Definition-Preparation/Briefing-RIBA plan of work) &(Output definition/Pre-feasibility study-GRIP), most of the information about the infrastructure projects are not well known and understood. The rough-order-estimate is produced here, and most strategic decisions are made based on it which is subject to errors or biases. An office of government commerce framework is used to ensure project value for money. The use of this framework starts from the output definition of the GRIP. It is described in fig 2.1.6 of this thesis. There is need to fully understand how the OGC framework process works to ascertain where focus section of this research work.

Producing a robust estimate that takes cognizance of uncertainties to mitigate the impact of cost overrun during the project lifecycle is quite importance for the success. It is pertinent to ensure that project management team utilizes holistic measures at the beginning of the project to identify uncertainty factors that may impact on the early estimate. The soft and hard information in the early estimate was determined in this thesis.

2.1.6 Office of Government Commerce framework (OGC)

OGC is a stand-alone department of HM Treasury that was created to assist the government in getting the most out of its spending. To ensure the accomplishment of six goals, the OGC collaborates with central government agencies and other public sector organisations (IPA, 2021). These six goals are stated below as follows:

- Delivery of value for money from third spend,
- Delivery of projects to time, quality, cost and realising benefits.
- Getting the best from the government
- Improving the sustainability of the government estate and operations
- Supporting the delivery of government policy goals
- Improving the central government capability in procurement, project and programme management and estates (IPA, 2021)

The OGC framework is meant to provide guidance about best practice in procurement and project management. It provides a framework for projects using these procurement approaches, centred on a series of independent peer evaluations completed at crucial points to confirm that projects should be permitted to move on to the following stage (DesignBuildings, 2022). This framework is used prior to the design phase according to the GRIP framework discussed in fig 2.1.5. There are five review processes followed which are listed below:

- **Gate review 0: Strategic assessment**: is the initial entrance. It is a programme evaluation that occurs before a decision is made to move forward with a project; it looks into the direction and anticipated results of the programme. The project that is being suggested is strategically evaluated, together with its drivers, benefits, and contribution to the overall business plan. High level options are also taken into account. (DesignBuildings, 2022). This is produced following the production of the programme brief (Output definition, according to the GRIP framework) or the initial version of the programme business case (IPA, 2021).
- **OGC gateway review 1: business justification:** It occurs after the feasibility studies stage once the preferred option's business case has been created. Prior to the crucial decision on whether to approve the development proposal, the evaluation concentrates on the project's business basis (DesignBuildings, 2022). Additionally, it is used to concentrate on defining, comparing, and establishing the tracking system for the benefits the Program will provide (Daniels, 2016).
- **OGC gateway review 2: delivery strategy:** this section involves concentrating on developing a precise definition of the project and a strategy for carrying it out. Any untested hypotheses from the project's business reason should now be confirmed (IPA, 2021). Also, the Project Board, wider Centre, and Departmental/Agency leadership are reassured by this Gate Review that the suggested delivery strategy is appropriate. It assesses the project viability, potential for success, value for money and proposed for achieving the delivery project’s objectives (IPA, 2021).

- **OGC gate review 3: investment decision:** this section investigates the Full Business Case and the governance structures for the investment decision to make sure the project is still necessary, feasible, and timely. The Gate Review will assess the viability of the implementation plans (IPA, 2021). Make arrangements to monitor risk allocation throughout the project lifecycle, including the amount of risk transfer, and ensure that risks are allocated to partners that are best prepared to handle them. Think about using incentives. Verify that the contract paperwork reflects business requirements. Comparing the updated estimate to the budget (DesignBuildings, 2022).
- **OGC gate review 4:readiness for service :** this section is to make sure that the project is fully prepared for its completion and that all regular and customary operating factors, finance considerations, and commercial dimensions are now firmly established (IPA, 2021). It also determines whether the organisation is prepared to move from the specification or solution to implementation and "go live." When necessary, it will evaluate the skills of service providers and delivery partners (IPA, 2021).
- **OGC gate review 5:** Operations review and benefit realisation: This Gate Review attests to the accomplishment of the benefits outlined in the Business Case, the smooth operation of the operational service (or facility), and the achievement of the agreed-upon strategic outcomes. This Gate Review can be conducted repeatedly over the course of the service, with the initial Gate Review typically taking place as the project is about to transition to Business-as-Usual operation. One-time use of this Gate Review is also possible to ensure that a project has produced the anticipated results (DesignBuildings, 2022). Understanding the OGC framework will enable the research work to focus on the stage where there is dearth of information prior to project initiation.

2.1.7 Construction project types

A construction project is a specialized form of project which can be capital intensive due to the purpose and skills involved. Due to the nature of the process involved in actualizing the objectives a need for adequate management and technical expertise is essential. Construction in the real term means the art and science to create or form an object, system, or organization. It is generally classified into three sectors building, infrastructure and industrial which is further segmented as well.

- **Building construction project**

  This is carried out to construct residential and non-residential project which can be termedcommercialorinstitutional,buildingsforhomes,offices,hospitaland institution etc.

- **Infrastructure Construction Project**

  Infrastructure project can be categorised as basic structures,systems and services required for operation.They can grouped into two major parts such as business and technology infrastructure(Information Technology and Soffware development) and economic infrastructure (Wrike, 2018). This involves heavy engineering facilities such as large public works,dams, bridges,highways and railways etc.The focus on thisresearchismainlyoneconomicinfrastructuresuchastransportation infrastructureprojectthatimpactontheeconomydirectly.

  According to Designingbuildings (2019a) infrastructure isdescribed asthe interconnected organisationalstructuresthatunderpinsocietyandensureitfunctions adequately. IPA (2019a) defines it as assets necessary tofacilitate the flow of supplies required by society.This characteristic of infrastructure in a society makes it very important to the economy. Keen attention is needed to invest in the sector so as to ensure or maintain a robust economy.According to HMTreasury (2014) the UK government’s ambition is to equip the economy with world-class infrastructure that positions the country in a competitive advantage in the global race.The delivery of infrastructureinvestmentefficientlyandeffectivelyisparamounttothe government so as to ensure tax payers benefits from the economic dividends (Treasury, 2014). Delivering infrastructure investment efficiently and effectively is vital to ensure that taxpayers and consumers get more for less.

- **Industrial Construction Project**

  These involve heavy duty industrial facilites such refineries,power generation plants and manufacturing plants etc.

  The construction project as described above is a capital intensive programme that needs to be managed carefully with appropriate technical,managerial and organizational skills so as to optimize cost effectively.if this is not managed carefully stakeholders might be locked in conflicting interest.A lot of constraint comes into play while a project is being implemented which cannot be seen completely.Managing these two vital constraints (risk and uncertainties) is very important to successful project delivery.Planning and managing of uncertainties and risks will ensure cost is being optimized adequately thus reducing overruns

2.2 Infrastructure project cost management

Cost management in the construction industry sector is quite vital in order to effectively optimize the project profitability in terms of goals and objectives. Cost optimization in a project without achieving its business case becomes sterile. Also business case achievement without adequate cost optimization and organization becomes moribund.Thereforethere should be a balance between cost optimization and objecives achievement in a project. Many organization have received criticism from their stakeholders due to the actual inccured cost at project completion which makes them unsustainable and uncompetitive in the market. According to PMI (2013) project cost management involves planning, estimating, budgeting, financing, funding, managing and controlling costs so that the project can be completed within the approved budget.There are a lot of ways stakeholders estimate the requirements for managing costs which really affect the initial estimation process (PMI, 2013).This research work focuses on the early estimating phase of the infrastructure project where there is a high level of uncertainties/risks and where government owned infrastructure project firms were utilized for the case studies.

A project's business case generally differs from another due to the core aim.A public funded project might not be profit driven while a privately funded one maybe.There will always be a conflict of interest during project implementation (Potts, 2008). it is therefore necessary to choose the appropriate project for the research work to really understand the cost implication of improper management of uncertainties prior to project implementation.

Many projects have failed globally due to inadequate management of uncertainties which has led to mainly cost and schedule overruns.The effect of this impact have been catastrophic on stakeholders.Many case studies of improper management of construction cost have been identified and the key cause is yet to be well investigated.The norm is always overbudget or underbudget by the subcontractor.The various world acclaimed projects that have been unsuccessful due to poor cost managements are well illustrated in the infrastructure project estimating phase of this thesis. There are stages in the infrastructure project cost management which are the underlisted below as follows:

- **Estimating cost**:this can be regarded as developing an approximation/estimate of the costs of the resources needed to complete or achieve a project (Oyler, 2014). PMI (2013) further explained it as the process of developing an approximation of the monetary resources required to complete project activities.The overral objective of this process is to determine the amount of cost needed to compete the project work (PMI, 2013). The initial estimate determination is the point of concern due to the level of uncertainty involveed with the information required to achieve it.A robust process is needed not a reductionist approach to achieve the estimate.

- **Budget determination:**this is carried out by allocating overall cost estimate to individual work items to estbalish a baseline for measuring performance (Oyler, 2014).
- **Cost control:**This involves controlling changes to the budget (Oyler, 2014).

The various stages of infrastructure project cost management are numerous throughout the respectivestagesoftheproject lifecycle.Nearaccuratedeterminationoftheinitial infrastructure project cost estimation is a key determinant of the commercial or financial success of the project.According to Policy and Cohesion (1998), the preparation of the project cost estimate is a cumbersome task because infrastructure project are subject to risks and uncertainties during the early stage when very limited information about the project is available. It is easier to formulate a proactive strategy for the initial cost estimate than reactive estimate which may still be prone to errors.Understanding the key aspect of uncertainties in infrastructure project cost estimation forms a massive part of this research work.

2.2.1 **Infrastructure project costestimation**

Construction cost estimate should be the utmost priority of the key stakeholders in order to justify the initiation of a project as well as monitor it efficiently.This process involves developing an approximation of the monetary resources needed to complete the project activities. It is normally based on the known information at a given point in time (PMI, 2013). In this process cost trade-offs and risk are often considered while performing it. In order to accurately predict the construction cost estimate a robust process which will be adequately cognisant of uncertainties (knowns & unknowns) adequately is required.It will truly reduce the effect of cost overruns and invariably improve cost performance during the actual project execution.

Traditional methods of construction estimation have been utilized to initiate a project but with some errors observed. The advent of more analytical methods such as Alphaneural Networks, Fuzzy methods and Regression Model etc has meant cost estimation accuracy has been improved.This research work will be more detailed on project risks and uncertainties so as to observe close to accuracy on estimation. Below are the brief description of traditional techniques of estimation in the construction industry.

- **Analogous estimation**

This type of estimation uses the historical records of past similar projects for estimation when there is limited information available.This utilizes the actual cost of the previous projects as theyardstick for estimating the cost ofthe current project.It isdone byusingthe scope,cost,budget and duration parameters ofsimilar projects. During the early stage of a project this is readily utilized using historical information andexpert judgement (PMI, 2013). There is a tendency for errors to be observed in this type of estimating approach due to the unknown information of the project which is prone to uncertainty.

- **Parametric Estimation**

This type of technique involves using a statistical relationship that exist between a series of historical data and other delineated list of other variables.It uses some vital aspect of values such as square footage in a contraction project,codes that exist in a software application and other similar variables. This information is then analysed and an estimate is derived for the entire parameters. In terms of this technique a high level of accuracy is observed depending on the authenticity of thedata used for analysis (PMI, 2013).

- **Bottom-Up Estimation.**

This technique is quite comprehensive due to the process involved in achieving it. A typical project work scope is detailed and analysed by summing up all the activities within it. The work scope is broken down to activities and further down to task level. The resources required to achieved this task is then summed-up to give a specific estimate. The aggregates of all these tasks will determine the estimate required to achieve the activities.The method is believed to be more accurate due to the attention paid to details (PMI, 2013).

- **Top-down estimation**

The technique involves reviewing the overral scope of a project in order to identify major elementsofworkandcharacteristicsthatcouldbeestimatedseparatelyfromother elements.Practically, this is achieved by considering the scope as a whole or broken down into Product Break Downstructure (PBS), WorkBreakdownStructure (WBS) or Service breakdown structure(SBS). The overall project base estimate will be created by adding these high level estimates altogther.This type of estimating technique is generally utilized for rough order estimate where limited information about the project is known (APM and ACostE, 2019).

- **Three Point Estimation**

This involves assuming a distribution of values within the range of three estimates then the expected cost can be determined. The three estimates are Most likely(cM),Optimistic(cO) and Pessimistic(cP).

Most likely(cM): This is the cost of activity determined by assessment of effort for the required work and expected or assumed expenses.

Optimistic(cO): This is based on best case scenario of the intended activity.

Pessimistic(cP): This is based on th worst case scenario of the intended activity.

There are two popular formula used in determining this estimate which are as follows:

Beta Distribution: cE =(c0+4cM+cP/6

Triangular Distribution: cE =(c0+cM+cP)/3 (PMI, 2013)

All the above techniques of estimation are quite useful for the determination of the initial infrastructure project estimation but they are still quite insufficient to date. Cost estimate are a prediction that are based on the informationgiven at the point in time.This include the identification and consideration of costing alternatives to initiate and complete the project (PMI, 2013). The level of information knownat the initiation stage will determine to some great extent the success of the project.According to PMI (2013) the cost estimate should be reviewed and refined during the course of the project life so as to reflect additional detail when it becomes available.This technique is not robust enough in executing modern day major project which are quite complex with multiple stakeholder interest to take into account.According to Shapland (2019) major infrastructure project and programmes suffer from a possibility to cost more or take longer than initially planned.It was further explained that the reasons behind this assertion is due to the complexity of the type of project executed.Major or large projects are typically complicated undertakings with unique requirements,bringing together multiple stakeholders with various interest (Shapland, 2019). Cost and schedule estimation of major projects and programmes often carries limited accuracy due to inherent prevalent uncertainties. Also due to the inability to predict the future as a result of changing economic or political circumstances, availability of materials or labor,realities of location,all these variables works against achieving certainty (Shapland, 2019). There are a lot of factors or variables which affects the production of realistic estimate tomatch-up with final cost out turn respectively.It is high time key stakeholders in infrastructure project management be aware of the interdependencies, interrelationships and interconnectedness amongst these variables to realistically determine key uncertainites or risks that may impact on the project adversely prior to producing the initial estimate.

There are different type so estimates utilized during each stages of the construction project lifecycleare subject to available information for concise and precise estimation. They are listed as follows:

- **Rough-order of magnitude estimate(ROM)**

  Project can vary from feasibility studies or complex/large type,regardless the estimate and type of information desired may differ (Kerzner, 2006). During the strategic brief (level-0) according to RIBA (2013) where limited information about the project is known or where there are limited details of engineering data is available, a Rough-Order of Magnitude (ROM) is utilized (Kerzner, 2006). PMDocuments (2018) further assert that ROM is an estimation of a project level's of effort and cost to complete.The accuracy level of this type of estimate is between -50% to +50% or -25% to +75% depending on the source of information available at the particular time.Listed are the typical characteristic of ROM which are as follows:

  - It is a ballpark estimate utilized to provide a starting estimate to proceed in the project lifecyle.
  - A top-down estimation approach.
  - Use of expert knowledge and experience.
  - A great deal of time is not necessarily spent on estimation(PMDocuments, 2018).

  The main purpose of carrying out ROM estimate is to provide decision makers with vital information necessary to make a decision whether it is viable to proceed forward with the project or not.At this stage according to RIBA (2013) it is callled the strategic definition(Level-0) stretching to the preparation and brief stage (Level-1).This is the main focus of the research work due to the high level of uncertainties involved. Any errors at this stage may impact adversely on the project lifecycle.According to Sodikov (2005) early cost estimation is considered as the most significant starting process to influence the fate of a new project. The accuracy of cost estimation improves toward the end of the project due to detailed and precise information. The early or conceptual phase is the first phase of a project in which the need is examined, alternatives are assessed, the goals and objectives of the project are established and asponsor is identified (Holm et al., 2005).Cost estimation of construction projects with high accuracy at the early phase of project development is crucial for planning and feasibility studies.Construction key stakeholders require early and accurate cost advice prior to site acquisition and commitment to build in order to enable them to make the right decision regarding the feasibility of the proposed project (Mahamid, 2011).

- **Preliminary estimate**

Preliminary estimate is a technique for predicting the possible cost incurred for a building or construction project through a systematic calculation and preparation at the early stages of the project. The purpose of the preliminary estimate is to determine the actual cost forecast of a project and help the client to understand how much money he needs to invest in a particular project (ChongYs, 2018). According to Totaltakeoffs (2019) gives an insight into the cost of a project before detailed plans are drawn up.it is often based on templates and information from past projects. Kerzner (2006) suggests that this type of estimate is prorated from previous projects that are similar in scope and capacity and maybe termed estimating by analogy, parametric curves, and rule of thumb and indexed cost of similar activities adjusted for capacity and technology. The percentage accuracy of this stage of construction project estimation is within the range of -15%+50% respectively.

Listed are the benefits of preliminary project estimate which are as follows:

- Increasing awareness of probable costs, to gain early financial commitment.

- To determine costs for budget control.

- To inform the architects and engineers of the cost of the project and the commitments required.

▪ **Budget estimate**

The RIBA (2013) plan of wok at stage 3 is where the technical design of the construction project is being developed from the concept/preliminary stage. The developed design will be co-ordinated and aligned with cost information. Due to the availability of the design requirements from the client a representative budget of the construction project is produced. The percentage accuracy of this type of budget is within the range of -10% to +25% respectively (Chung, 2019).

▪ **Definitive estimate**

This type of estimate is well-defined from coordinated engineering data including vendor quotes, fairly completed plans, specifications, unit prices and estimate to complete (Kerzner, 2006). It is readily utilized to commence the execution phase of the construction project. At this stage all the potential known risks and uncertainties have been readily identified and inculcated into the definitive budget. The percentage accuracy of this estimate is within the range of -5% to +10% respectively (Chung, 2019). All estimates produced in the construction industry are approximations mainly based on expert knowledge and experiences (Badeh, 2019). This will be subject to some form of bias in the overall process of estimation due to the human error judgement factor. These biases in construction cost estimation are utilized in determining the contingency estimate which takes care of known risk events during the project lifecycle.

According to the Queensland Governement (2007), quantification of contingency allowances for cost estimating items are achieved by applying the risk management process but due to the uncertain nature of the assessment process.

it is cumbersome to be prescriptive as to how contingency costs should be estimated. Key stakeholders (Project managers and Estimators) are advised to use their experience and professional judgement to weigh the competing factors at the most likely value (QueenslandGovernement, 2007). Over dependency on this type of strategy leads to biases or error in construction project estimation.

2.2.2 Contingency estimation

The production of a project cost estimate is a cumbersome task due to risks and uncertainties which construction projects are subject to, particularly at the early stages when is limited information about the project is available (Policy and Cohesion, 1998). The initial project estimate is the most important estimate for the key stakeholders because they often form the basis of the solicitation for funds from project financier (Policy and Cohesion, 1998). Estimating for the unknown risks and uncertainties in construction project are vital in determining the initial project estimate. A contingency estimate is that part of the budget retained to deal with risks and uncertainties (InfrastructureRiskGroup, 2013). It is utilized to deal with situations where the costs allocated to specific activities turn out to be false where risk materialises, or uncertainties crystallise. According to Bingol (2013),the determination of the right amount of cost contingency suitable enough to be included in the budget is important in achieving the target profit margins. He further asserts that making a reliable decision on the size of contingency is very difficult. There are several factors that affect contingency cost estimation which are complex risk factors, uncertainties and the quantification is problematic due to limited availability of information at the early stage of estimation (Bingol, 2013). It is a general practice for construction project estimators to add reserve amount to the estimated project cost. The reserve amount is to absorb the monetary impact of uncertainties/risk and mitigate the impact of cost overrun to an acceptable level (Touran, 2014). Over the years many construction project professionals have utilized different approaches and assumptions for the calculation of the contingency estimate but with no clear-cut method for a particular construction project. This is the case because no two construction projects are identical during delivery. They pose different challenges and issues, respectively. Contingency has been probably the most misunderstood, misinterpreted, and misapplied word in project execution (Love, 2014). The need and amount for contingency reflects the existence of risk and uncertainty in projects. The addition of contingencies within a budget represents the total financial commitments for a project (Love et al., 2002). In a typical construction project, the contingency estimate is utilized for variability, risk events, unknown/unknown and unforeseeable situations. Variability is a form of uncertainty known as aleatory. It relates to the uncertainty of the size of variable parameters (Love et al., 2002). Robust identification and estimation of these uncertainties within the construction project during the early stage(Strategic preparation-Lv-0 & Preparation and Brief-Lv-1 in the RIBA Plan of work) is the key focus of this research work.

There are ranges of techniques used for cost contingency in construction project. The traditional technique involves adding across the board percentage to the base estimate, typically derived from intuition, experience and historical data. It has been highly criticized in various literature. It is considered to be arbitrary and with no statistical significance (Yeo, 1990).The traditional approach has contributed to a lot of projects running over budgets (Hartmann, 2000). Several attempts have been developed to better forecast the certainty of project cost estimate via the inclusion of contingency, cost over budget still remains pervasive (Love, 2014). This really undermines the accuracy and reliability of existing formulated method of cost contingency estimation. Flyvbjerg and COWI (2004) states that inaccurate budgets are a result of optimism bias. A reference class forecasting was developed to mitigate the impact of optimism bias during the formulation of the project cost estimation. There was a shortcoming in these methods due to the inability to forecast specific uncertain events that will affect a particular project (Flyvbjerg, 2008). Love (2014) postulates that cost contingency estimates have not really been cognisant of specific risks which impacts on project adversely. A holistic understanding of the interrelationships, interconnectedness, and interdependencies amongst variables within the construction project processes, phases and stages will assist in identifying the key uncertainties that impact on the project adversely using system thinking. Below are the various types of contingency method calculation

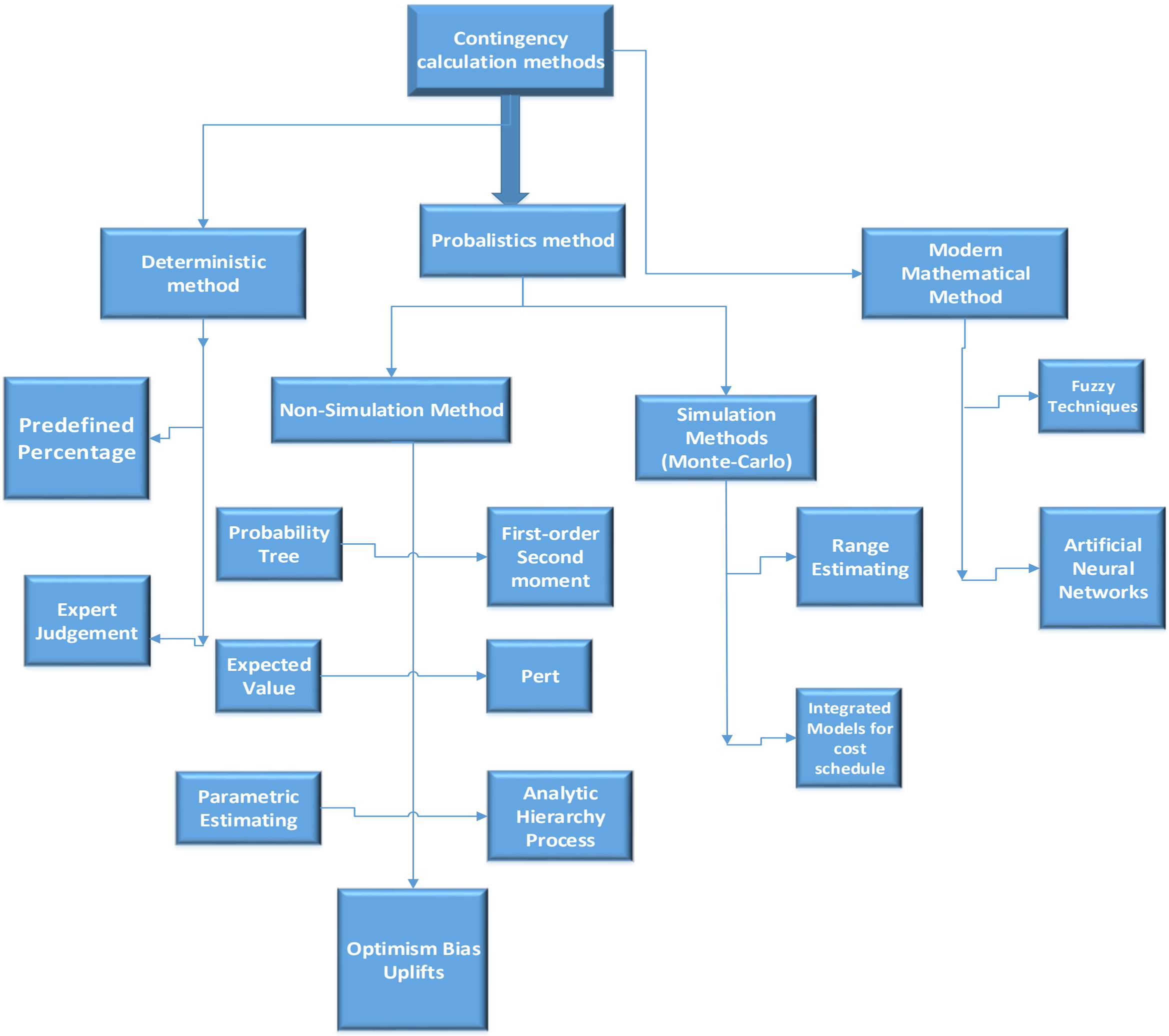


Fig-2.3 Diagrammatic illustration of contingency method (Touran, 2014)

I. **Deterministic method**

This is the most common and simplest form of contingency method used in the industry to establish contingency budget (AACE, 2008). This type of method is used when there is no formal risk assessment on a project. The deterministic approach is a point estimate for a contingency budget. It is utilized when there is no formal risk assessment for the project, considering the project complexity, location, and market condition (Olumide et al., 2010). This type of method in the contingency budget method is not robust enough to mitigate the risks or uncertainties in the project. Underlisted are the two most common types of contingency budget estimating method described below as follows:

- **Predefined percentage**: this is regarded as one of the simplest methods of contingency allocation. It involves allocating or adding predetermined percentage of amount across the base cost or various percentage of line items will be added to the project budget as contingency. According to (Touran, 2014) when contingency is added separately for each line item, it can be regarded as overall contingency as unallocated contingency added to the project on top of the allocated contingency. Each organization has its own guidelines and procedures in allocating contingency percentage. So that's why it is subjective and prone to errors.
- **Expert knowledge**. This involves group of experts in risk management process utilizing their expertise in determining the contingency budget allocation. There is a major difference between this method and the predefined percentages which is not the case in this method (Touran, 2014). This type of method does not provide confidence level for the sufficiency of contingency estimating budget for a project.

II. Probabilistic method

In this type of method uncertainties and risks are explicitly modelled using appropriate statistical distributions. This is the major difference between the deterministic and probabilistic approach (Touran, 2006). The cost estimate is probabilistic in nature, due to the nature of the risks and uncertainties associated with construction project, producing the exact cost estimate becomes almost impossible. This is why range or distribution of cost estimate is utilized today in determining the realistic estimate (Dysert, 2006). In utilizing a cost distribution one can define the level of confidence against different values of project cost. The needed contingency budget is estimated based on the desired confidence level decided by the project sponsor. In this type of method, a range of estimate are undertaken rather than a point estimate. The main advantage of these probabilistic models are that they assist the key project stakeholders to understand the possible consequences of their decision where point estimate do not have this flexibility (AACE, 2008). According to Bohn (1999) a probabilistic method normally needs more time and budget to conduct and some agencies or contractor don't employ it for this reason. Contractors with complex procurement programmes of a complex project employs them for formal risk analysis (Bohn, 1999). Listed below are the descriptions of the various type of probabilistic methods employed in estimating contingency budget.

- **Non-simulation method**

  This type of method analyses project risk and contingency estimation without the use of stimulation software package. Large complex infrastructure projects are not suitable for this method. It can be used at the early stage of a project where information about the project is not readily available. Listed below are the types of non-simulation method used in the construction industry (Touran, 2014).

- **Probability Tree**

  This provides a systematic method utilized to transform individual risks each with a conditional expected value impact and the probability of occurrence into an overall probability and expected value. It utilizes a diagrammatic representation of possible outcomes of consequences events (Parsons. et al., 2004). According to Parsons. et al. (2004) this method is not practical when delivering a large project where the number of risks becomes enormous.

- **First-Order Second Moment**

  This is an approximate method used to calculate mean and standard deviation of complex functions. The first-order second moment (FOSM) method is widely used in uncertainty analysis. It uses a linearization of the function that relates the input variables and parameters to the output variables (GUINOT, 2003).

- **Expected Value**

  Expected Monetary Value is a statistical technique that has been in use for both decision and risk management for many decades. It is used to quantify the impact of each significant identified risk, which in turn assists in the calculation of the contingency reserve (Ghorbani, 2017). This method identifies all the significant risks in the risk register. The quantified risk probability occurrence and impact are estimated. The expected value of each risk is calculated by multiplying the probability of occurrence and its impact (Touran, 2014). Below is the mathematical illustration.

  Expected Value = Probability of Risk Occurring x Impact If It occurs (Ghorbani, 2017)

  The estimated contingency is considered to be the sum of all expected values and has cumulative distribution function (CDF) when impacts are uncertain (Touran, 2014).

- **Regression**

  This type of model is utilized during the early stage of cost estimate where there is insufficient information on the project. Regression model must be simple and without unnecessary parameters and should provide best fit for data at hand

(Baccarini, 2006). It is recommended where there is a linear relationship between dependent and independent variables (Risk factors).

- **Analytical Hierarchy Process (AHP)**

  To assess the effect of risks on the projects, various methods have been proposed that utilizes probability analysis and Monte-Carlo simulation. In most cases there is inadequate information to develop the needed model for the contingency estimation. This method is a simple and flexible way of presenting project risks analysis (Touran, 2014). Subjectivity, expert knowledge, and experience are employed in carrying out this method. This is a more of intuitive and natural way of solving issues and it is subjected to errors. The process involves classifying project into Work Break Down structure (WBS) and risk analysis is done for individual work package accordingly. The risk factors and sub factors are identified, then the overall risk of the work package is determined using AHP. The contingency budget is estimated using tier-2 sections, which involves implementing PERT approach on each work package to estimate the total cost distribution. The overall estimated risks from the work package are used to calculate the targeted cost from the cost distribution (Dey et al., 1990). The contingency estimation is derived from the difference between the targeted cost and base cost.**Optimism Bias uplifts**

  This is a non-simulation probabilistic method developed by Flyvbjerg and COWI (2004) for the British Department of Transport to deal with optimism bias in capital project cost estimate. "Uplift" is the term used to show the amount that the original estimate needs to be increased to arrive at the project budget for a given level of certainty with respect to cost adequacy (Touran, 2014). It is set-up as a function of the level of risk the department of transport is willing to accept regarding cost overrun. This approach assumes that projects in future will have similar behaviour to the past projects from a budgeting perspective. These uplifts are based on a relatively small number of projects. This can be prone to errors while calculating the uplifts.

- **Simulation method**

This method combines both expert judgement and analytical method in reaching a probabilistic output using a simulation routine (AACE, 2008). A times due to the unavailability of closed-form equations, mathematical operations of distributions and analytical models become more cumbersome. Simulation is utilized to find probabilistic output. The most common simulation method is Monte-Carlo analysis in the construction industry applied in risk analysis and contingency calculation (Touran, 2014). Listed below are the types of simulation method.

  - **Range estimating**

    This type of contingency estimating method utilizes critical cost items identified and deterministic estimate of each critical cost item is considered as the most likely value. Definition of the minimum and maximum values are done by the key project stakeholders. Monte-Carlo simulation is used to calculate the total cost cumulative distribution function(CDF). According to AACE (2008) critical items are items which deviations from the target can result to ±0.5% change(Critical variance) in the bottom line at the conceptual estimate or ±0.2% at the detailed estimate. These critical items are identified using Pareto's Law.

    Only those cost items identified as critical are ranged by a project team based on their knowledge and experience.

  - **Integrated Models for Cost and Schedule**

There is importance in the direct link between cost and schedule in cost estimation. When there is no direct between schedule and cost estimate of a project, the model developed will not capture the impact of risk and uncertainty on a project. This will impact on the estimated contingency budget produced (Isidore and Back, 2002). Activity Based Costing Simulation was developed by Isidore and Back (2002) which involves the range of estimating and probabilistic scheduling. There are applied simultaneously on appropriately modelled construction project at the work break down level. In order to produce a robust cost estimate, Roberds and McGrath (2006) suggest an integrated cost and schedule risk assessment approach for infrastructure projects .An adjusted integrated cost and schedule model has been developed by Touran and Bakhshi (2010). This method considers uncertainties in cost, risk, and schedule in contingency cost estimation.

III. Modern Mathematical Methods

- **Artificial Neural Network**

Artificial neural networks (ANNs) are biologically inspired computer programs designed to simulate the way in which the human brain processes information (Agatonovic-Kustrin and Beresford, 2000).

ANNs gather their knowledge by detecting the patterns and relationships in data and learn (or are trained) through experience, not from programming. An ANN is formed from hundreds of single units, artificial neurons, or processing elements (PE), connected with coefficients (weights), which constitute the neural structure and are organised in layers (Agatonovic-Kustrin and Beresford, 2000).

ANN uses a mechanism to learn from training examples and detect hidden relationships among data for generalizing solutions to future problems (Baccarini, 2006). According to Chen and Hartman (2000) ANN is a better solution for modelling complex nonlinear relationships than conventional method such as nonlinear regression analysis.

- **Fuzzy Techniques**

  This is a method used for capturing vagueness, uncertainty, imprecision, embedded human knowledge, human behaviour, and intuition. Also, it allows computing with word where words are used instead of numbers (Sachs and Tiong, 2009). Fuzzy set theory is a mathematical tool that can help analyst quantify these linguistic terms (Choi et al., 2004). This risk assessment process is often performed where there is no statistical data available and opinions of expert with years of experience are used in performing qualitative risk assessment. Conversion of qualitative statements to numbers for estimating uncertainties is quite cumbersome. Sachs and Tiong (2009) developed a method for quantifying qualitative information on risk called Quantitative Qualitative Information on Risks (QQIR). Fuzzy sets are utilized for capturing expert opinions and fuzzy weighted average method is employed for aggregating that information.

  Most of the methods and techniques used in estimating contingency budget are quite formidable due to the inculcation of both risks and uncertainties in the estimation calculation. The method of the risks and uncertainties are not robust enough. A reductionist approach is used in identifying key variables for the contingency estimation as shown on the above description. A robust approach that is cognisant of all the variables, stages, process, and phases within the project and external to it is urgently required to identify critical uncertainties and risks that may impact adversely on the construction project.

Many contingency estimating models have been produced by researchers using all the above-mentioned approaches. Diab et al. (2017), analyse the dependency between specified cost contingency levels and the perceived ratings of risk factors determined by project professionals using multiple regression, and Thal et al. (2010) Utilize multiple regression to forecast cost overruns for a construction project using empirical data that was available before the contract was awarded. Regression analysis of this kind offers a deterministic model but necessitates data from a large number of past projects with a similar scope, which is not always feasible for complicated infrastructure projects (Curto et al., 2022). Other writers transform semantic expert judgements into probability and percentage cost overruns using fuzzy approaches (Afzal et al., 2020) (Salah and Moselhi, 2015). Various other publications emphasise probabilistic models. None has really focused on the holistic identification of uncertainty factors at the early stage which is then incorporated with aleatory uncertainties using GLM and BHRM, respectively. This is more robust in the calculation of contingency estimate due to the determination of mean, lower and upper boundary posterior estimation.

2.2.3 Infrastructure project cost estimation accuracy

Construction clients or key stakeholders require early and accurate cost estimate prior to project initiation. This is to enable them to assess the feasibility of the proposed project. It is a vital task performed by cost engineers or quantity surveyors (Lowe et al., 2006a). The key objective of feasibility(early) stage construction contract price forecast is to produce an indication of a project's likely cost. This is done to assist the key stakeholders in setting a budget, predicting the tender price, and managing design so that it meets the budget. Most of the estimate produced during the early stage is prone to inherent uncertainties due to inadequate information available (Lowe et al., 2006a). Fortune and Lees (1996) state that traditional techniques of estimation are still very much in vogue compared to newer type amongst project control and management professionals. This is quite dependent on the organization size (Fortune and Lees, 1996).Many studies have shown that construction key stakeholders are generally dissatisfied with the early cost estimate provided by the project control and management professionals (Procter et al., 1996). According to RICS (1991), the need to provide a more accurate and robust forecasts of construction cost is inevitable. It has been concluded that it is not possible to produce an error-free estimate due to inherent risks. The goal of a cost estimator is to provide the maximum level of accuracy practicable. Birnie (1993) arrived at the conclusion that cost prediction produced by quantity surveyors or cost estimators may not be as good as it may seem. This may be a form of optimism bias syndrome and it is another aspect of research that should be intensively delved into. Studying and understanding more on the process of early cost estimation in a construction project becomes inevitable to improve upon it.

The initial infrastructure cost estimate is performed in the initiation process group where information is vague about the project. The initiation process group consists of those processes carried out to define a new project or a new phase of an existing project by obtaining authorization to start the project or phase (PMI, 2013). During this stage the initial scope, high level assumption, risk are identified as well as the financial resources commitment (PMI, 2013). Also, the internal and external stakeholders who will influence the project tremendously are identified. According to PMI (2013) the purpose of the initiation process group is to align stakeholder expectations with the project's purpose, giving them clarity on scope and objectives, and finally display how their involvement will meet their expectations . The RIBA plan of work document tends to split the project initiation process group into two parts which are the strategic definition and preparation/brief. These two stages (0&1) are where the business case/strategic brief/requirements identification takes place. Project objectives, Initial budget and feasibility studies are also done at this stage (RIBA, 2013). The interplay of the internal/external stakeholders' expectations on the projects may differs considering variables, factors, and drivers of the project. A need to clearly analyse or understand the interconnectedness, interdependency and interrelationships amongst these variables, factors, and drivers prior to actually producing the initial budget of the project becomes inevitable. This analysis may improve the overall initial project cost estimate that will mitigate the impact of cost overrun on the project by proactively identifying all the potential uncertainties.

APM and ACostE (2019) asserts that estimation and its careful application within any project is one of the cornerstones of successful project delivery. Project estimates are quite vital to the key stakeholders most especially the project manager as they are needed to make informed decisions about projects across different stages of the whole project lifecycle (APM and ACostE, 2019). It is therefore important to produce a robust initial project estimate against which project performance can be measured. Listed below are important reasons to produce a high-quality initial estimate.

- Cost estimates are utilized in option appraisals.
- Key stakeholders (Sponsors) require estimates to predict return on investment so as to determine whether to support or make financial commitment.
- Organizations with a good governance structure often review projects at key stages and require them to meet internal governance guidelines on cost-benefit-risk.
- A portfolio of projects within a mature organization requires credible cost estimate in order to manage the spending profile of the portfolio (APM and ACostE, 2019).

There is formidable proof that error in project estimation is a key reason for project failure. It has been discovered that inadequate understanding of the real cost was one of the major reasons of 70% of public sector projects have gone over-budget or delivered late (NationalAuditoffice, 2013). KPMG (2015) asserts that this problem still lingers. Academics and industry professionals have collected concrete evidence of infrastructure projects that went over-budget, running close to billions of pounds worldwide (Flyvbjerg et al., 2013). A nascent investigation by NationalAuditoffice (2013) shows that errors in project estimation were due to unserious estimating culture, jeopardized by poor quality data and unrealistic assumption. It is quite pertinent to understand the early cost estimation during the initiation stage so as to produce a robust estimate for the key stakeholders. Much research in the construction industry has shown that inaccurate early cost is a recipe for cost management disaster throughout the project lifecycle. Cost estimating is a vital element within the project lifecycle. Comprehensive information, expanded knowledge, adequate expertise and continuous improvement are required to produce accurate estimation (Hatamleh et al., 2018). Early-stage cost during the initiation stage plays a vital role in a construction project despite non-finalization of scope and inadequate information from the design (Moahmmed Arafa and Alquera, 2011). A lot of factors impact on the early estimate according to the previous literatures of construction project management professionals and academia. These factors vary according to project executed. Factors affecting the early estimate of the project cost will be the main focus of this research work. Underlisted are the major factors impacting on infrastructure project early cost estimation which are as follows:

2.2.4 Factors impacting on infrastructure project early cost estimate

- **Project specification**

  This involves mainly the respective physical attributes associated with the project. It describes the products materials and work required by a construction contract (Designingbuildings, 2020b). In Railway Transportation construction, track is one of the vital components. The track design and construction are part of a complex and multi-disciplinary engineering science involving earthworks steelwork, timber, and suspension system (Connor, 2017). The variation and performance of these components will determine the specification thus making it more expensive to build. Specification of a project somewhat directly proportional to the cost of a project (Policy and

Cohesion, 1998). The early estimate is heavily influence with this parameter and impact on it as well, especially where there is complex design on the project with multiple stakeholders' requirements changing before the actual project commencement.

- **Project location**

  Institutional factors through geographical realities affects project costing. Location has an adverse impact on initial project costing in various ways (Policy and Cohesion, 1998). For instance, consent procedures in a stable country are quite different than in a war zone. In addition, in places where the bureaucratic process is complex and stringent procedures are needed to execute a project. Allowance for the costs involved in sustaining a long public consultation exercise is a common example. The Heathrow third run away expansion project has been deemed illegal due to the failure of the government to conform with the Paris agreement (Carrington, 2020). This legal and consultation battle was pursued for years before it came to a halt. All the legal costs in battling the environment activist will compound the overall cost of the Heathrow expansion project tremendously. In terms of geographical location of the project, construction and materials cost, land cost as well as design standard varies across the globe due to the distances to suppliers, climate, and weather conditions(Policy and Cohesion, 1998). General market conditions within a country are even a major factor in terms of materials and equipment required for construction. All these factors contribute to increase the early cost prior to actual project initiation and execution as well. It is high time project control and management of infrastructure projects start considering of the interdependence, interconnectedness & interrelationship of these uncertainty factors prior to the production of the early estimate. This will eventually result in robust estimate production that will mitigate the impact of cost overrun to an acceptable level to the key stakeholders.

- **Procurement/contract form**

  The type of contract utilized in the construction project will impact on the early cost. The lump price for instance will transfer most of the risk of the construction project to participant thus making the contractor to incur more cost for the project. According to Policy and Cohesion (1998), cost savings maybe made by lumpsum contract which are usually marginal in relation to the total project cost.

- **Site characteristics**

  Site investigation may be required for certain infrastructure project. Brownfields are always remediated using special techniques according to the desk study result during the site investigation process. All these extra activities add cost to the early estimate. Sometimes a site may be affected by contaminants a combined geotechnical and environmental investigation will be required (Buildings, 2019).

- **New build or improvements**

  Generally, a lot of cost incurred in new build projects are due to land acquisition, foundations and services cost which are mostly are non-building costs. In comparison to improvement construction project, which involves simply upgrading and all the above non-building cost rarely exist (Policy and Cohesion, 1998).

  Inflation

  Policy and Cohesion (1998) asserts that the longer the infrastructure project duration the more account will need to be taken of expected inflationary price increases over time. This is more vital when a government owned expenditure programme is involved. A need for the initial cost estimates to allow for the value that will need to be paid at the project outset will be required.

- **Tax liabilities**

Some organizations are liable to pay tax while carrying out infrastructure project which increases the initial cost estimate of the project considerably. This is compared to government owned infrastructure project such as those undertaken by local authorities which are not liable to tax. This tax payment has a significant impact on the initial cost estimate (Policy and Cohesion, 1998).

- **Timescale.**

  The longer a project takes the more cost it incurs thus adding considerably more to the initial project cost. The complexity of a project may cause it to have a longer duration during feasibility studies due to the multiple requirements of stakeholders (Policy and Cohesion, 1998). All these aforementioned factors are peculiar to European Union member states infrastructure project and other geographical location may have other factors which may not have been mentioned. Generally, these factors are standard or well known to impact adversely on initial cost estimate thus making the project more expensive to commence. It will be more robust if a system thinking approach is utilized to capture all the interconnectedness, interrelationships and interdependencies of these varying factors and identify potential uncertainty factors that may impact on the overall project. It will enable adequate planning and efficient budget production as well.

2.2.5 Psychology of cost estimating

The last 70 years has witnessed a tremendous amount of research into human psychology and behavioural economics. This has yielded interesting findings into how human process and use information to make judgements and decisions (Price, 2015). Listed are the discoveries of scientists which are interesting and pertinent to this study.

- Humans are often irrational and illogical beings.
- They make decisions based on factors such emotions and perception, rather than facts and data (Price, 2015). All these findings build biases into the mode of thinking of

potential project control/management professionals, and this affects the quality of estimate produced. Human typically violates logic and probability rules thus resort to simple and sub-optimal heuristic decision rules (mental shortcuts) to optimize the likelihood of an acceptable outcome (Korteling et al., 2018). This behavioural trait maybe effective where there is time a constraint, a lack of information when no visible optimal solution is evident (Gigerenzer and Gaissmaier, 2011). This can be related to the project control and management professionals involved in early-stage cost estimation where there is vague information and time constraints in producing initial estimate for the key stakeholders in making decisions on whether a project is feasible financially. Understanding the knowledge of biases will assist in improving the cost estimate and interaction amongst key stakeholders. The decision making by human often shows systematic simplifications and deviations from the tenets of rationality(heuristics) that may lead to suboptimal decisional outcomes(cognitive biases) (Korteling et al., 2018). According to Lumencandela (2018), decision making is inherently a cognitive activity thus the result of thinking that maybe rational or irrational. The model of rational action postulated by classical economics, is that a person is expected to weigh the benefits and drawbacks of action and then choose the best possible option, However, people rarely behave in this manner as demonstrated by behavioural economics. Individuals are often influenced by emotions and innate biases (such as future discounting) to make choices that are not in their best interests in the long run (Psychologytoday, 2018a). This can be based on assumptions that are not supported with factual evidence. Personality and experience influence how people generally make decisions. In other words, an individual’s predispositions can either be an enabler or obstacle to the decision-making process. In project cost estimation where experience and knowledge are highly required in producing a budget for key stakeholders' decisions, there is a tendency for biases. Bias can be regarded as the tendency, inclination, or prejudice toward or against something or someone (Psychologytoday, 2018b). This research work will not go deep into the psychology of human thinking completely but focus on the type of biases that impact on the project control and management professionals of infrastructure project. Listed below are the various types of possible biases that may impact the decision making

2.2.6 Bias in project cost estimation

Psychologist have discovered that the human thought process is surprisingly irrational. Some of the findings are listed below:

- Humans are unfailingly optimistic.
- They are overconfident in their abilities.
- Their thinking is very shallow and crowded with emotions.
- Stories and anecdotes are preferred over facts and data.
- They Discount and misuses statistic. They are non-intuitive.
- There is an Unacceptability of randomness, and they are always seeking explanation.
- They Fear losses more than the value of gains.
- Personal experience and knowledge trumps everything (Douglass, 2010).

According to Douglas (2010) humans are not purely calculating machine but have special adaptation mechanisms in coping with the environment .They possess a complex system that seems to comprehend and adapts to its environment with an array of simplifying rules. Human brain generally prefer simplicity over rationality. It has been further discovered that the human decision-making process is blurred with extraneous information, beliefs, and unconscious thoughts (Douglas, 2010). This mechanism leads to irrational decision making and thus affects the estimate produced by infrastructure project professionals. Cost estimates are predictions of future outcomes and key project stakeholders used it in making vital decisions. Various types of decision-making biases are listed below:

FIG 2.4 DECISION MAKING BIASES DIAGRAM (PRICE, 2015)

- **Overconfidence or optimism bias:** It has been proven generally that human are naturally optimistic. Research has further shown that an absence of optimism can lead to depression. Optimism itself is a form of self-delusion and too much of it leads to overconfidence. This discovery often affects infrastructure project control and management professionals in underestimating risk/uncertainty and poor understanding of the probability of failure (Price, 2015). Having a poor judgement of risk and uncertainties lead to inaccurate cost estimation.

- **Anchoring**

  Anchoring is a behavioural bias in which the use of a psychological benchmark carries a disproportionately high weight in a market participant's decision-making process (Investopedia, 2019a). This is quite common trait in the budgeting or finance process where irrelevant information such as the purchase price of a security is used as a reference for evaluating or estimating an unknown value of a financial instrument (Investopedia, 2019a).

- **Selective perception**

  This function by guiding the extraction of information or data from briefly viewed stimuli (Gummerman, 2013). It enables the human thinking to see things from their own perspective. Also, it influences what we pay attention to and the problem we identify, and the alternatives we develop or consider (USCMarshall, 2019).

- **Availability**

  This involves an over reliance on knowledge that is readily available rather than examining other alternatives or procedures (USCMarshall, 2019). Psychologist have proven through experimentation that there is tendency of assigning higher probability of occurrence to information that is easy to retrieve (Price, 2015). This occurs during the initial project cost estimation where historical records are readily available for analysis without considering the picture of the project. This impact on the estimate out rightly.

- **Sunk cost and constraint**

  This is the tendency of honouring already spent resources that are not affected by present or future decisions. According to the *Economist*, it is generally regarded as irrational behaviour (USCMarshall, 2019). It is quite inefficient because it misallocates resources depending on information that is irrelevant to the decision being made (USCMarshall, 2019).

- **Self-serving bias**

  This involves selecting information or making decisions that further our own self-interest instead of the whole team or organization. It includes the association of personal credit for success to oneself while blaming outside sources for failure (USCMarshall, 2019).

- **Framing**

  This is the tendency to be influenced by the way a problem is formulated even if doesn't affect the solution (USCMarshall, 2019). According to the prospect theory, Framing often comes in the form of gains or losses. This theory postulates that a loss is perceived as more significant, and thus more worthy of avoiding, than an equivalent gain. The hierarchy of choice architecture prefers a sure gain and is preferred to a probable one, while a probable loss is preferred to a sure loss (Decisionlab, 2018).

- **Immediate gratification**

  This involves making decision in a haste and wanting immediate results from them as well. Cost is not always a consideration but the instant pay-off appeal (Lal, 2019). This can be related to when project control and management professionals are making decision on cost estimate that will be presented to key stakeholders. It can lead to the presentation of padded estimate which can be error prone if not properly produced.

- **Hindsight**

  Hindsight bias is referred as a psychological phenomenon in which individuals tend to overestimate their own ability to have predicted an outcome that they would have been unable to predict before an event took place. Hindsight bias can lead an individual to believe that an event was more predictable than it actually was and can result in an oversimplification in cause and effect (Investopedia, 2019b). All the aforementioned biases can be referred to as psychological traps caused by innate cognitive biases or heuristics which often cause to misinterpret reality (Intaver, 2017). Making or creating a robust cost estimate is quite a rigorous mental process which is affected by the psychology of the participants and statistical data available. There are many biases that impact on the infrastructure project control and management professionals during cost estimation which may lead to the creation of an inaccurate project cost estimation. This is one of the major causes of cost overrun in infrastructure project. This research is not focusing on the whole psychology of cost estimation but some soft information which impacts upon it. The effects of soft skills on project control and management professionals were investigated using system thinking.

2.2.7 Cost overrun in infrastructure project

Early estimates are generally challenging, due to the nature, scale and complexity of projects or programmes. Inadequate data from incomplete design, scoping and investigation and the nature of working in an established construction project delivering organization all add to this challenge (Shapland, 2019). Some research has revealed that early cost estimation is quite cumbersome. Creating a robust cost estimate during the initiation stage is vital for a successful project or at least mitigate the impact of cost overrun to an acceptable level to the key stakeholders. According to Makovšek (2014), cost-overruns in publicly financed projects often receive the enormous attention of the public due to the substantial impact on the economy. With the current global economic climate and tightening of government expenditures in many countries, the understanding of the implications of infrastructure project investments is vital for government to make effective fiscal and economic decisions about their budget (Flyvbjerg et al., 2016). For example, the impact of cost-overruns on the Olympic games hosted by Greece is still being felt after several decades. The impact really weakened the economy and led to their worst financial and economic crisis (Flyvbjerg et al., 2016). Also, in Brazil during the preparation of the Olympic Games, the state government declared a state of emergency so as to secure additional funding for the games. This economy went into serious crises with negative growth and inadequate funds to cover the remainder cost of the Olympic games project (Flyvbjerg et al., 2016). The cost of hosting the Greece Olympics in 2004 was doubled from £3.2bn to £6.3bn which does not include the cost infrastructure expenditures (Hermann, 2004). The main causes of the construction delays were security and environmental conditions, which should have been foreseen if an adequate holistic approach was utilized. A project of that magnitude should have been expected to utilize a robust approach in identifying all the potential risks and uncertainties that may impact on the project adversely. Similarly, the Rio Olympics games cost rose from £6.9bn to £10.29bn. One of the major causes of the cost overrun was the weather condition which impacted adversely on the construction project. The London Olympic Games hosted in 2012 was a success according to the UK government but witnessed cost overrun as well. During the bidding phase it was estimated it would cost over £4bn but, after the award it was revised to £9.325b (HC, 2008).The actual cost of completing the London Olympic games was £11.66bn (SkyNews, 2012). According to Jennings (2012), the main causes of cost overrun in the London Olympic game were uncertainties in economic and technical dimensions of project management and inattention to risk inside government. It was further postulated that the British government failed to recognize the uncertainties surrounding key assumptions and cost forecast. Conspicuous scope-creep in technical design and structural requirements was observed as well (Jennings, 2012). It is expected that embarking on Megaproject of this magnitude requires adequate and robust identification of risks and uncertainties. Project control and management professionals still don’t get it right in terms of robust risks and uncertainties identification. Other sectors of infrastructure projects also face cost-overrun issues such as the transportation, building and energy sectors. Many projects have failed globally due to the inability to manage the impact of cost-overruns which have led to project failures. The effect of this impact has been catastrophic for stakeholders. Many case studies of improper management of construction cost have been identified and always attributed to bias or decision making. The norm is always over budget or under budget by the subcontractor. It is high time adequate attention is paid to the holistic identification of uncertainties which may impact on the objectives of the project adversely. Below are examples of both successful and unsuccessful project that went over budget after cost estimates have been established.

The Sydney Opera House Project is a unique project that went over-budget in terms of cost and schedule but it became a symbol of the 2000 Olympics hosted by Australia(New South Wales Province). The initial estimate of the cost of the project was about $7,000,000 with a schedule duration of 5years (1958-1963) but was completed over 14years later in 1973.The actual cost at completion was approximately $102m.Overall the project went over budget by 1,375% in reality (Potts, 2008). The lesson learned from this project was that there was no concrete technical know-how of the uncertainty that would be faced during the project phases. If there had been sufficient design analysis and technical know-how the imbedded uncertainties would have been inculcated into the cost estimate. The issue of both cost and schedule estimate overrun would have been reduced drastically to a bearable level. According to Magnussen and Olsson (2006), studies of major projects show that cost overruns are not uncommon. Morris (1987) states that cost overruns in large project (complex) are within the range of 40%-200% chances of occurrence. Cost is the most vital aspect of construction project and cumbersome to manage throughout the project lifecycle (Durdyev et al., 2012). Flyvberg et al. (2002) researched transportation projects and concluded that in 9 out of 10 projects cost estimation is escalated. This appears to be a global phenomenon which requires urgent attention. In the UK, the rate at which government infrastructure fails in UK now is quite alarming after extensive planning and coordination. Hodge (2018) observed that considering the amount of planning done by experts and implementation by skilled workers one will think disasters would be limited. This is far from the truth and things go wrong, people bicker, and products and services become defective. Most professionals will conclude that the main reasons are poor planning, unrealistic timelines, and poor communication. These issues or reasons for most project failures are a deep-seated scourge that need holistic attention and approaches. Below are some of well-known over budgeted infrastructure projects witnessed in last decades in the UK.

The Edinburgh Tram project was estimated initially for £375m in 2003 but rose to more than £776m during completion plus more than £200m in interest on a 30year loan sourced by the council to cover a funding shortfall (Hodge, 2018). It was a 14km line between York place in the New Town and Edinburgh Airport with approximately 16 stops Donald (2018a) has written about the main reasons why Edinburgh Tram failed explained by a retired civil engineer (John Carson).Some of his reasons are listed as follows:

- Inadequate Staffing
- Flaws in Scottish parliament bill process
- Lack of Scottish government support
- Excessive political will (Donald, 2018).

Some of these issues described above are deep seated and would have been managed if a holistic approach was taken from the initial stage. Key stakeholders buy-in were not attained prior to project initiation.

The Scottish parliament building is a similar case of government infrastructure project failure in which the final cost at completion was astronomically higher than the initial estimate. It was initially estimated to cost about £10m-£40m but rose to about £414m and was delivered about

3yrs after the initial schedule. Many reasons were attributed to the failure, but some are listed as follows:

- Poor communication amongst project participants.
- Design changes
- Budget constraint (Simonwmoore, 2011).

In Europe, Kolltveit (2002) also researched on Norwegian projects and founds out that large project ends up with 160% cost overruns. The tendency of this issue to reoccur in almost every projects is quite high and the causes are completely unpredictable, making it hard to mitigate or manage effectively (Magnussen and Olsson, 2006). According to Morris (1987) it is believed that the causative factors are outside the project's area of control (unpredictability). A lot of factors can cause this issue which range from deliberate price escalation, government action and strikes etc. There are no precise determinants of cost overrun from the conceptual stage although during project initiation high risk, issues are identified but experience have shown that it isn't adequate . Flyvbjerg et al. (2002) has tried to explain the rationale behind cost overruns on infrastructure projects he deduces that cost escalation is dependent on the duration of the execution phase. This will invariably translate to the risk of cost escalation. It is further projects grow overtime and expand into a longer duration. According to Nijkamp and Ubbels (1999), inflation is the major cause ascribed to cost overrun. This is due to bureaucracy involved in planning and implementation of construction project. A rise in prices during this duration play a major role causing incomplete estimation by omitting some vital costing information. Better accuracy in cost estimation is therefore required, which plays a vital role in the decision-making process by key project stakeholders. Lhee et al. (2014) state that a lot of uncertainties and risks are involved in all phases of construction projects which impacts on the progression of the activities. Although during the planning stage most of the potential risks would have been identified and planned against with a risk management strategy but this isn't sufficient without an early robust uncertainty management strategy. Unidentified risks emanate from uncertainties during construction project execution which impacts adversely on the goals and objectives. Management reserves are used to manage unidentified risks in a project, but this doesn't really mitigate the cost overruns issue to an acceptable level. Research has shown that one of the construction project success criteria is the effective improvement in the cost estimation techniques as well as the contingency estimation (Uzzafer, 2013). A contingency budget is used to reduce the level of risk of cost overruns to an acceptable level which is quite different from management reserve (Hammad et al., 2016). This is mainly achieved by Expert Judgement which is more of deterministic approach, and it exposes the estimation to flaws. A robust approach of contingency estimation is needed which will consider potential uncertainties that may impact on the project estimation. Cost management in construction infrastructure project is vital. Clients need adequate knowledge of cost to complete a project so as to budget sufficient funds (Williams and Gong, 2014). To produce an effective cost estimate for an infrastructure project a holistic approach is needed to identify early enough the main uncertainties and risks that may impact adversely on the project cost. Due to a lack of causes of cost overruns in an infrastructure project, from the literatures one can assume that unfounded factors can contribute to this issue. Understanding the interrelationships between construction processes can pave the way for the possibility of detecting embedded uncertainties and risks in an infrastructure project which wouldn't have been predicted prior to initiation. These uncertainties will then be factored into the cost estimate of the project. Early identification of potentials uncertainties, risks and mitigating procedures are key strategies to effective construction project management (Stewart and Fortune, 1995). Non-systemic strategies are well understood and applied to various projects, but one can argue that it isn't sufficient to mitigate the effect of uncertainties and risks on construction cost estimate. Construction project professionals are faced with complexities arising from the business environment in which the projects are being carried out. It is high time to inculcate holistic strategic analysis and general management coupled with traditional approaches to manage construction projects effectively (Saynisch, 2010). In a dynamic and complex environment such as infrastructure project the uncertainty and uniqueness of activities make control more cumbersome and deviation from plans more probable. Plans are a set of strategies for a set of contingencies that wouldn't have been preconceived (Sydow and Staber, 2002).

According to Reich (2007) in the traditional approach to project management there is an assumption of the decomposition, predictability of activities, handling relational instability and operation change as aberrations. Applying this type of narrow approach serves as an impediment in producing a predictive and robust framework for projects (Müller, 2003). This is due to a lack of flexibility as a result of a prescriptive theoretical framework. There is an eventual need for a more robust approach like system thinking which will be aware of flexibility, dynamism, complexity, interconnectedness, interdependency and rationality amongst participants and variables within the construction processes. Systems thinking can be utilized to resolve this issue of unknown factors impacting on the project cost estimate. Systems thinking has been described by various researchers but for the purpose of this research a particular definition which suits the research work will be utilized. (Moore et al., 2010b) describes system thinking as the ability to understand and synthesize, recognize the interdependencies and interactions in a set of components (system) designed to achieve a particular function.

There are lots of factors that causes cost overrun in a project but for the purpose of this research, the impact of inadequate uncertainty management is one of the main foci. The influence of soft skills (behavioural factor) on project control and management professionals involved in cost estimation will be investigated as well. Lastly understanding the relationship between the contract cost, cost overrun, final cost, expected duration, uncertainty factors and delay duration using Generalized linear model and Bayesian hierarchical regression Model.

2.2.8 Challenges of infrastructure project cost estimation model

Accurate cost prediction is essential to the success of a project because it helps managers to adjust their strategy and actions to match the current risks and uncertainties (Ottaviani and Marco, 2022). In order to contribute to organisational profitability or to the measurement and management of project costs over the course of project life cycles, cost estimation is generally understood to be the application of principles, techniques, judgement, and experience to cost estimation, engineering function or project planning and scheduling, and cost control (Cotter, 2022).Loads of engineering principles, scientific approaches and statistical analysis techniques have been used to improve the cost estimation of infrastructure project during its lifecycle without profound success. Numerous academics have employed a variety of methods to forecast the precision of construction cost estimates. Numerous methods, such as Neural Network (NN), Regression Analysis, Case-Based Reasoning (CBR), Fuzzy expert system(FES) and Analytical Hierarchy Process, have been utilised to enhance and anticipate the cost estimate (AHP) with some success (Kim et al. (2005); Kwak and Watson (2005); Lowe et al. (2006b), Chou (2009); Idrus et al. (2011); (Ibrahim and Mohamed, 2021)).The use of Reference class forecasting has gained some popularity within the construction estimating society. This is due to the recognition of optimism bias in cost estimation process. Individuals with various levels of cognitive capabilities are involved in the formulation of cost estimate. This approach is based on theories of planning and decision making under uncertainty (Alexander and Budzier, 2018). Due to the complexities in the infrastructure project and which is a times labour intensive, these models have not really addressed adequately the soft input of the process. To adequately produce a realistic cost model which looks at life costs across the whole lifecycle of a project from definition through to disposal, there is need to pay keen attention to the early input. Cost models need input such cost data, schedule, risks, expertise, knowledge to provide outputs such as discounted cash flows, output cost, cost drivers and confidence limits etc (Gosden, 2017). There are many challenges faced in achieving a robust cost estimate such realism, securing critical resources, quality of estimates, available cash flow, project interdependencies, supplier interfaces and expectations of stakeholders (Gosden, 2017). The series of information, activities and processes needed to achieve a robust cost estimate requires project control and management professionals with holistic view capabilities. It is high time project delivery team/sponsors recognize the soft competencies or capabilities of the project control and management professionals of infrastructure project. The importance of "soft" talents in describing the accomplishments and shortcomings of project managers is becoming more widely acknowledged in the project management literature (Wiewora et al., 2021). For instance, project managers' personality traits and their managerial, intellectual, and emotional competencies have all been linked to project success and have been found to contribute more than "technical skills" like planning or scheduling (Rezvani et al., 2016; Gray and Ulbrich, 2017). During the early stage of a project, project management team experiences ambiguity due to dearth of information. This incomplete or lacking information frequently causes negative feelings like worry or anxiety and may lead to burnout over time. Successful leaders and effective project managers are seen to have the capacity to successfully recognise and handle confusing situations (O'Connor et al., 2017). More recently, tolerance of ambiguity has been recognized as a highly desirable personality trait in project managers. The tendency to view ambiguous situations as desirable is known as TOA. When there is just limited or inaccurate information available, it creates ambiguity and makes it difficult to make decisions. This incomplete or lacking information frequently causes negative feelings like worry or anxiety and may lead to burnout over time. Successful leaders and effective project managers are seen to have the capacity to successfully recognise and handle confusing situations

(O'Connor et al., 2018). Ability to understand or comprehend an activity under ambiguity will be useful in producing a robust early project cost estimate. According to O'Connor et al. (2017) research on TOA is best understood as a group of connected skills that are differently related to successful outcomes rather than as a single competency. There are three dimension of this concept which are listed below:

- **Comfort with ambiguity:** it demonstrates how well people remain collected and serene in the face of ambiguity and uncertainty. High scorers on this dimension maintain cool in tense circumstances and do not frequently succumb to stress or worry.
- **Desire for challenging work:** It represents how much people look for innovation and difficulty in their work. High scorers on this dimension are very creative people who become bored easily when forced to complete boring things.
- **Managing uncertainty:** It demonstrates how well people can deal with uncertainty when it arises. High scorers in this area excel at planning, using networks, and solving problems (O'Connor et al., 2018).The present cost estimating model does not take cognizance of the soft skills/information input but just the hard information. Below is the present-day cost estimating model used in infrastructure project estimating process
- **Artificial intelligence model:** There are many projects cost estimation model produced using artificial intelligence to estimate project cost at the early stage or throughout the project lifecycle. To guarantee client satisfaction and repeat business, rapid and precise project cost estimation is essential. Even so, it continues to be one of the most difficult tasks in project, especially when dealing with complicated, large-scale, and innovative projects (Laqrichi et al., 2015) .The commonly used method is Neural Networks(NN) which In an effort to partially mimic the capabilities of the human nervous system and take advantage of some of its computational prowess, NN is a massively parallel

adaptive network of simple nonlinear computing units called neurons (Laqrichi et al., 2015).This technique is commonly regarded as machine learning methods.

- **Case-based reasoning (CBR)**: is a cognitive science and artificial intelligence paradigm that views memory as the primary basis for reasoning. Case-based reasoners change their solutions to suit new requirements by obtaining stored "cases" documenting analogous former problem-solving episodes (Zima, 2015). In the CBR technique, a collection of cases that were encountered in earlier challenges and remembered serve as the main source of knowledge. By locating the best situations and adapting them to the new case, the solution to a brand-new problem is created. This have been used in the calculation unit price of construction element (Zima, 2015).
- **Fuzzy expert system:** it takes care of the ambiguity that comes with human judgement, particularly when it comes to intangible factors. An expert system is a computer programme that applies reasoning techniques to knowledge to execute tasks at a high level that would ordinarily take years of specialised training from a human. Fuzzy expert systems make use of fuzzy logic, which is a logically sound method of reasoning that can deal with incomplete or ambiguous data and is a feature of human though (Islam et al., 2021). Also, it is a kind of artificial intelligence that uses a set of membership functions and rules to make decisions about data. This is commonly used in the construction and engineering field for cost prediction as well.
- **Analytical Hierarchy Process model:** is a method for selecting and prioritising options or projects in complicated contexts by taking into account a wide range of variables or criteria (Anderluh et al., 2020). The first step in applying AHP is to break down a problem into a hierarchy of criteria so that it may be more quickly studied and contrasted independently. The decision-makers can then compare the options pair-by-pair for each of the selected criteria after this logical hierarchy has been built. Concrete

information from the alternatives or human assessments could be used in this comparison to provide relevant data (Anderluh et al., 2020). This type of model has been extensively used by the project delivery team in solving issues and also improving cost estimate due to the inculcation soft issues analysis. There is also a need to consider the abilities of professionals to practice holism. Since cost estimation process consists of interrelated variables from different factors which must be taking into consideration holistically.

Regression analysis model is a statistical technique used in the fields of engineering, finance, and investment that aims to establish the nature and strength of the relationship between a single dependent variable (often represented by Y) and a number of independent variables (known as independent variables) (Beers, 2022). This technique is one of the common and powerful analytical tools used in producing a robust cost estimate. All these models mentioned above are well equipped to produce reliable estimate for the project to some extent. Presently, infrastructure projects are being carried out in a very complex and challenging environments where multiple factors impact on them. Identifying the causes of project issues is undoubtedly a difficult and complex task. The phenomenon, however, is frequently attributed to a number of causes, such as scope creep and rework, inflated cost targets, and misguided trade-offs between project scope, time, and cost, a lack of understanding of the systemic and dynamic nature of projects, unidentified or improperly managed risk and uncertainty, and suspicions of wrongdoing and corruption (Ahiaga-Dagbui et al., 2017). The most prevalent weakness of project issues research that has been done is a poor understanding and treatment of project complexity and system thinking (i.e., the complex, dynamic behaviour shown by systems). Although there is a growing amount of research investigating cost and schedule overruns in infrastructure projects using systems thinking, the vast majority of studies overlook the complex, numerous feedback, and extremely dynamic context of projects when framing the overrun problem (Boateng et al., 2015). For instance, most studies pinpoint specific instances where an intervention could have been implemented to alter behaviour and avert an undesired outcome. Since runaway causation can only be understood by considering the entire project system in which it occurs and how variables interact dynamically, the identification of isolated and independent causes, which in most situations only represent the proximal causes, is unhelpful (Love et al., 2016). Understand this key relationship interconnectivity amongst the variables will assist in identifying uncertainties and risks at the early which will forestall any sudden event throughout the project lifecycle.

2.2.9 Dearth of information at the project early cost estimation process

The feasibility stage, pre-design stage, or preliminary stage are all terms used to describe the early stage. On the basis of past projects with a similar scale, the project's overall cost, hazards, and duration are estimated at this stage (Badawy et al., 2022). Project strategic decisions are based on the information derived at this stage. This is used as a guidance for decision makers during financial planning and construct budget estimation (Maruvanchery et al., 2020). In infrastructure project management, accurate cost projections must be obtained utilising efficient techniques (İnan et al., 2022). Producing a robust estimate for strategic decision at the early stage is quite cumbersome. Most of the estimates produced at this stage are based on experience, expert judgment and a times based on intuition using historical records of similar project. This in turn impact on the project cost lifecycle due to the inaccuracy at the early stage. Accounting for risk and uncertainty at the early stage is the key to robust cost estimate and contingency estimate. According to Islam et al. (2021), lack of a thorough understanding of project risks, their causal relationships, and their consequences on project costs, stakeholders currently distribute contingency costs based on expert judgement. This practice has led to so many projects to experience cost and time overrun eventually leading to failure or abandonment. The client's costs of infrastructure projects frequently exceed their budget on a global scale. Infrastructure project mostly experience this scourge with an average mean of 66.3% ($968 million) over budget rate. This is the result of the many risks and uncertainties present during the various project execution phases (Gilbert et al., 2017). The impact of the risks and uncertainties would have been mitigated to an acceptable level if thorough causal relationships of various processes, stages and variables were identified at the early stage. Many strategies have been deployed to control the impact of risks and uncertainties on project cost, the most common one is for estimators to include a contingency amount in their cost prediction and budgeting process. This is a reserve fund set up to shield project stakeholders against unfavourable results by covering the impact of risks and uncertainty (Love et al., 2015). Nevertheless, the contingency estimate should be well anticipated, budgeted for, and properly managed throughout the project lifecycle (Diab et al., 2017). The allocation of client's contingencies is a highly risky activity because infrastructure projects are frequently complicated and only little information is normally available regarding their risks and uncertainties when evaluating the potential owner cost involved (Love et al., 2015). This requires high level identification of risks and uncertainties at the early stage to effectively produce a reliable contingency estimate which will mitigate the impact throughout the project lifecycle. Another constraint is the lack of readily accessible, accurate historical cost data for comparable projects. Many techniques such as expert judgement, risk analysis based educated guessing, parametric modelling, probabilistic distribution models and artificial intelligence (AI) have bene utilized for estimation of contingency (Diab et al., 2017). It has been studied that there is still improper rigorous risk analysis and experts typically arrive at their estimates as an arbitrary proportion of the stakeholder's anticipated project costs (Maronati and Petrovic, 2019) & (Salah and Moselhi, 2015). Employing such technique or method in producing contingency estimate for infrastructure project is quite detrimental to successful project delivery. Subjective and judgement-based contingency allocation is obviously illogical and not supported by any rationale (Islam et al., 2021). Holistic understanding of the variables (mainly risks and uncertainties) at the early stage is the footprint in producing reliable contingency estimate that mitigate the impact of risks and uncertainty in the project lifecycle. Presently, the lack of information and resources required to produce a robust contingency estimate is still a scourge in today's infrastructure project management. Infrastructure project are becoming more complex and carried out in hostile environment which required adequate and effective planning prior to initiation. Alongside this development, the demand for new infrastructure is also increasing, for instance as a result of sustainability-related investments and the increasing global population (Hueskes et al., 2017). According to Hub (2017), the world would need to invest $94 trillion in infrastructure by 2040. This is a stupendous amount that will be invested in infrastructure project and there is need for a paradigm shift in its management urgently. Most especially at the early stage where there are many uncertainties and risks due to inadequate information to produce a robust decision in terms of cost to initiate the project effectively.

2.3 Risk management in infrastructure project

Construction projects are complex in nature and can be unwieldy to manage in order to produce effective deliverables. There are various unforeseen factors that can affect the delivery of a complex project which needs to be managed at an earlier stage of the project so as to forestall any form of eventuality. A successful project is one that delivered within the budgeted time, cost, and schedule, quality and scope agreed upon by stakeholders as well as under uncertain variable factors which might have impacted on it positively or negatively. The management of risk in construction project has been seen as a very crucial process in order to accomplish project objectives (Zou et al., 2007). A multitude of research has been done in the field of risk management of construction project related risks but the dynamics in which the risk studied occurs hasn't been explored extensively prior to analysis. Much of the research on risk management has focused solely on the negative impact on the project without laying more emphasis on the event and condition that resulted to the actual risk being identified (Bryde and Volm, 2009). There is a need to be more concerned about knowns/Unknowns and Unknowns/Unknowns which are a result of uncertainty. Unidentified risks can occur at the later stage of a construction project due to inadequate uncertainty management. This may lead to catastrophic effect on the project deliverables. The traditional method of managing unidentified risks at the later stage of the project by the stakeholders is to use either contingency or the management reserve budget. This may be prevented if the uncertainties are adequately managed either during the pre-project initiation or initiation stage. To fully understand the construction project risk a full knowledge of risk management needs to be explored comprehensively. An inadequate understanding of uncertainties by project stakeholders will invariably expose the project to unidentified risks which will later hinder the progress of the project deliverables in the future.

According to Ward and Chapman (2008), the term risk and uncertainty are often used interchangeably but there is difference between the two of them. Uncertainty can be referred to as a lack of certainty or variability in relation to performance measures, a lack of data, a lack of structure to consider issues related to unknown and known sources of bias. According to the definition given by Ward and Chapman(2008), one can easily claim that uncertainty means that all alternative sources cannot be easily identified or probability quantification cannot be justified (Rafindadi et al., 2014). It is time that key stakeholders in the construction project be cognisant of uncertainties which are a major sources of risk generation. Construction projects can be generally regarded as one-off ventures with many distinct features such as complicated process, financial intensity, over stretched period, a challenging environment, and dynamic organization structures. This structure of complexity will obviously generate enormous risk. The various interests of stakeholders on a construction project will further compound the changeability and complexity of the risks (Zou et al., 2007). Now there is no clear-cut definition or description of a risk it all depends on the perception of each stakeholder. According to Zou et al. (2007) risk is regarded as the potential for unwanted or negative consequences of an event or activity alternatively combination of hazard as well as exposure. This description of risk is very streamlined to a double-edged nature of a threat and challenge. The chance of an event happening and having an impact on key objectives (positively or negatively). In order to generate an adequate understanding of complex risk situations by breaking the sole reliance on the traditionally probability-based perspective, additional characterisations that can provide further insights about knowledge and lack of knowledge as well as potential surprises need to be comprehensively researched (Aven, 2014). The lack of knowledge concept captures facts that the probability used to measure uncertainty or degree of disbelief are not adequate enough to reflect the strength of the knowledge in which the probability is based. Also does not take into consideration the assumptions on which the probabilistic analysis is based can conceal some aspect of uncertainties which might require further analysis (Aven, 2014).

`2.3.1 Traditional approach of Risk management

Risk has long been recognised in the construction industry. Contractors are required to accept some level of risk due to the unforeseen cost exposure that is incurred during the execution stage (Mak and Picken, 2000). This risk manifest itself during the execution stage thus creating a big issue for the key stakeholders. At the different stages of the project development phases there are various types of risks the construction project is exposed to. This research will focus mainly on the risk during the feasibility and inception phase where there is vague information on the project. According to PMI (2013) project risk management includes the process of conducting risk management planning, analysis, identification, response planning and controlling risk on a project.it is further illustrated by the project management body of knowledge that the sole objectives of project risk management are to maximise positive outcomes of a risky event and to minimise the negative outcome. The traditional approach to project risk management is highlighted below:

A. **Plan risk management:** This includes the process of defining how to conduct risk management activities for a project.
B. **Identifying risk:** This involves the process of determining possible risk that may impact on the project.

C. **Perform Qualitative Risk Analysis:** this involves the process of prioritizing risks for further analysis or action by assessing and multiplying their probability of occurrence and impact.

D. **Perform Quantitative Risk Analysis:** this includes the numerical analyzation of the identified effect of risks on overall project objectives.

E. **Plan Risk Responses:** this involves the process of developing options and actions to improve opportunities and to reduce threats to project objectives.

F. **Control Risk:** this involves the strategy of implementing risk response plans, locating identified risks, monitoring residual risks, identifying new risks, and evaluating risk process effectiveness throughout the project (PMI, 2013).

The above-mentioned project risk management processes are being executed mainly with relevant and active project information (during the design stage and project execution) which the research will not be focusing on rather it will be focusing on the project strategic definition and preparation/brief stage (RIBA plan of work).

According to PMI (2013), risk is an uncertain event or condition that, if it occurs has a negative or positive effect on cost, scope schedule or quality. It is very clear from this definition of risk that it is an integral part of uncertainty not vice versa as seen or explained in some other previous research. There is an interrelationship in the use of risk and uncertainty that is interchangeable causing some confusion amongst project control and management professionals. The term uncertainty is used in most of the scientific literature concerning risk management. It can be defined as the lack of certainty involving variability and/ or ambiguity (Ustinovičius et al., 2007). According to Migilinskas and Ustinovichius (2006), in risk events, there are uncertain parameters controlled by probability distributions known to the key stakeholders (also known as risk). While in uncertainty situations, parametersareuncertainthusnoclear-cutinformationontheprobability is known (unknow-

unknown). In this situation, a lot of risk conditions are generated that may impact on the project objectives. It is therefore necessary to manage uncertainty conditions or situations holistically. Most project control/management professionals pay more attention to risk based on the ease of analysis (a linear or reductionist approach). Managing uncertainty holistically will invariably manage risk as well. The sole objective or intent is to optimize the expected value of some objective function and problems. Uncertainty often attempts to optimize the worst-case performance of a system (Ustinovičius et al., 2007). This is more of robust optimization of the system under consideration. It can only be achieved via a strong holistic approach using systems thinking. Risk management represents an important and inseparable segment of project management. All projects carried out are unique in nature and assessed independently due to the financial demand and a longer duration for delivering the projects (Buganová and Šimíčková, 2019). Infrastructure projects are faced with magnitudes, combinations, and sometimes even types of risks commonly not experienced in more traditional project concepts (Schroeder and Jackson, 2007). Citing such challenges, conventional risk categories and traditional approaches to risk mitigation are insufficient for infrastructure project (Schroeder and Jackson, 2007). The traditional method of risk management is quite linear in approach to more of reductionist strategy. According to Atkinson (2006) and Cooke-Davies (2007), traditional project management methodologies and practices have been demonstrated to be rational and linear, proving unsuccessful in properly managing project uncertainties/risks and the entire project lifecycle in general according to project management studies. Some research challenges whether such approaches can adequately deal with project irrationality and complexity (Smith, 2006). Chapman (2002) stresses the importance of shifting to an uncertainty management paradigm.

2.3.2 Decision making under project risk management.

There are three main categories which decision making falls under which are risk, certainty, and uncertainty (Kerzner,2016). It is well assumed that under certainty all the necessary information is readily available for making the appropriate decision. This enables a high level of accuracy in prediction (Kerzner, 2006). Risk can be described as an outcome that is established within confidence limits. It is therefore recommended that the probability distributions should be derived from either estimated or defined from experimental data (Kerzner, 2006). One of the crucial factors in decision-making under risk is probability assignment for each state of nature. There is error in probability assignment, the expected results become invalid thus giving rise to a different perception of results. In the early stage of the project most of the assigned probabilities are through expert judgement. Sometimes these are heavily subjected to bias thus giving rise to erroneous outcomes affecting the expected values as well.it has been hypnotised by Douglas (2010), that no matter how much experience is accumulated by the project control/management professionals, there seem to be inconsistencies in their estimates as well as opinions. According to Hubbard (2009b), estimates of things change for random and unknown reasons. It has been further illustrated that most methods of risk assessment always rely on some subjective inputs by human experts which is sometimes erroneous about uncertainty and risk (Hubbard, 2009b). There are some other particular errors found in the project risk management which influences the decision inordinately leading to unexpected values and results. Use of Ineffectual subjective scoring methods is an issue in project risk management. Arbitrary rules and values created in scoring methods fails to consider subjective risk thereby introducing errors into the expected outcomes. Institutional factors are another key component for project risk management error (Hubbard, 2009b). This happens when the organization separate risk analyst from one another within the same organization or lack of outright involvement (risk assessment) in some cases as well.

Most of the biases observed in the project risk management are largely due to overreliance on human judgement which is quite subjective in nature. This subjective nature is honed from experience of the subject matter expert during the project risk management process. According to Hubbard (2009b), there are limits to experience in carrying out project risk management effectively. Listed below are some of the features of experience that leads to the creation of biases during the decision-making process:

- Experience tends to be more memory-based thus very selective regarding what we choose to remember.
- The conclusion derived from experience can be full of logical errors.
- There are always inconsistencies in experience no matter how much is accumulated.
- Until there is reliable feedback from past decision, there is no reason to believe our experience will tell use much.
- Experience is a non-random, non-scientific sample of events throughout our lifetime (Hubbard, 2009b). Most of the features of experience mentioned above are recipes for subjective bias during project risk management. In as much as expert knowledge is required during project risk management, there is a need to robustly mitigate the impact on subjective biases.

It is high time that project control and management professionals start taking human errors into consideration in project risk management decision throughout the project lifecycle. A more robust approach is needed in the identification of potential risk and uncertainties in the project which recognizes interconnectivity, interrelationships & feedbacks for reliability and integrity. Since project risk management is carried out throughout the lifecycle, it is quite pertinent to get it right from the beginning of the project.

2.4 Uncertainty management in infrastructure project

In construction project, owners understand design and building contains inherent traits of uncertainties which can't be totally mitigated. Stakeholders are therefore faced with challenges in identifying, anticipating, and mitigating factors that drives uncertainties in a construction project (Kathryn Cassino et al., 2014). According to Drucker (1993) a problem anticipated is a problem half solved. It has been noted that even with the smart ways in which construction project owners are taking in approaching risk and uncertainties by using different project delivery systems, the adoption of lean building approaches, improved information mobility and wider use of prefabrication and modularization to improve productivity, quality and profitability, there is still a high frequency of unanticipated problems that adversely impact on quality, cost and schedule (Kathryn Cassino et al., 2014). To understand uncertainties fully, the management of them becomes very paramount. This involves the integration of risk and value management approaches of the construction process (Smith, 2003). It can also be seen as the managing of perceived threats and opportunities and their risk implications as well as managing various sources of uncertainties which gives rise to and risk, threat, and opportunity (Chapman, 2003). According to Valtonen (2014), risks arise out of uncertainties. In uncertain situation most especially in the construction project where comprehensive information about the project is vague, it is readily advisable to employ uncertainty management strategy to manage unknown, unforeseen occurrences which may impede the project progression. Most parameters are uncertain or unsure and no information on the probabilities of existence is known. This makes it more difficult for construction project professionals to evaluate the challenges or issues that the project may face in the future. The traditional method is to employ robust optimization of the worst-case scenario, which is tends to be more deterministic, unlike when the parameters are controlled by probability distributions and they are well known by the construction project professionals (Ustinovičius et al., 2005). The Project pre-initiation stage is always devoid of information especially when it is being newly carried out. This is when the uncertainties in the project becomes more pronounced and adequate risk and uncertainty management is inevitable (Smith, 2003). Project decision stages are of high uncertainties and risk as described above. This is generally divided into concept viability and project feasibility. If the project is determined to be more viable it will progress to the feasibility stage which is approved by the key stakeholders. At this stage, the uncertainties and risk remain very high due to inadequate information on the project. The accuracy of the estimated cost of implementing the project becomes artificial but as the project progresses into stages this is reduced (Chris Hendrickson, 1989). Uncertainty management should be done throughout the project lifecycle just the same as risk management which is disproportionate at the appraisal phase. During this period relative or small portions are appropriated for these activities but forgetting that decisions made at this stage affects the overall project implementation outa. There is a need to have highly qualified construction project personnel to make effective decisions to be able to deliver the project objectives in a timely manner without impairing on cost, schedule, and quality of the deliverables.

According to Nowak (2014), there is no clear method utilized in making this crucial decision during the appraisal phase of the project. This is the stage where all the uncertainties and risks related to the project are being evaluated to come up with a robust strategy in implementing the project. Evaluation of uncertainties and risks will ensure robust construction cost estimation of the project to mitigate the impact of cost overruns. It can be achieved conveniently, if the contingency budget is properly appropriated and this can only be done when proper uncertainty as well as risk management is efficiently evaluated. In today's world the construction industry impact on almost all sectors of a nation's economy, there is an urgent need to curb the effect of cost overruns on a project. The traditional construction project can be regarded as a model covering all stages of implementation which includes development and planning, design, and economic assessment, tender and negotiations, construction and handover, maintenance, and utilization (Ustinovičius et al., 2005). During these stages participants such as key stakeholders are involved in the implementation activities which makes it more prone to various forms of uncertainties. Identification of these uncertainties in all these stages will be the key drivers on how it affects the cost information required in estimating the accurate project cost. The uncertainty in carrying out a construction project emanate from different sections is described above. Since each key stakeholders tries to minimize uncertainties and risks, a conflict is generated and its management is crucial to project delivery (Chris Hendrickson, 1989). A lackadaisical approach to this issue by construction project professionals will lead to undesirable outcome (Ustinovičius et al., 2005). Ustinovičius et al. (2005) asserts that the predictions made by the project designers and contractors during the conceptual and design phase may prevent the most cost-effective approach being applied. This may lead to a disastrous end. Construction projects are comprised of a unique set of well-co-ordinated activities with a start and finish date carried out by an organization or individual to meet a unique objective with a well-defined cost, schedule, and performance parameters. It is a dynamic process easily influenced by multiple factors (Risks and Uncertainties etc.). A properly planned and organized Uncertainty and risk management is required to be able to identify and reduce these effects or threats all together (Verzuh, 2003). It is highly important to take risks into consideration while trying to factor the uncertainties in a construction project. This is due to the origin of risk which is the uncertainty inherent in the project. The ability of construction project professionals to systematically manage these inherent uncertainties within this construction project increases the likelihood or chances of the project achieving the objectives. Research has shown that there is a need to inculcate the importance of uncertainty factors in project planning and decision making at every stage (Project Cost and Time Forecast). This will prevent or mitigate the occurrence of an uncertainty event (Fahathul Aziz and Kumar, 2015). Ultimately this will eventually prevent any form of delays in the project which can be in the form of schedule, cost, and time. It will be very interesting to identify the uncertainty factors and drivers as well as the effects in achieving successful project completion in this research work. Fahathul Aziz and Kumar (2015) state that project success depends on meeting client objectives within the estimated budget. One of the major factors which is detriment to the project success is delay. Invariably this means a loss of income to both parties (Client and Contractor). According to Love et al. (2002), the external and internal environment of a construction project is dynamic and relatively unstable. The management of construction project on its own is very complex without even any changes to project requirements, scope, and design etc. To effectively manage these stages, project managers need to undertake detailed planning so as to integrate the work activities of consultants, subcontractors, and suppliers (Love et al., 2002). Uncertainty and risk management needs to be considered prior to initiation to forestall any form of sudden or unwanted events in the project stages. To really understand the impact of uncertainties and risks within a construction project the dynamics needs to be carefully taught through. There are significant questions that needs to be asked when analysing the impact of uncertainties in construction project. This can be significantly better understood by analysing the project dynamics. According to Love and Gunasekaran (1998), construction projects are comprised of interdependent skills which are carefully fostered or harnessed together to achieve a specific objective and goal. . This can be categorised as a system since it is composed of an organization, so in the perspective of system theory, the aim is to analyse how sub-systems interrelate with one another to achieve a significant goal (Sharif, 1997). Having taken account of this, it can be considered as a sub-system comprising of planning, coordinating, and organizing of project related activities. The inputs to this system are identification and development of project requirements, objectives, resources, and scope as well as the formalisation of relationships between these independent variables. The product of this system is a completed project deliverables which meets the client's objectives and goals. In this dynamic environment the relationship between the variables changes intermittently. It poses a great challenge to the modern construction project stakeholders especially the project leader, manager, or director as the case maybe (Akintoye, 2015). According to Love and Gunasekaran (1998), a construction project management is a unique aspect with its own tools and techniques. The control mechanisms such as work break down structure, Gantt charts, PERT/ CPM networks, project crashing analysis etc. are not adequate to manage the complexity of the recent challenges faced. It is therefore advisable to inculcate the system dynamic mechanism of construction project management to be able to understand the impact of uncertainty and risk throughout the project lifecycle. This research work will explore the construction project dynamic system and how it impacts on uncertainty and risk. Being cognisant of this will enable adequate exploration of the impact of uncertainty on construction cost.

2.4.1 Causes of uncertainty in infrastructure project

There are many causes of uncertainties in infrastructure project which impact adversely on the project delivery. According to Kathryn Cassino et al. (2014), perspectives vary between owners, architects, and contractors on the importance of key drivers of uncertainty on infrastructure project. In this research, the key drivers of uncertainty in infrastructure project will be referred to as uncertainty factors. They are underlisted as follows:

- **Unforeseen site conditions or Construction Issues**: this can be regarded as the unexpected physical state of an existing structures or site. This may have a significant effect on the project and create a lot of construction issues for the stakeholders at large (Elliot, 2018). The consequence of this uncertainty driver(factor) will be a need to change the working method, by altering the design method or abandoning the site in extreme cases. To forestall this type of uncertainty, factor a need to proactively plan against it becomes imperative. If this type of uncertainty factor is proactively planned against, unknown/known events will be mitigated.

- **Design error or omission:** this can be referred to as an instruction in the plans and specifications that, if implemented by the contractor, will require replacement or correction at a cost respectively (Potts, 2016). Every infrastructure project is unique and complex in nature with various issues attached to it. This gives rise to potential mistakes that emanate from design error or omission. Reliable project control and management professionals will put appropriate measures in place to plan against the error to prevent unknown/known events in the future of the project. This type of uncertainty factor is a cause of risks at the early stage of the project or in the future.
- **Contractors caused delays and coordination issues**: In construction project, delays always cast a dark shadow over it. Surprisingly, they can be caused by key stakeholders involved in the planning, execution, and delivery of the project (Pittayaporn and Pongpeng, 2018). There are various delays caused by contractors and these differs according to the project executed. According to Fallahnejad (2013) and Ruqaishi and Bashir (2015), contractors and suppliers are the major cause of delay in energy project. Poor site management and contractor supervision has been seen as a cause of project delay in the Gulf region as well (Ruqaishi and Bashir, 2015). These delays and coordination issues can cause a lot of risks at the early stage of the project. Adverse impact will be seen as well if not properly handled. Identifying these uncertainty factors will further increase the chances of preventing risks that may emanate later.
- **Owner driven changes:** Change in a project can have both positive and negative impact on the project delivery**.** Change sometimes is not well understood by the key stakeholders and the impact can be detrimental to the project objectives.

Casey (2019), states that many changes to the initial project plans have impacts on the entire project. Eventually, these changes may lead to unknown risks emanating from them.

- **Accelerated schedules:** this can be regarded as a very intense time during the construction process when resources, such as materials and labour , are consumed at a faster rate than anticipated(Mitchell, 2009). There are several causes of schedule acceleration which won't be discussed in detail in this research work. Some of the reasons for accelerated schedule are as follows: site access restriction, procurement issues and a delay in allocation of resources. All these can result in key stakeholders deciding to accelerate their schedules to mitigate against the delays experienced. Working on constrained resources and time often lead to unknown risks which may impact adversely on the project.
- **Team formation process:** In order to build effective teamwork, team formation is a critical process to ensure that team consists of effective team members (Abed Aljasim Muhisn et al., 2015). Infrastructure project can involve large numbers of people, with particular disciplines, background, diversity of skills and personalities (Designingbuildings, 2019b). This makes the team formation process more laborious and potentially troublesome. Assigning the roles and responsibilities to the team by the project manager can be quite challenging. A poorly designed project team can be a risk to the achievement of the project objectives.
- **Project delivery method:** this is the structure of the relationships of the parties, the roles and responsibilities of the parties and the overall sequence of activities required to deliver the project (Moore, 2000). The delivery system of infrastructure project differs from one another due to complexity and a range of issues which will not be discussed in this research work. There are three main structured project delivery method

which are as follows: Single source responsibility, dual source responsibility and triple source responsibility. Most of these project delivery methods are being shaped by the procurement method/contract method utilized in handling them. A project may possess some uncertainties at the early stage due to wrongly chosen delivery method. This may lead to outright project failure.

- **Project complexity:** The construction process can be considered the most complex undertaking of any industry (Baccarini, 2006). In recent years, construction projects have displayed immense difficulty in coping with the increasing complexity of some major projects (Baccarini, 2006). It is vital to understand the project complexity so as to be able to manage the delivery effectively. Complex project often demands exceptional project management knowledge in dealing with the eventual embedded uncertainties within them. According to Baccarini (2006), complex project requires appropriate managerial actions to deliver them successfully.
- **Regulatory permitting process:** this is a formal procedure required to control construction activities safely. During the mobilization of resources to the site for a particular project, permits are required by the contractor from government regulatory agencies. A typical example is the HSE permit required by government to ensure construction project adheres to the stipulated regulations. The delay in issuance of this permit may possess some level of uncertainties which may result to risks.
- **Miscommunication between teams:** Communication is the central part of an effective project execution strategy, where project managers use 90% of their time communicating with project participants (Taleb et al., 2017). Potential for miscommunication will always be abundant in a project team. According to Preda (2016), clarifying everyone's expectations and roles will help you as a team leader or business owner to increase communication. Team members will eventually have

greater trust and purpose as a result, which will boost productivity. It has been confirmed by various researchers that communication plays a vital role for projects and it plays an essential factor of project success (Zulch, 2014). Project may perform poorly If there are too many barriers to communication amongst participants. Ineffective communication is a potential recipe for project uncertainties which may impact on its objectives adversely.

- **Unclear project requirements**: It is quite important to have concise project tasks to ensure successful delivery of objectives. It starts with a high-level definition of project scope, which sets the boundaries for areas within the organization that are anticipated to change (Paul, 2008). This is to efficiently set out plans and strategies on how the project will be executed to deliver the objectives. Any failure to adequately understand the project requirements will lead to unknown risks which may have adverse impact. Scope gap (incomplete requirements) is a potential recipe for project execution uncertainties as well. Uncertainties emanating from scope gap can result in risks which may impact on project objectives.
- **Underperforming/unqualified/inexperienced staff:** lack of efficient expertise in a project is a potential recipe for all sorts of project uncertainties. Inefficient expertise in the project can lead to a lack of thorough preconstruction project planning, execution, and estimation. Most of the uncertainty factors are relative to one another but with little difference on the impacts it has on project objectives. Planning robustly for the impacts of uncertainty factors on project objectives will mitigate cost overrun to an acceptable level to key stakeholders. One of the vital roles of the key project stakeholders is to identify and manage uncertainties efficiently.
- **Scope gaps:** This refers to a situation when the project expectations are not fully understood. Due to the underlying lack of clarity and knowledge of the project's

objectives, deliverables, and expectations, scope gaps can have a negative impact on delivery on time and within budget (Andrew, 2021). It may lead to scope creep later in the project lifecycle if not properly managed.

- **Lack of thoroughness of preconstruction planning, estimating, and scheduling**: As the name implies, if the preconstruction planning, estimating, and scheduling are not properly planned at the early stage, they are all recipe for uncertainty in the project lifecycle. Due to numerous external and local influences on the construction process, the construction industry is a volatile one with many unknowns. Every construction project passes through various stages, including planning, designing, building, operating, and maintaining (Vidyasagar Reddy and Rao, 2022). If these stages are not adequately and thoroughly planned the project may not progress from the initiation stage.
- **Weather condition:** The impact of (unfavourable) weather is a frequent reason for construction project delays, lawsuits, and financial losses (Ballesteros-Pérez, 2018). Most construction activities cannot progress properly if the weather is not favourable. Appropriate plans need to be in place to monitor the weather condition while planning for construction project. Atmospheric conditions are very uncertain this a recipe for unknown unknown events in a project.
- **Government policies:** The government frequently launches projects through its policies in highly regulated industries (Fitria et al., 2017). In the UK for instance there has been a soften stance on offshore wind farm which permits more project to be initiated in that sector. A significant policy move by the UK government will see planning regulations for onshore wind projects relaxed to facilitate project deployment (Mathis, 2022). Projects like this can be very political in nature and can be uncertain if initiated thus yielding some uncertainties during the project lifecycle.

- **Quality assurance:** Project management uses quality assurance to assist organisations prevent mistakes and reduce potential hazards. Project managers can begin preparing for the quality of their deliverables from the very beginning of their project plans by keeping quality assurance in mind (Andrew, 2021). Many firms are in a negative spiral that could get worse over time because of the lack of attention to quality. According to studies, senior management and the team are negligent in a project in 85% of cases where there are quality difficulties (Pradip, 2017). Inadequate planning of quality assurance at the planning stage may generate some uncertainties during the project lifecycle.
- **Stakeholder issues:** One of the most important soft skills a project manager requires is stakeholder management. Success of the project depends on maintaining the stakeholders' engagement and satisfaction. Construction projects are linked to high dynamics and uncertainty. Attributes and positions of stakeholders change as a project progresses through various stages (Aaltonen et al., 2015). These dynamic stakeholders must work together to address new problems that are also unforeseen (Aaltonen and Kujala, 2016). Unmanaged stakeholders are recipe for unforeseen events in the project lifecycle.
- **Socio-economic condition:** this play a major role for any organization to initiate a project when the economic condition is unstable. Presently, the HS2 project is going through some issues due to the funding uncertainty by the UK government fiscal budget deficit. According to top Tory Michael Gove, the government will reconsider its investment in HS2 as it works to close a gaping financial hole in the nation. In the autumn budget, the government will need to make "difficult" decisions (Hallam, 2022). This is a typical instance of uncertainties in a project lifecycle. Some part of the project will be impacted negatively due to the uncertainty of the government budget deficit.

- **Resources availability:** One of the most crucial responsibilities in resource forecasting is planning resources, which considers how the makeup of the project team matches the needs of the project (Hoban, 2019). Lack of needed resources in a project poses adverse effect on it and thus create many uncertainties as well.
- **Adaptation of advance technology:** Technology developments over the past 20 years that enable project management have led to ground-breaking new computing and communication products and services. Project managers have adopted new hardware, software, and network services during this time by keeping up with improvements in these products. Due to several technological advancements, our world is changing more quickly than ever. Even more quickly, our behaviours are altering. A new generation of employees manages their personal and professional lives utilising social media and collaborative platforms (Johnson, 2013). Inability of the project control and management staffs to adapt to new technology can create uncertainties in the project lifecycle.

Aside the sources of project uncertainties mentioned above, there are other sources which uncertainties can emanate from. Some uncertainties cannot be measured due to its inherent nature. In reliability theory, there are two types of uncertainty that are defined: aleatory uncertainty and epistemic uncertainty. Epistemic uncertainty is ascribed to a lack of information or knowledge while aleatory uncertainty is the term for uncertainty resulting from the phenomenon under study's inherent unpredictability (Qiu and Ming, 2019). Further explanation and classification are given below in chapter 2.4.2.

2.4.2 Classification of uncertainties

In past literature, the concepts of uncertainty classification have been misunderstood to be risk management knowledge continuity. There is always a misconception of these entities when managing infrastructure project. As stated above already by Valtonen (2014), risk can be described as the effect of uncertain events on a company. Risk arises out of uncertainty. It is more effective and efficient to carry out uncertainty management robustly to envisage or plan against the unknown and unknowns adequately. The above description was utilized for this research work throughout.

Uncertainty is an inevitable aspect of most projects, the most proficient project control and management professionals face challenges in handling it robustly. Decision milestones and risk management are measures used in preventing disaster and sequential iteration to make sure everyone is making the desired product (De Meyer et al., 2002). The projects handled using these measures still end up with an overrun schedule, budget, and compromised specifications. According to De Meyer et al. (2002), project control and management professionals still can't get a well-grounded understanding of different types of uncertainties in projects. This is a very concerning norm that needs urgent attention in the construction industry. There is dire need of forward-thinking approach in project, which is uncertainty-based management. This involves planning, monitoring and management style from uncertainty profile comprising various type of uncertainties (De Meyer et al., 2002). There are various classification of uncertainties identified in infrastructure projects but for the purpose of this research work, a fundamentally accepted description according to the Engineering and Validation is utilized in this research work. Listed below is the classification of uncertainties.

- **Aleatory uncertainty:** this is regarded as an inherent variation associated with a parameter, physical system, or environment. This can also be referred to as variability, stochastic uncertainty, and irreducible uncertainty (Oberkampf and Ferson, 2007). Goh et al.(2010), states that the inherent variability cannot be reduced by further measurement but better sampling can improve knowledge about it. Earl et al. (2005) refers to this type of uncertainty as a 'Known uncertainty.' In project management terminology, it is referred to as known risk. This type of uncertainty can be further broken down into variation and foreseen uncertainty. Variation emanates from many small influences and yields a range of values on a particular activity (De Meyer et al., 2002). While foreseen uncertainties, are identifiable and understood influences that the team are not certain of their occurrence. It is quite distinct and may require comprehensive risk management with several alternative plans (De Meyer et al., 2002).

- **Epistemic Uncertainty:** this results from a lack of knowledge or ignorance (Oberkampf and Ferson, 2007). The lack of knowledge can be reduced by accurate measurement or expert judgement (Goh et al., 2010). The generic or conventional name for this type of uncertainty is called unknown and unknown risk. Management reserve is used to mitigate the impact of this type of uncertainties. The allocation of this reserve is done using expert knowledge due to an inadequate or lack of knowledge. In modern day scientific analysis, epistemic uncertainty is modelled by alternative probability distributions. In continuous random variable, epistemic uncertainty is modelled using alternative probability density functions (Braunschweig et al., 1990). Using this method as a measure of uncertainty is subjective and it varies from one analyst to the other (Siegmund, 2018). Due to the subjective nature of the probability experiment, it is prone to error or bias. A more robust approach is needed in analysing epistemic uncertainty (Unknown/Unknown).

2.4.3 The concepts of risk and uncertainty in project management

Project control and management professionals are faced with increasing complexities in delivering projects. This may be due to the business environment in which the project is undertaken (Stewart and Fortune, 1995). Project management lifecycle is domain specific, however this consist of sequence of stages and activities, from start to completion. Potentially from experience, there are always risks associated with the respective stages (Stewart and Fortune, 1995). Berkeley et al. (1991), suggest that the identification of risk sources is the paramount duty of the project managers. They further state that the goal is to encourage project managers to be more proactive of the potential sources of risks, to anticipate their occurrence, recognize their impacts on the project objectives and reduce future impacts through adequate risk management approaches. As previously stated in above section 4.0 already, Valtonen (2014) asserts that risk arises from uncertainty. According to Schroeder and Jackson (2007), the nature of risk is uncertainty. It is further described as any uncertainty when it occurs would affect one or more project objectives. It is therefore necessary to fully identify and understand uncertainties in projects, since it is the primary source of risks.

Presently, the risk management strategies utilized in the construction industry have been found to be less effective due to experimental evidence of serious bias and errors. This is so due to an overreliance on human judgement while carrying out risk assessment (Hubbard, 2009b). The systematic and misperception of risks are the major sources of concern of using human judgment in risk management (Hubbard, 2009b). During the early stage of a project, project control and management professionals (Including risk expert) rely upon previous experiences and personal judgment in giving cost advice (Akintoye and Fitzgerald, 2000). It has been further asserted by Lees and Fortune (1996), that misjudgement is inherently experienced using previous experiences and personal judgement. Information from human judgement and personal experiences are regarded as soft information that need to be adequately investigated and managed while carrying out project management functions. According to Brigitte Godbillon-Camus and Godlewski (2005), an estimate which is largely made up of soft information are susceptible to manipulation. While carrying out risk and uncertainty management in a project, there are great deals of soft information as inputs. These are subject to biases. Recently, research shown that the conventional project management practice and approach are linear and rational, proving inefficient in successfully managing project lifecycles in general (Cooke-Davies et al., 2007) and (Atkinson et al., 2006b). There has been criticism of the prescribed industrial risk management technique used to manage uncertainty and risk by De Meyer et al., (2002), Stoelsness and Bea, (2005) and Atkinson et al. (2006b). According to Chapman and Ward (2002) & Stoelsness and Bea (2005), there is urgent need for the project control and management professionals to move towards uncertainty management paradigm. According to Carson et al. (2006), uncertainty consist of ambiguity and volatility. This can be further expanded as lack of clear information about environmental variables, cause and relationships uncertainty, courses of action and potential effects of uncertainty. Also, the rate and unpredictability of change in an environment over time, which results to uncertainty about future conditions (Volatility). The project management lifecycle possesses all the features above such as variabilities and unpredictability (Changes) at the beginning/end of the project. Understanding the cause and effects, interrelationships amongst the variables and stages will enable effective identification of potential uncertainties in the project. To support the assertion of Chapman and Ward (2002) as well as Stoelsness and Bea (2005), an uncertainty management paradigm is required to be cognisant of soft information and volatility. Inculcation of a systems thinking approach will be quite useful in understanding and identifying the uncertainties that may impact the project objectives.

2.5 System thinking approach

It is quite glaring that there is rapid growth of complex systems within our society which requires keen attention. We are in the world of technological growth and the advent of artificial intelligence gives room for more innovation. More challenging technology is being needed for daily activities. In 2020, the UK will commence the use of driverless car for transportation although this has been experimented with in other parts of the world (Nordic Region, Asia, and Middle East etc.). According to Arnold and Wade (2015), one of the effects of globalization is the growth of social systems within nations which are creating new complex system. There are observed interconnectivities, and international trade ties nation together resulting into powerful feedback loop. Policies in one country result in ripple or observable effect in other country. Therefore, it is pertinent now to fully inculcate a more holistic approach in understanding this emerging trend. It is believed that system thinking will provide the appropriate steps in understanding this impact. There is a need to have an appreciable number of systems thinkers in our organizations to tackle the complex issues. This type of skill sets is quite different from the traditional engineering and science disciplines, and it encompasses the reality of life.

System thinking is a skill set utilised to better understand the complex behaviour of a system to predict it and alter its outcomes positively. The geometric growth of system within our world of today cannot be overemphasised. So therefore the people involved in system thinking should be well prepared for complex, globalized system future Arnold and Wade (2015). There is a conflicting definition of system thinking. According to Arnold and Wade (2015), system thinking can be clearly explained as the set of synergistic analytic skills utilized to upgrade the efficiency of identifying and understanding systems, predicting their behaviours, and devising modifications to them so as to produce desired effects. These work in conjunction with one another as a system. Some extensive research has been done on system thinking but the applicability is not well established. According to Phillips (1995), the discipline of system thinking involves a framework for understanding the interrelationships and repeated events rather than things, for seeing patterns of change instead of a snapshot. It is guided with a set of general principles and specific tools and that have been developed over a period of years. Utilizing this principle and disciplines in solving complex organizational goals such projects will be quite interesting and useful.

According to Sage (1995), system thinking is regarded as a fifth discipline underpinned as catalyst and cornerstone of a learning organization that encourages success through some other notable four dimensions which are listed as follows:

- Shared vision for the future of the organization.

- Team enhancement and learning.
- Shared mental models of the organization markets and competitors.
- Mastery through commitment to lifelong learning and proficiency.

The above stated advantages of system thinking enables the systems thinker to be able to see beyond just mere cause and effects of an organization which is part of a reductionism approach. It sees patterns of interaction and underlying structures which are responsible for the observed variability. It is a holistic approach in understanding the parts and the entire system as well. This type of approach enables the system thinker to adequately understand events prior to occurring and proper mitigating measures will be put in place. According to Kasser et al. (2013), it sees the world as a complex system as well as supporting the understanding of its interconnectedness and relationships. It utilizes the strategy that a system is bigger than the sum of its parts and thus should be explained holistically. Applying this approach in a construction project which is complex and dynamic in nature will assist in understanding not just traditional constraints but factors, relationships, and feedback behaviours in the project. The approach is not just restricted to construction project but applied to other sectors such as healthcare and education as well as other service sectors. In order to obtain a robust system thinking analysis there are various expected features that need to be identified which are as follows, interconnections recognition, feedback identification, dynamic behaviour identification, variables and flows differentiation, conceptual models' creation, and policy testing (Behl and Ferreira, 2014).

Generally, system thinking can influence various existing concepts, theories, and knowledge in each of these fields. According to Cabrera et al. (2008), it is a structured cognitive endeavour which is formal and abstract. All thinking is known to be complex but not all systems are complex. It has been found that system thinking is based on contextual pattern adopted by an individual or organization and is thus not a specific content strategy. Understanding that the approach is patterned and is quite essential in gaining full in depth of its application in solving real-time issues.

This conceptual fact will tend to improve the approach towards managing construction project(infrastructure). According to Kapsali (2011), conventional project management practices have led a lot of projects to failure due to a lack of a holistic view of the strategies employed. This finding was based on twelve projects within European and one of the key findings was that a systems thinking approach manages complexities successfully in an innovative project. In this research project, it will be widely utilised in the identification of key uncertainties that can impact on the delivery of project objectives during the early stage.

2.5.1 Brief history of systems thinking evolution

System thinking has been in existence for a long time but started gaining recognition in the academia and industrial world recently. The wide holistic application in science and engineering has really created the needed impact. According to Checkland (1994), due to the global status the world is attaining more and more problems continues to emerge which needs to be examined in global rather than local context. Unfortunately, our ideas on management are rather primitive or probably not up to the task of present-day challenges. This stem from the technological oriented thinking of the 1960s which now need to be improved on drastically. A lot of methods utilized in research follows the traditional path of reductionism as established by scientist (Taborga, 2011). Reductionism has triumphed exceedingly well for closed and mechanical systems. However,20th century scientist began questioning whether this approach applies to human and social system. System thinking was gradually improved by Ludwig von Bertalanffy in the 1940s. He postulated the general system theory in which he states that systems continually interacted with environment not just within itself (Taborga, 2011). The view brought about the advent of open system together with other interested scientist formed an association known as international society of system sciences (ISSS) in 1954.According to

ISSS, the society was conceived initially in 1954 at the Stanford centre for Advanced Study in Behavioural Sciences which was formally established as an affiliate of the American Association for the Advancement of Science in 1956.

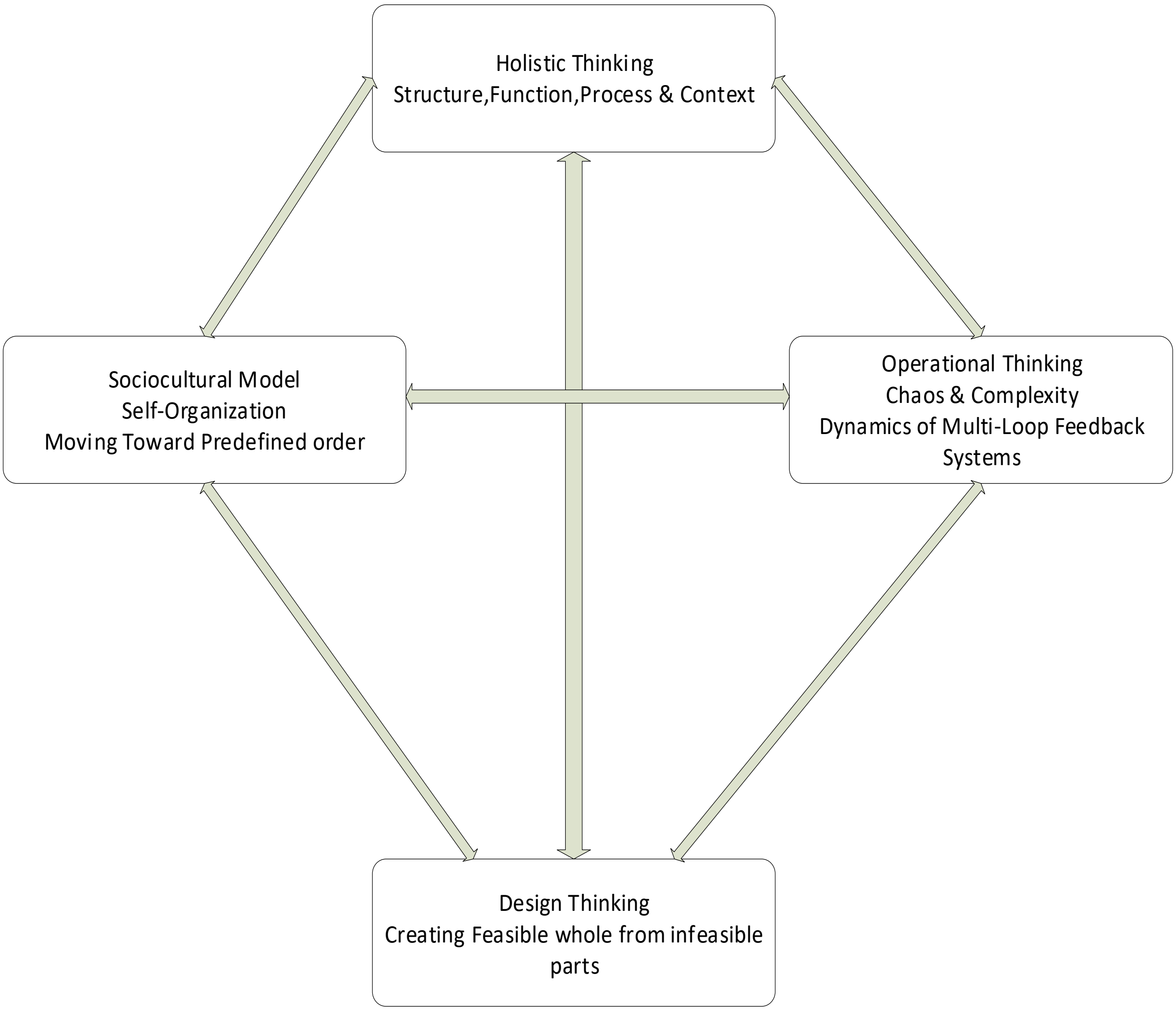


Fig 2.5 Diagrammatical illustration of system thinking foundation (Gharajedaghi, 2011)

2.5.2 System thinking application

The system thinking approach can be regarded as being holistic as against the prevailing reductionist approach utilized traditionally. Smuts (1926), views holisms as the key to all or most of daily problems. A systems thinking approach is a holistic way of looking at the world and understanding of fundamental problem. It is regarded as more than anything else, a mind set for understanding how things work. It is a perspective for reaching far beyond events, to examine the patterns of behaviour and seeking underlying systemic interrelationships which are responsible for the patterns of behaviour and the events as well (Bellinger, 1999). There are specific characteristics of a system which makes it distinctive for proper examination in understanding it behaviour. According to Ossimitz (1997) a system is supposed to possess the characteristics listed below:

- A system must consist of a definable element
- There must be an interrelation between these elements.
- Every system should have a boundary to the surrounding environment.
- Possessing a dynamic behaviour over time which is often related to the aim of the system.
- It consists of an individual system which may be considered sub-system.

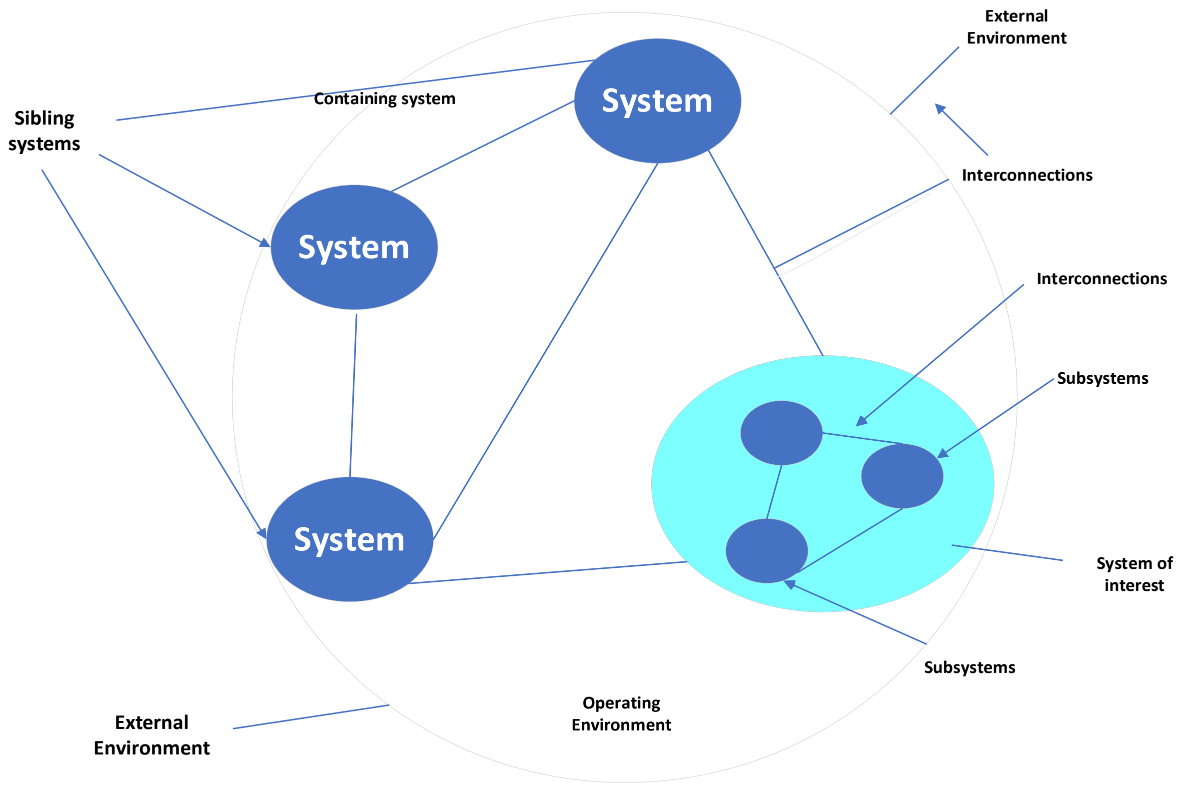


Fig 2.6 A simple system model (Hitchins, 2000)

To accurately utilize system thinking in improving the cost estimate produced by infrastructure project professionals, there is a need to understand the features partially described above. There are fundamental features that need to be understood before system thinking approaches become tenable in their application. The features listed below are as follows: Holism & System, Causal loop system, hard & soft system.

5.2.1 Holism and System

The Holism paradigm or practice lays emphasis on the whole system. This means understanding the whole, rather than the constituent part of a system (Jackson, 2003). It takes into consideration of how the world looks for how an entity forms part of some larger whole. It is defined by relations and functioning within the broader system (Jackson, 2003). In the context of this research, infrastructure cost estimation is regarded as a part of a whole system (Infrastructure project). In the past, reductionism paradigm has been employed in managing the infrastructure project cost estimation leading to mostly inaccurate estimate. Reductionism practice involves analyses and description of a complex phenomenon in terms of elementary parts that exist on simpler level. According to Donella (2009), system is an aggregate of elements or components interconnected to each other to achieve a specific objective. The components of a system are elements, interconnection, and purpose. The breaking down of a whole system into simpler level to decipher the constituent components into more understandable parts is referred to as reductionism. Many projects control and management professionals utilize this approach in delivering project. In this type of approach, deciphered part within the system is analysed critically without considering the whole system. This may sometimes lead to error in decision or analysis. There are many factors considered during infrastructure project cost estimation which has been described in chapter 2.2.2.1 in the previous chapters. All these factors need to be analysed holistically so as to produce a robust estimate during the initiation stage. In infrastructure project cost estimation, the main objective is to predict a robust estimate of the project. According to Rush and Roy (2001), cost estimation utilizes skill sets such as experience, logic, common sense, and judgement in producing a robust estimate. It can be deduced that cost estimation in infrastructure projects is not completely linear as it is being treated by project control and management professionals. The inputs contain both soft and hard information . Bertomeu and Marinovic (2015), suggest that inaccuracies in cost estimation are more likely when soft and hard information are utilized together. The nature of infrastructure project carried out today, involves multiple stakeholders with various interests. This may lead to manipulation and biases during the estimation process mostly in the initiation stage due to the multitude of stakeholders involved. This is because of expecting strong stakeholder buy-in in term of budget approval for the project. Understanding the various variables, elements and the soft information involved during the initiation stage will enable adequate uncertainty identification.

5.2.2 Soft system methodology (SSM)

This an area of system thinking that deals with both hard-tangible information and soft complexity due to human involvement as well. It takes feelings, attitudes and perception of individuals or groups into consideration (Stewart and Fortune, 1995). As described above in chapter 5.2.1, infrastructure cost estimation involves mainly human judgement and expertise which are quite subjective during this process. This methodology is quite useful for a system that is cumbersome and cannot be quantified. According to Yan and Yan (2010), this approach is utilized in understanding and resolving cumbersome issues associated with humans' perception, reactions, intentions, and actions. The important role of cost estimation in the modern-day infrastructure project delivery system has highlighted some of the weaknesses of the traditional techniques (Reductionist approach) and quest for alternative approach. The traditional techniques used can be narrower and more linear, concentrating on the detailed planning and studies. It has been observed that there is a need for more strategic approach (Davidson and Huot, 1991). There are many soft factors that need to be considered while delivering infrastructure project which the traditional technique is yet to inculcate namely, staff attrition, schedule pressure and communication overheads (Rodrigues and Bowers, 1996).

Application of soft system methodology is explicitly exhaustive in dealing with soft information managed subjectively by professionals utilizing it. The methodology contains stages and is quite iterative as well. The phases are listed below as follows:

- **Situation definition**
- **Situation expression using diagramming technique.**
- **Concept selection**
- **Assemblage of concept into meaningful structure**
- **Utilization of structure to resolve situation**
- **Changes definition to situation.**
- **Implementation of change process(Rodrigues and Bowers, 1996).**

An early model of SSM was developed by Checkland (1981), which utilizes the concept of human activity. This concept has been developed and improved upon by various researchers in the field of system thinking. Below is a diagrammatic illustration of the conceptual model which is the foundation through which other researchers build upon when formulating or designing a soft system methodology.

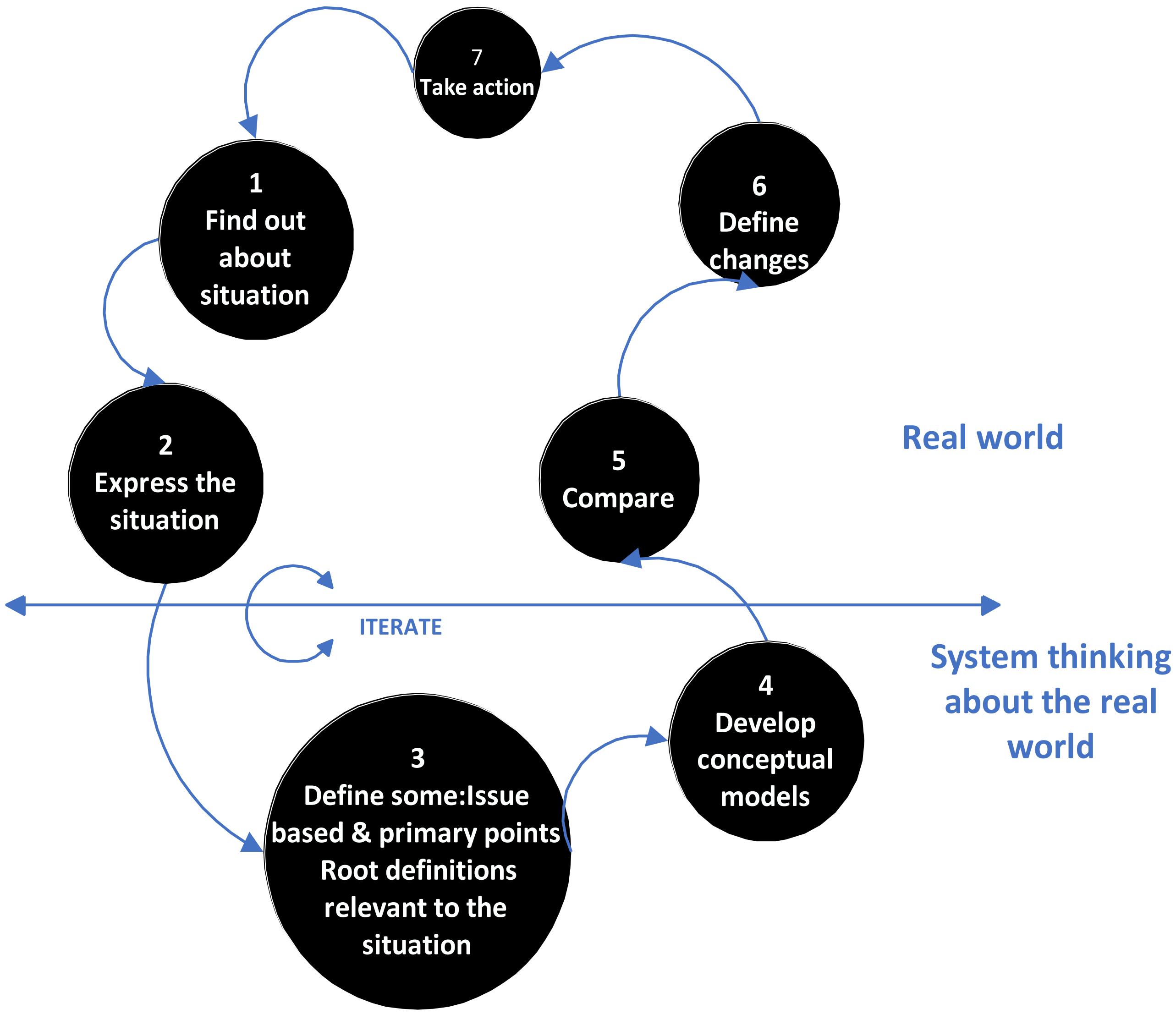


Fig 2.7 Diagrammatic illustration of Check land's conceptual SSM (Checkland, 1994).

System diagramming technique will be used to represent situation and concepts assemblage as well. It is utilized in modelling chosen or specific system and in the area of problem investigation (Stewart and Fortune, 1995). The key advantage of this technique is that it depicts the holism, interdependent and interconnectivity amongst the system and subsystem involved. Rich picture, concept mapping and causal diagram will be used for this research system diagramming technique.

- **Rich picture.** This is a graphical representation technique of soft system methodology which represents a complex situation (Pain, 2012). This will be quite useful during an infrastructure project initiation stage precisely during the conceptual estimation phase. The conceptual and preliminary estimating phase normally takes place prior to the engineering and design completion. This is when there is limited information about the infrastructure project to make a robust estimate. It is done in the schematic and budgetary section of the project initiation stage. It is generally susceptible to a high level of uncertainties due to vague information available. It can be readily utilized to organize complex situations and identify underlying issues and stakeholders of a system (Pain, 2012). Any tools can be used to represent a rich picture as long as it encourages discussion, interaction as well as attaining a holistic understanding overview of a system by key stakeholders (Pain, 2012). Infrastructure projects can be well represented holistically using rich pictures during the initiation stage so as to identify potential uncertainties that might impact on project objectives. Some of the inputs for this technique will be related to history and lessons learned, from files similar projects. This technique gives a preliminary overview of the operating environment of the infrastructure project with external influences and doesn't really dig deep into the dynamics that might impact on the project objectives. Another soft system methodology is required for further analysis.
- **Concept mapping:** This can be simply described as the integration of qualitative and quantitative methods designed to enable a group of people to articulate and depict graphically a coherent conceptual framework or model of any issue or task of interest (Trochim and McLinden, 2016). This is quite resourceful during infrastructure project uncertainties identification. It enables multiple stakeholders within the infrastructure project to produce an interpretable pictorial view of their various ideas, concepts,

including how they are interrelated. The interrelationships between the elements within the system can be adequately depicted using concept mapping. The input directly from the rich picture can be studied to some extent using this soft system methodology. During the infrastructure project initiation, when high level risks, assumptions, issues, and constraints etc. are being identified, a concept mapping approach is effective. It can assist in providing information where potential constraints and uncertainties might spring-up from having analysed the operating environment and external influence on the project via rich picture. To depict the entire interconnectedness and to a robust feedback loop amongst the system elements, a further soft system analysis is required, namely causal diagrams.

- **A causal diagram** is utilized by identifying key variables (Elements) within a complex system and indicating the causal relationships between them via a feedback loop. This constructed loop is then used to create a concise framework about a particular issue or task (Lannon, 2018). Causal diagrams assist complex systems to understand the behaviour of elements within them thus creating more insight into how the subsystem behaves. The input from both the rich picture and concept map can really assist in generating a robust causal diagram of an infrastructure project. Understanding how the infrastructure project phases work, especially the activities within the initiation stage, where limited information is available will assist greatly in generating potential uncertainty sources and factors as well. A crucial relationship between the system and the external environment is essential. For instance, depicting the causal effect of finances, geological conditions and the political atmosphere on the project will be quite helpful in planning for proactive strategies. It can also be utilized for stakeholder analysis and their influences on the project as well. It will assist the project management team to plan accurately the communication channels.

5.2.3 Feedback loop system (Causal loop)

This can be regarded as the transmission and return of information within a system. To be more concise, it is a closed sequence of cause and effects, which is a closed path of action and information (Kim, 1992). This is quite a useful in soft system approach in determining the root cause and effect of an issue or problem within a system. It checks the correlation between an input and output of a system. The reductionist approach utilized by infrastructure project control and management professionals does not give room for feedback loop system thus preventing a holistic view of the estimation. In cost estimation process during the initiation stage, there are many interrelations between variables that impact on the estimation which need to adequately investigate. There are two main types of feedback loop system utilized in system thinking which are described below as follows:

- **Open loop system:** This can be described as a linear chain of causes and effects which does not close back on itself. An account of the feedback loop is not taken into consideration (Kim, 1992). This type of loop system is synonymous to the reductionist approach employed in cost estimation.
- **Close loop system:** this is the opposite of the open loop system. It is mindful of the feedback loop system. This research work will be employing this system for the robust identification of the uncertainties that may impact the cost estimation.

2.5.3 System thinking application in cost estimation

The cost estimation process is regarded as a system to be robustly dealt with during the initiation stage of project delivery. In the traditional approach used in carrying out cost estimation, an open loop system is involved. A linear approach where there is an input and output without feedback impact on the overall process will omit much useful information. Fig 2.8 is the simplified feedback loop system of a cost estimation process system description.

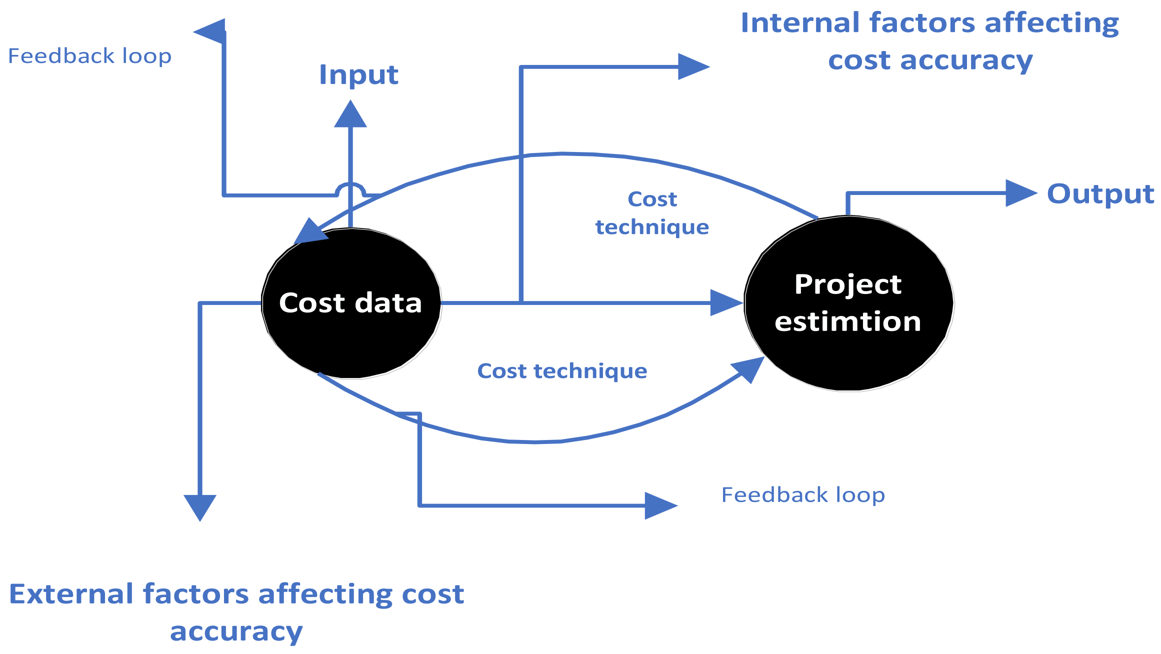


Fig 2.8 Diagrammatic illustration of simplified cost estimating process system

As illustrated above in Fig-2.8 there is a cause and effects of the inputs and outputs. Many variables impact on the cost estimation process prior to the production of the project estimate. The interrelationships amongst elements and, variables within the cost estimation process will produce a holistic overview. In this research work, the focus will be the identification of uncertainty variables impacting on the cost estimation. The vital aspect of cost estimation is to accurately predict the needed cost to initiate a project. Producing a robust estimate that will accurately predict the project cost to initiate the project is quite cumbersome with the traditional approach employed by project control and management professionals. A system thinking approach will serve as supplement not replacement to the conventional approach of cost estimation. The advantage of taking consideration of both soft and hard information during the cost estimation process is a key in ensuring robustness of the whole process in its entirety. Below is the diagram showing a holistic overview of the cost estimating process.

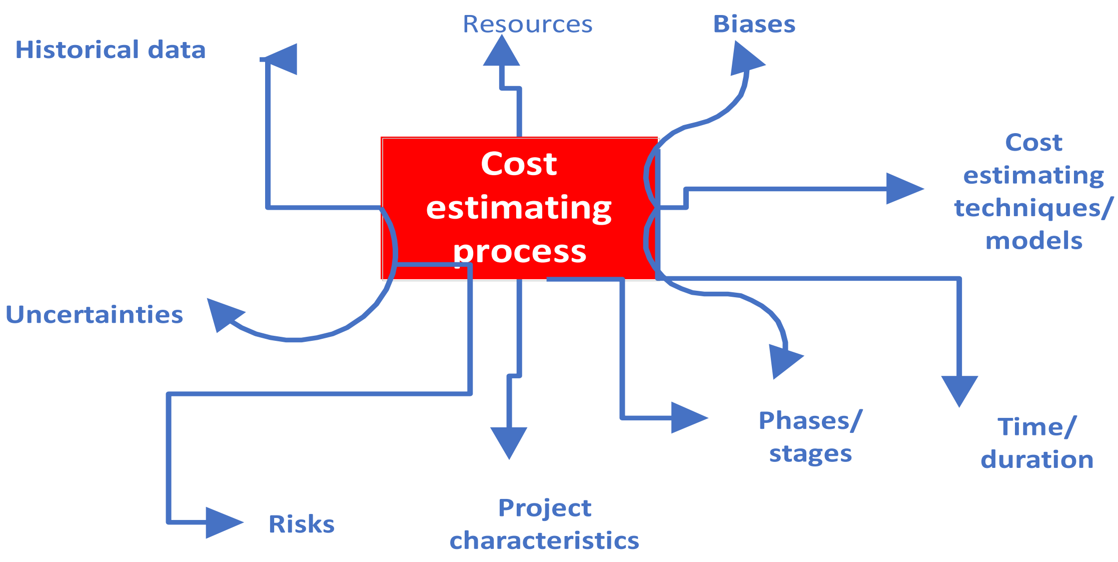


Fig 2.9 Diagrammatic illustration of holistic overview cost estimating process (Checkland, 1994)

There are many elements, variables and stages/phases that need to be adequately inculcated into the process to produce a robust estimate. Most of this information is both soft and hard. The hard information for this research was derived from both case studies of firms and surveys while the soft information is deduced by using system thinking and need for cognition scale. These scales will investigate the engagement of project control and management professionals in thinking. The need for cognition assessment scale is an instrument used to quantitatively measure the tendency for an individual to engage in and enjoy thinking.

2.6 Research gap.

The literature review in this chapter as revealed that infrastructure project still consistently goes overbudget despite the highly capable project control and management professionals involved. Presently, there is no clear-cut demarcation where the error in estimation lies at the appraisal stage(initiation) or during the planning/execution stage. The main analysis of this research relates to the appraisal stages where there is dearth of detailed information for robust cost estimation decision procedures under uncertainty and risk. There is limited evidence of empirical research on a holistic informed decision under uncertainty and risk utilized in production of early project cost estimate during the project appraisal phase. Also, there is no consistent holistic framework for the identification and management of uncertainty during the project appraisal phase. Additionally, researchers have not been able to consider the soft data that influences an early cost estimate. This is considered a gap considering the inability of the linear project management paradigm (traditional risk management) to effectively manage risk, uncertainty and understand the soft data that impact on the cost estimate in challenging and complex environment at project early stage. It is seen as a research problem which many researchers are constantly trying to find an effective and reliable solution.

2.7 Chapter summary

The literature review has shown that there is extensive reference to errors in early cost estimation due to inadequate management of uncertainty and risk. Uncertainty and risk have been explained, and it has been discovered that there is still significant discussion between subjective and objective perspectives of uncertainty and its management. It has also emphasised the importance of comprehending epistemological assumptions when dealing with uncertainty and risk management. The significance of system thinking in improving the early cost estimate of infrastructure project was emphasized as well. The literature review highlighted a study gap to empirically investigate how system thinking will be utilized to identify uncertainty factors and estimate them as well as to improve on prior research on infrastructure project early cost estimate.

Chapter 3 Research methodology

3.1 Introduction

This chapter explains the various procedures, principles of research philosophy/paradigms, design, methods, and data collection/analysis, specifically utilised in this research work. Initially, it discusses the overview of the research philosophies, paradigms, methodologies, and methods available. According to Kumar (2019) to the study design, methods, tactics, and processes utilised in an investigation that is adequately described and designed to find out or discover anything are regarded as the methodology. Also, to acquire a deeper understanding of the research problem, it is important to consider the logic and flow of the systematic processes used to perform the study. Additionally, it is the logic and flow of the systematic processes followed in conducting a research work so as to gain a more comprehensive into the research problem (Prhabat et al., 2015).

It is reasonably difficult to overstate the importance of methods in research works. Essentially, they are a means by which empirical evidence is gathered to advance knowledge (Plonsky, 2014). Shanti and Shashi (2017) present two approaches for resolving the problem at hand: either using one strategy or combining several suitable approaches, depending on the nature of the problem(s) to be investigated. After identifying the gap via an intensive literature review, a mixed method is adopted, which comprises both qualitative and quantitative methods. This mixed method was used to explicitly investigate the gap identified during the literature review, which is the inability of the linear project management paradigm to effectively manage risk and uncertainty and understand the cost data that impact on the cost estimate in challenging and complex environment at project early stage. Infrastructure projects are relatively complex and encounter numerous uncertainties during execution due to inadequate robust uncertainty management. The system thinking approach adopted for the identification of uncertainties involves soft skills which are observed and collated using a qualitative and quantitative methods. This research is important to eliminate unproven hypotheses for a range of events, apply a formal, systematic explanation, and utilise methods that have been shown to produce results with high power and generality (Goundar, 2012).

The research approach utilised for this thesis is the inductive approach. The primary rationale behind using the inductive approach is to explore new phenomena in the application of system thinking to solve a cost estimating problem during the early stage of the project. Research questions are also generated after a literature review to be answered using the appropriate process and design. According to Gabriel (2013), the inductive approach in research is concerned with the generation of new theory emerging from collated and analysed data. Using the inductive approach for this research prevents any bias from respondents during surveys due to reliance on previous theories regarding uncertainty and risk management for infrastructure project management.

Bryman (2016) emphasises the importance of theory, by stating that it provides a background and justification for research that is conducted as well as providing a framework within which a social phenomenon is understood. This chapter also explains more on the challenges that emerged during the pre-study and main study phase.

3.2 Research scope

The research work is focused primarily on the infrastructure project management aspect of the rail infrastructure project. Cost management and optimisation is the core aspect of this research work together with studying the impact of varying aspect of uncertainties on it. A comprehensive and literature review of the system thinking approach, the uncertainties, costing as well as risk has been performed to fully understand the background problems and gaps fully. Primary and secondary data are sourced from both the literature review and case study area to produce robust research work.

3.3 Research design and process

The research process is regarded as the various steps, actions and functions adopted to achieve the aim and objectives of the research work., while the research design is the chosen research process to achieve the goal and objectives, respectively (Arab, 2011). It is worth stating that the process and design are somewhat intertwined in actual practice. Bryman (2016) specifies that the research design of research work is subject to the identified problem, respectively. Adequate care was taken into consideration prior to choosing the process and design in order not to produce an excessive amount of research work with no distinct path.

The research process pertaining to this thesis and the design were implemented to address the gap identified after the literature review, which is the inability of the linear project management paradigm to effectively manage risk and uncertainty and understand the soft data that impact on cost estimate in a challenging and complex environment at project early stage. Also, the focus is on uncertainties and the impact on cost during the initiation stage. The research design was designed to address the research questions while the process is utilised to implement the plan. Hence, both the research design and process go concurrently. To further illustrate the importance of a research design prior to the actual thesis work, Vaus (2001), states that it is the overall strategy a researcher chose with the intention of integrating different components of the study coherently and logically, thus ensuring that the research problem is addressed. To ascertain a solution to the identified gap and problems, distinctive research design and strategy is vital. There is an apparent need to understand the research paradigm before the actual design and plan to be able to elaborate on the findings at the concluding part of the thesis. According to Patel (2015), the research paradigm is a set of beliefs and agreements shared between scientists about how problems should be addressed and understood. Bogdan (1998) further explained that it influences the way knowledge on the research topic is studied and interpreted. Likewise, there is a requirement to clearly define the research paradigm to design a robust research strategy that support the methods, methodology and to establish solutions to research questions and problems effectively (Mertens, 2005). Below is the diagrammatical illustration of the research design process of the thesis.

- **Theoretical framework for research**

The theoretical framework is required for this research work after a careful creation of the research design. According to Dickson Adom et al. (2018), the theoretical framework explains the path of the research and grounds it firmly in theoretical constructs. The sole benefit of a theoretical framework is to provide a structure showing how a researcher defines the study philosophically, epistemologically methodology and analytically (Grant and Osanloo, 2014). Ravitch and Carl (2016) further concurred that the theoretical framework assists researchers in situating and contextualizing formal theories into their studies as a guide thus positioning their research work in an academic manner. It serves as the focus of the research and links it to the research problem under study. Likewise, it helps to guide the research design and data analysis plan, thereby guiding the type of data to be collected for a research study (Lester, 2005). It has been evidently demonstrated that without a proper theoretical framework research work will lack direction to search for appropriate literature and scholarly discussions related to the research findings (Imenda, 2014). Creating a well laid out theoretical framework makes the research findings, meaningful and generalisable (Akintoye, 2015). The theoretical framework for this research began by identifying the research problem and gap via an intensive literature review. Research questions were generated which answer the aim and objectives of the research work, respectively. Fig 3.1 below is the diagrammatic illustration of the theoretical framework for this research work.

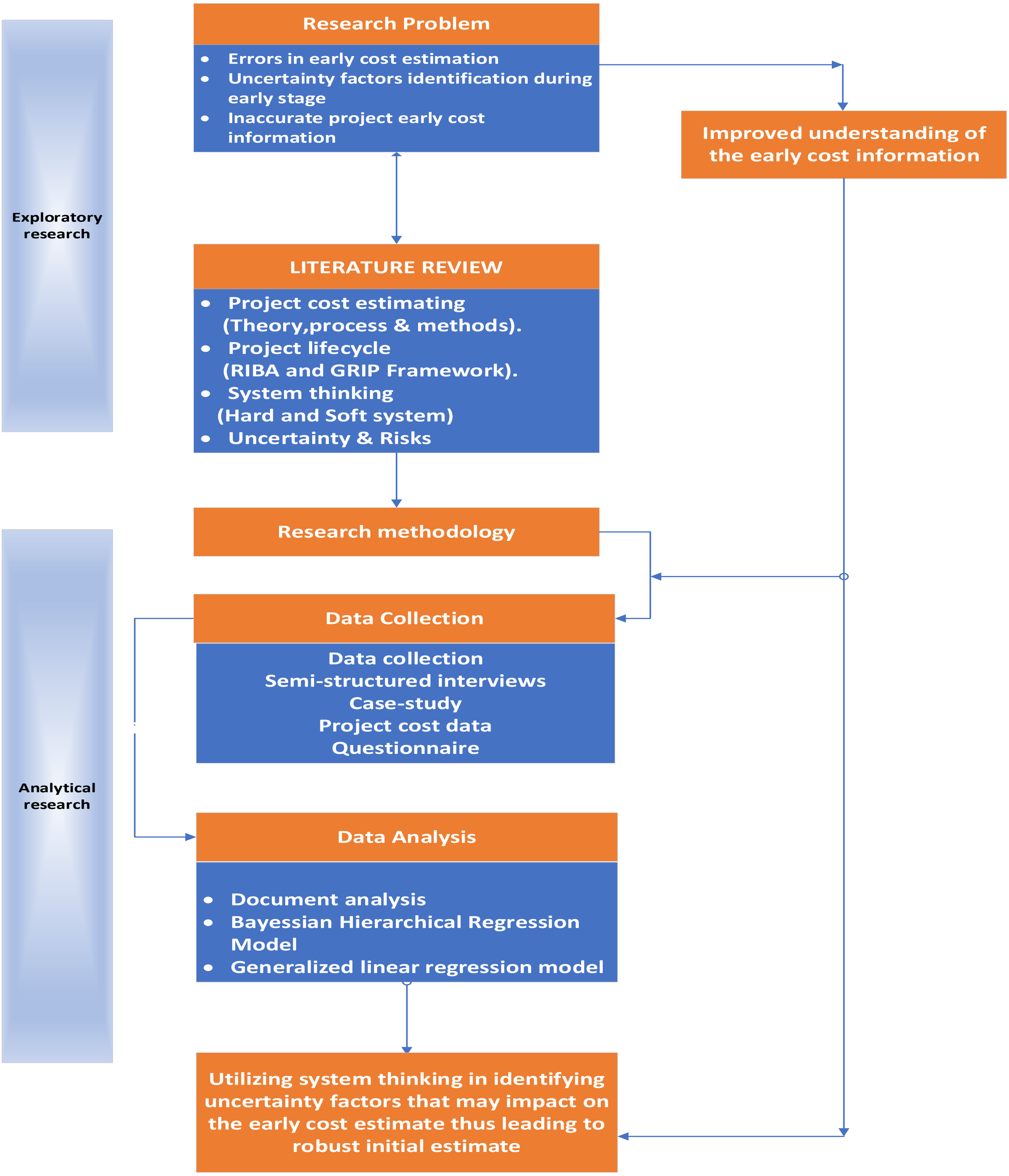


Fig- 3.1 Theoretical framework diagram of the research work.

3.3.1 Research paradigm

The word paradigm implies a philosophical way of thinking and has its aetiology in Greek, where it connotes pattern. In educational research, it implies the worldview of a researcher

(Kuyini, 2017b). It is the perspective of thinking and a shared set of beliefs that inform the meaning or interpretation of research data. Additionally, it signifies that the abstract beliefs and principles that shape the way a researcher sees the world and how descriptions are made within (Kuyini, 2017b). Morgan (2007), further contends that the paradigm encompasses various ways of experiencing and thinking about the world, including beliefs concerning morals, values, and aesthetics. An important relationship exists between paradigm and methodology. The methodological implications of choosing a paradigm choice cut across, the research questions, participants' selection, data collection instruments and collection procedures, as well as data analysis (Kuyini, 2017a).

Therefore, the paradigm for this research was carefully chosen after identifying the problem and gap to be investigated accordingly which is interpretivisms and pragmatism. Interpretivism approach is to understand the subjective world of human experience (Kuyini, 2017).

The pragmatic approach allows different ways of interpreting the world and undertaking research. No single point of view can ever give the entire picture (Dudovskiy, 2018).A thorough study of uncertainty management and how it impacts on cost estimation at the initiation stage was conducted, resulting in the generation of a new theory. Two major types of research design were employed, specifically exploratory and conclusive research. Exploratory research is aimed at exploring a specific aspect of the research area (Dudovskiy, 2018). System thinking approach is quite broad but nascent in its application for uncertainty management of infrastructure project. Conclusive research is a type of research design that assists a researcher in determining, deciding, evaluating, and choosing an appropriate path of action (Malhotra, 1999). It is also conducted to provide an insight to verify and quantify the findings obtained from carrying out exploratory research.

This research is guided methodologically with the robust concept to obtain a sustainable solution to the identified problem and contribute significantly to the body of knowledge. A well-planned research philosophy was employed to guide the strategy for this thesis. The actual study of phenomena in their natural state is a criterion for this type of philosophy and of the opinion that scientist cannot avoid affecting it as well. Also, it is the believe that only through the subjective interpretation of and intervention can the reality be better understood (Wanda et al., 1991). It is also referred to as the phenomenological approach which aims to understand people and the surroundings. It should be noted that the focus is primarily on exploring the complexity of social phenomenon (Mouton, 2008). Interpretivism thus focuses on exploring the complexity of social phenomena with a view to gaining understanding. The goal of utilizing the interpretivism approach in research is to gain an understanding and interpret everyday occurrences as well as social structures (Collis and Hussey, 2009).

It is extremely obvious that the research approach will undeniably shape the outcome of the findings, thus enhancing the chances of significantly contributing to knowledge, if chosen correctly. Conceptualizing a methodological position as a specific set of ontological and epistemological assumptions there are two significant research paradigms which are applied as focal points. They are referred to as positivist and interpretivist paradigm (Yang, 2014). Most research philosophies fall within this category, but this research work utilises both the philosophies of interpretivism and pragmatism. Epistemology provides philosophical groundings for deciding what nature of knowledge is possible and ensures adequacy as well as legitimacy (Maynard, 1994). Fellows (1997), demonstrates that epistemology is the aspect of philosophy that deals with the origin, environment, methods, and limits of human knowledge. Understandingthesubjectiveinterpretationoftheprojectcontrolandmanagement professionals in estimating infrastructure project cost using system thinking was the main aspect of this research. Similarly, constructing a theory backed by empirical evidence from the identification of uncertainties in infrastructure project during the initiation stage using system thinking also forms the bedrock of this research as well. It should also be noted that a philosophical view of the overall research was paramount as regards robustly guiding the deliverables.

Manion (1994) claims that interpretivism understands the world of human experience. Yan and Yan (2010) further elaborate that the interpretivist researcher discovers reality by the way of the participant's perspective, their own background, and experiences. The use of the interpretivist paradigm allowed the examination of the research through the perception and experiences of the project control and management professionals who were participating. Part of this research seeks to understand and explore the experiences and perception of the project control and management professionals concerning infrastructure project cost estimation.

Interpretivist paradigm thus accepts and seeks multiples perspectives, being open to change, practicing iterative and emergent date collection techniques, promoting participatory and holistic research (Willis, 2007). The acceptance of several perspective in interpretivism often generates a more comprehensive understanding of the situation (Meyers, 1998). To explore the understanding of the participants involved in this research, an interpretive methodology provides a context that allows the examination of what case study participants have to say about their experiences. According to Willis (2007) interpretive research is more subjective in relation to other research paradigms. The system thinking approach utilised in this research is more qualitative but will also be interpreted quantitatively. It is more appropriate to employ interpretive philosophy here to give an account of the study that captures the position of the participant on cost estimation, risk, uncertainty, and system thinking.

Dudovskiy (2018) stipulates that research question is the most important determinant of the research philosophy. Pragmatism emphasizes that research involves decisions about which goals are most meaningful and which methods most suitable. It is also concerned with evaluating and transforming features of real-world, psychological, social and educational phenomena (Frey, 2018). Pragmatism is based on understanding human experience; therefore, pragmatic studies often seek to understand the numerous factors involved in people's actions in a given situation (Duram, 2012). Additionally, pragmatism allows open and comprehensive investigation, as there are no theoretical constraints that limit the inquiries (Duram, 2012). Patton (1990) asserts that a pragmatic approach provides a method of research that is found to be appropriate for studying the phenomenon at hand. Moreover, it is a practical and pluralistic approach that allows a combination of methods that in conjunction could give insight into the actual behaviour of participants, beliefs that stand behind those behaviours and the consequential actions which follow it.

Pragmatism favours both the qualitative and quantitative method in relation to this research. One of the proposed advantages of mixed methods research is that it can overcome the disadvantages that are inherent when adopting monomethod research (Tashakkori, 2006) Research questions form the principal part of this research so as to generate robust theory. A pragmatic approach allows researchers to be flexible enough to adopt the most practicable approach to address research questions (Creswell, 2003). Hence, a need to utilise precise research philosophies that will guide the deliverables of this work becomes inevitable.

3.3.2 Research approach

The establishment of the research philosophy and questions utilised in this research guides the approach formulated. Inductive research involves the search for pattern from observation and the development of explanations (Dudovskiy, 2018). It is an analytical process that involves going from the specific to the general purpose while deduction approach is contrariwise (Christensen et al., 2015). The inductive approach observes the data collected via survey and interviews and for theory to be generated from it (O'Reilly, 2012). Furthermore, it provides a convenient and efficient way of analysing qualitative data for many research purposes

(Thomas, 2003). Inductive approaches are meant to promote an understanding of meaning in complex data through the development of summary themes or categories from the raw data (Backett and Davison, 1995). It should be mentioned that the purpose of utilizing the inductive approach is to enable research findings to emerge from the frequent, dominant, or significant themes inherent in raw data without the limitation of structured methodologies (Thomas, 2003). According to Corbin (1998), the inductive approach begins with an area of study and allows the theory to emerge from data.

Utilizing the inductive approach in this research enables the establishment of an obvious connection between the research objectives and to summarize the findings derived from raw data. It also enables the development of framework of the underlying structure of experiences or process that is forthcoming in the data collated (Thomas, 2003).

3.3.3 Research strategies

The research strategies for this research work were carefully selected so as to answer the questions and achieve the objectives. Saunders et al. (2009) asserts that there are seven different types of research strategies employed in the field of research: Experiment, survey, case study, action research, grounded theory, ethnography, and archival research strategies. They are employed in answering research questions and fulfil the research objectives, respectively. The research strategies utilised in this research work were guided by the research problem, gap, research philosophy and approach identified. The assumption and the understanding of the knowledge of the identified problem determined the research strategies employed. The research strategies utilised in this research are the case study and survey, respectively. They are illustrated below:

3.3.3.1 Case study

The case study involves a detailed of a single individual, group/organisation, event/project, or process. The sources for this type of study can emanate from observation, interviews, questionnaires, reports, and archival report (Liu, 2015). The main benefit of utilising this type of study in qualitative research method is the provision of insights and ideas in the early stage of investigating a topic (Liu, 2015).

The nature of the research requires in-depth knowledge and understanding to enable an efficient and effective solution to the identified research problem. This should correlate with the assumptions, approach and beliefs adopted for the sole of the research work. According to Sanders (2007), it is relatively important in a doctoral study to have consistent research questions, besides mythological and theoretical approaches within the thesis. A well-planned research strategy was required to answer the research questions and fulfil the research objectives. Additionally, a research strategy provides the overall direction of the research including the process by which the research is conducted (Remenyi et al., 2003).The case study approach is utilized in this research. Sanders (2007), clearly states that an appropriate research strategy must be selected based on the research questions, objectives, existing knowledge horizon to be researched, the available resources/time and the philosophical underpinnings of the researcher. A necessary research strategy has to be selected based on three vital conditions, namely the type of research questions, the degree of control, the investigator has over actual behavioural events and the degree of focus on contemporary or historical events (Yin, 2003b).

The case study is regarded as a documented empirical inquiry that investigates a contemporary phenomenon within its real-life context, in particular when the boundaries between phenomenon and context are not clearly evident (Wedawatta et al., 2011). Understanding how infrastructure cost estimation is being carried out within the government owned infrastructure project institution was vital to the success of this research work. According to Saunders et al.

(2009), case study research strategy enables questions such as why, what, and how to be utilised which are mostly exploratory and explanatory research in nature to be utilised. There is different method of data collection methods used in case study research, specifically which are as follows: interview observation, document analysis etc. They can be employed separately or in conjunction to answer research questions (Saunders et al., 2009). 6 case studies were employed for this research work to properly understand how the generated models performed in its real practical terms.

3.3.3.2 Survey

The key aspect of this research is collating the subjective information from a specific population involved in the government owned infrastructure project institutions and performing statistical analysis to understand identified variables. According to Check and Schutt (2012), the collection of information from a sample of individuals via their responses to questions. It entails several of methods for example the recruitment of participants, collection of data and utilization of various instrumentation methods. It uses both quantitative and qualitative research strategies or mixed method which is somewhat advantageous for this research. Similarly, survey methods describe what exists in what amount and in what context too. The survey strategy is typically associated with the deductive approach to research and is primarily used to answer the 'who,' 'what,' 'where', 'how much' and 'how many' research questions (Saunders et al., 2009). The most popular data collection methods are questionnaires, interviews, and documentation review (Denscombe, 2010). The data collection method exploited in this research are questionnaires and interviews . Research survey also possess distinctive characteristics which signifies that this method is suitable for this research. Pinsonneault et al. (1993) identify three major characteristics of the research survey which makes it effective for this research. Listed below:

- Quantitatively describing specific aspect of a given population. It involves examination of relationships among variables.
- Collection of subjective data from participants.
- Utilization of selected portion of sample and findings deduction from the same sample.

The use of system thinking in the identification of uncertainties during the project initiation stage makes the survey method effective due to the collation of soft information which are mostly subjective. Surveys can also be used to elicit information regarding attitudes that are otherwise difficult to measure using observational techniques (Lisa, 1999).

3.3.4 Research methods

The implementation of the research method for this thesis was guided by the research philosophy and approach. This was undertaken to effectively provide robust answers to the research objectives and questions. The tactics, processes, or techniques used to gather data or evidence for analysis with the goal of learning new facts or developing a deeper comprehension of a subject are known as research methods (Clark et al., 2021). The different techniques and tools used by the researchers to collect and analyse data are known as research methods (Saunders et al., 2009). It has been noted that mixed, qualitative, and quantitative research methods are most frequently used in the construction management industry, with a strong preference for the quantitative method (Wilkinson, 2020).According to Loosemore et al. (1996) published papers in construction management and economics used the quantitative method (57%),qualitative method (8%), mixed-method (22%) and discussion papers (22%) respectively. Carter et al. (2004), confirms the finding by elaborating that published papers in 2000 and 2001 by the Association of Researchers in Construction Management (ARCOM) annual conferences applied the quantitative method than other recognised research methods. Both research approaches can coexist in construction management studies, and they also benefit from one another (Bartlett and Milligan, 2021). This shows that a variety of research techniques can be used to carry out study quickly and objectively (Hennink et al., 2020). The research problem, question and objectives are the influential variables for the strategies and design. The strategies, design and process this research followed are clearly defined and well planned out.

3.3.4.1 Qualitative research method

Qualitative research is a strategy employed in research to emphasize words rather than quantification in the collection and analysis of data (Bryman, 2016). Understanding the meaning of knowledge and how it is constructed is the primary interest of qualitative research (Merriam, 2015). Gannon and Fauchon (2021), describe in more detail how qualitative research is used to create new theoretical concepts and interpret a theory or important phenomenon. Also, it was explained that qualitative research is applied to develop new theoretical ideas and make interpretations of a theory or a significant phenomenon. According to Curry (2018), the foundation of interpretivism is the idea that people's interpretations of information and events shape how they are understood and how they act. The belief that reality is created by people interacting with their social worlds is the philosophical premise on which various types of qualitative research are founded (Kara, 2022). The philosophical assumption and paradigm (Interpretivism) were utilised in investigating the interconnectedness, interrelationship s and interdependencies amongst variables, stages and processes. The majority of the attention is given to investigating, analysing, and describing individuals and their natural environs(Hein, 2020). According to Vindrola-Padros (2021), qualitative research is more focused on developing a hypothesis that aids in explaining a phenomenon than it is on testing a theory. System thinking approach applied in this research work concentrated on both the hard and soft information. Hence, the need to ascertain a suitable research method to explain the emic perspective of the research findings is inevitable. To be more explicit, three kinds of data gathering are frequently used in qualitative research approaches: In addition to open questions where people are asked to provide written descriptions of their experience of a phenomenon, observation, in which descriptions of verbal and non-verbal behaviour are presented, unstructured interviews, in which verbal descriptions of people's experiences of a phenomenon are elicited (Jaiswal et al., 2020).

In this research work interview, survey and a case-study were utilised for the purpose of qualitative and quantitative research.

3.3.4.2 Quantitative research

The quantitative approach focuses on evaluating and measuring numerical data (Cohen et al., 2011). Quantitative research methods are employed for the empirical and systematic investigation of quantitative phenomena or properties (Bryman, 2016). Most people believe or consider it to be objective in nature (Berard and Smith, 2020). According to Baxter et al. (2010), quantitative research seeks the facts/causes of social phenomena together with obtrusive and controlled measurement. Several of the characteristics comprise objectivity, the outsider’s perspective, ungrounded, verification oriented, reductionist, hypothetical-deductive, outcome-oriented, reliable; hard and replicable data, generalisable and multiple case studies, particularistic, assumes a stable.

Fremeth et al. (2016), illustrates how a considerable amount of literature is analysed to identify the study topic, variables, and hypotheses precisely at the beginning of the research process in quantitative research. This is followed by the collection of the relevant data to test them, and then reflecting on whether the theory is confirmed or unconfirmed by the results of the study. In the social sciences, several quantitative techniques, including structured interviews, structured surveys, symbolic models, and physical testing, are increasingly widely used (Clark et al., 2021). The application of this research method in this research work was to establish relationships amongst variables. To mitigate any form of bias, data was collated from diverse representative samples regarding infrastructure project control and management professionals.

To avoid bias, data collection or compilation should use a representative sample of a large population (Bauer and Scheim, 2019). Data was collated using questionnaire survey from a representative sample of infrastructure project control and professionals. Additionally, adequate statistical analysis was carried out using factor analysis, Generalized linear Model and Bayesian Hierarchical Regression Model.

3.3.4.3.Mix research method

The objective of the study, as well as the type and accessibility of the necessary information, all influence the choice of research methodology (Harvey and Land, 2022).Coe et al. (2017) believes that, whilst preserving the unique contributions and integrity of each separate technique, mixed methods research functions as a bridge connecting two or more research approaches to make them more mutually informative .This specific approach has many advantages, including trust in the results, assistance in identifying anomalous or unexpected aspects of a phenomenon, integration, theory, and enriched descriptions (Coe et al., 2021). The use of a variety of methodologies in this study is meant to enhance one another. The qualitative research approach typically aids quantitative research in improving concept developments during the design stage, making data collection, validation contributions, interpretation, and the illustration of quantitative outputs during the analysis stage easier (Arukwe and Okwara, 2020).

The interview and questionnaire method of data collection was deemed the most reliable approach for this research work to answer the research questions and achieve the objectives. Moreover, the use of a case study in this research work helped considerably by focusing primarily on the key professionals involved in the infrastructure project management by studying how estimation is being carried out at the initiation stage and as a result, gaining a significant insight into it. The soft information necessary for this research was gathered via interview, survey and supported by a robust quantitative study to achieve a statistical significance.

3.3.5 Data Collection

Two primary data collection method were utilized for this research work, namely semi-structure interview and survey-questionnaire method. It was ensured that data collection utilized for this research aligns with the research design, strategy, approach, and philosophy, respectively. Data collection can be regarded as a process of collecting information from all relevant sources to find answers to research problem test hypothesis and evaluate the outcomes (Dudovskiy, 2018).

3.3.6 Secondary data

Secondary data is regarded as data that have been collected for various other reasons. Most of the data gathered for this purpose are derived predominantly from literature review which are further classified into raw data, compiled data and data collected from survey strategies (Sindin, 2017). Raw data includes organisation databases, websites, newspapers while the compiled data refers to government publication, books, journals, industry statistics and report.

Literature review from past journals, articles, publications, workshop, and papers account for the predominant secondary data collected for this piece of research.

The data used for the GLM & BHRM model were obtained via published articles and the cost data of 31 UK infrastructure projects.

- **Literature review**

The first secondary data source collected in this research work was by means of a literature review of journals, articles, papers, and related thesis. Prominent authors in the field were identified from books, journal articles and searches were performed in known databases (Elsevier, ScienceDirect and Ebsco etc). Topic-related keywords were used, for instance uncertainty management, risk management, construction project, infrastructure project, UK construction project, project control and management team, system thinking and holism etc. The objective was to search for and highlight some various methodologies that have been utilized to study holistic infrastructure project cost improvement and compare their results with the present research work to ensure the reliability of the final findings.

- **Document review**

The data collected for the Bayesian regression model were obtained from the project documents belonging to UK infrastructure project organizations. It is important to state that the names of the organization cannot be disclosed due to the confidential reasons pertaining to cost information. Document analysis can be referred as a systematic procedure for reviewing or evaluating documents (printed & electronic types) (Bowen, 2009). Project documents are utilized to corroborate and augment evidence from other sources (Yin, 2003a). Project documents employed for some of the data analysis needs to be established so as to have greater understanding of the research area.

- **Project file**

  The project cost information used for the data analysis in creating the model are derived from the progress reports of rail infrastructure companies in the UK, capital expenditure business case and information published online as articles or journals. Due to the non-disclosure agreement, the specific names of the UK infrastructure project companies will not be identified in this research work. The company used as case study operates a special investment plan known as control periods. Network rail is the owner and infrastructure manager of most of the railway network in the UK. It is a subsidiary of the Department for Transport (Networkrail, 2020). The financial investment of this arm of the Department for Transport is divided into control periods. It is 5-year timespans into which the government body, the owner and operator of the rail infrastructure in UK, works for financial and planning purposes (Networkrail, 2020). The project cost information collated for this research work is from the Control period 4-6.

- **Project Progress report**

  These reports are prepared regularly by the project management team during construction phase and issued to the key stakeholders or client (DesignBuildings, 2020a). It is used to update the stakeholders on all the activities carried out in the project. This can be issued weekly, monthly, or quarterly as obligated by the clients to the subcontractor. The UK infrastructure management firm requires subcontractor to provide progress reports of project activities. The progress report used by the subcontractor working for the delivery of the UK infrastructure project contains the following details:

  - **Report details**: Date of issue of the report and names of the reporter (Programme/Project manager as well as the project status.
  - **Programme/Project summary**: Gives the summary of the work/activities to be performed in the project to achieve the objectives/benefits.
  - **Key/updates/status**: Provides updates of all the activities as planned against the actual as prepared by the project management team.

- **Key Milestones**: Includes all the major events that need to be achieved prior to lump sum payment according to the contractual requirements.
- **Major Risks/Issues**: All the risk/issues that are impacting on the projects are listed in this section.
- **Budget**: Comprises the budget required to complete the project, what has been spent and what is expected to be spent.
- **Timeline**: Contains the duration of the project. Compares the actual and planned.

Most of the cost information and risk/issues are derived from this report. They are further used for data analysis in producing the model for this research work. Capex report is a subordinate data to corroborate the information derived from the progress report. It contains the initial budgeted amount approved by the sponsors, business need, deliverables, and options for the project completion of a project. Below are the details within the Capex report:

- **Roles/Responsibilities**: Includes all the key stakeholders involved in the project's strategic decisions.
- **Executive summary**: This consist of the business need and options considered for the project & recommendation.
- **Project descriptions**: Contains the background, option analysis/detailed proposal, budget/5year plan assumptions etc.
- **Project deliverables**: Comprises all the deliverables expected from the project outcomes.
- **Financial appraisal**: Contains the project costing details and financial returns.

These reports contain all the necessary project cost information (Initial and final cost) and timeline. Fig 3.3 below is the Capex report template used for the case study:

Project Progress Report

1. Report Details

Report week ending:		Programme Number:	N/A	Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of the existing footbridge in the station which includes stripping back existing paintwork, repair to revealed metalwork , installation of new stair threads, drainage and overall redecoration. Handrail heights will be increased and mesh introduced in order to improve safety.

3. Key Updates/Project Status

The project has progressed with the following carried out this period:

- ✓ Steel work repairs continues with further exposed defective steel members identified
- ✓ Priming of the exposed steelwork 90% completed
- ✓ Fabrication of new handrails

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Contract Award	Blue	12/06/15	12/06/15	Letter of intent issued on 1st June 2015 to enable planning to commence
Completion of design and submission for approval	Blue	15/07/15	25/07/15	Initial Design review meeting held and design specifications and parameters agreed
Commence works on site	Blue	15/07/15	15/07/15	This period reflects Y planning of completing the project within the school holidays so as to minimise local disruption.
Complete Construction	Amber	21/09/15	12/10/15	Works slipped 3 weeks due to delay to the approval of the bridge closure by the Local Authority
Reopen Footbridge	Green	29/09/15	29/09/15	On Target
HandBack Footbridge	Amber	01/10/15	22/10/15	Slipped due to knock-on effect of closure application approval delay

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	**Possession availability**	Amber	We continue to liaise with and interface with NR with regard to planned possessions.
2	**Cancelled possession**	Amber	The possession of the sidings and the applied for possessions have been granted. The delay in closing the footbridge, however, might mean additional possession will be required.
3	**Potential Variation**	Amber	Bridge is now being refurbished in-situ. Variation is still likely to arise as a result of the delays to the works and out-of-sequence working for the contractor.

FIG 3.2 INFRASTRUCTURE PROJECT COST INFORMATION PROGRESS REPORT

3.3.7 Primary data

These are data originating from first-hand source for a specific research purpose or

Project. Primary data can be collected in following ways: surveys, interviews, field observation

and experiments. For this purpose of this research work survey (questionnaire and interviews) and case study were used for the collection of primary data. This research utilised longitudinal survey using both a questionnaire and interviews. This study distributed 300 questionnaires to project control and management professionals using snow-balling sampling technique and 76 respondents were received. Interviews were conducted with 20 professionals in project control and management involved in infrastructure project.

3.3.7.1 Semi-structure interview

An interview is a type of survey method applied for the collection of primary data conducted with a number of respondents to explore their perspectives on a particular idea, situation, issues, or programme (Neale, 2006). It is primarily qualitative technique undertaken to reflect emotions, experiences and explore issues with greater depth (Dudovskiy, 2018). There are three main types of interviews, specifically semi-structured and unstructured interview. Interviews are employed to obtain in-depth opinions regarding new issues. To this research work, semi-structured interview was used. A semi-structured interview uses both the structured and unstructured techniques to fulfil the objective (Dudovskiy, 2018). I It also presents and provide new context in relation to other data (Neale, 2006). The respondents were sorted from the organization handling different infrastructure projects to make it more robust. In this research work, NVIVO software was employed to perform the qualitative analysis on the transcribed interviews. Sample selection was completed from the government owned infrastructure project delivery firm project control and management professionals. Snowballing sampling technique was used to gather interviewees due to the difficulties in getting access to project control and management professionals during the pandemic period. 20 respondents were gathered for the semi-structured interview. The actual interview method (telephone) differed for respondents due to their work schedule. It took an average of 35mins for each respondent (interviewees) to complete the interviews. Based on the limited study of system thinking approaches in identifying infrastructure project uncertainty, exploratory study (using semi-structured interviews) of the application and importance was performed. The findings with respect to the application of system thinking in the identification of infrastructure project uncertainty justifies the need for adequate management of uncertainties. Also, semi-structure interview enables the proper understanding of the factors impacting on cost estimation and methods used in producing it as well. Overall, the findings of the semi-structure interview were utilized to guide the establishment of the framework.

3.3.7.2 Questionnaire

A questionnaire is an instrument or technique to collect primary data (Cohen et al., 2013). Questionnaires are generally employed for market research, political polling, customer service feedback, evaluations, opinion polls and social science research (O'Leary, 2004). Boynton (2004) asserts that questionnaires offer an objective means of collecting information concerning people’s knowledge, beliefs, attitudes, and behaviour. According to Dudovskiy (2018), questionnaires can be classified as quantitative and qualitative method depending on the nature of questions posed. Closed ended questions with multiple choice answer options are analysed using quantitative research while open-ended questions are analysed using qualitative research which involves discussions and critical analyses without the use of numbers or calculation (Dudovskiy, 2018). The questionnaire for this research includes both open and closed ended questions that will be analysed quantitatively and qualitatively. Careful selection and creation of questions that will answer research questions are a considerable challenge within the world of research. In this research, the questions are carefully tailored to meet the objectives. The sample size of the respondents was carefully designed to represent the target population for the research. 76 respondents were gathered for this research using snowballing sampling due to challenges involved in getting access to project control and management professionals during the pandemic period. Overall, the main reason for using questionnaire is due to the flexibility in its administration and gathering of open-ended questions to collate some in-depth, subjective data from which new concept can emerge. The quantitative data collected was analysed using statistical analysis to generate the produced models.

3.3.7.3 Sampling.

It is pertinent to select the appropriate sample size for this research work to answer the research question adequately. Additionally, a technique in which a sample is drawn from population to serve as a representation of the population of interest is required. Sample is a representation of the target population so as to reduce number of cases (Taherdoost, 2016). Population defines the set of entities from which samples are drawn. To control extraneous variation, careful selection of appropriate population is necessary to limit the generalization of findings (Liu, 2015). The sample for this research was carefully drawn from the project control and management professionals with experience infrastructure project delivery within the government owned infrastructure project institution. A non-probability sampling technique (Snowballing technique) was utilized to acquire the required sample size. This was used due to the difficulty in assessing respondents during the covid-period. The sensitivity of the of the project cost information posed a challenge in getting access to respondents as well. Government owned infrastructure project organizations were contacted for the survey. The professionals from private sectors with relevant experience in executing and delivering government owned infrastructure project were also consulted. 20 respondents were derived for the semi-structured interview. Most researchers who conduct qualitative research believe that an adequate sample size is a crucial indicator of the research's quality. However, there is disagreement over the precise size of a suitable sample (Daniela, 2020). In qualitative research, saturation is a standard for stopping data collecting and/or analysis (Saunders et al., 2018). According to Bryman (2016), saturation was achieved at 12 transcripts when thematically analysed using structured interviews as data collection in an experiment done with women in West African countries. For this research work, saturation occurred at the 16th respondent response where similar responses was given to each questions answered.

The formulated questionnaires were pilot tested prior to being distributed to the final respondents. This approach was particularly helpful in curbing or drastically reducing errors in the questionnaire. Also, valuable input from experienced respondents was sorted, which improved the overall quality of the final distributed questionnaires. Considering similar research on infrastructure projects(construction),a sample size of 50-100 respondents was expected to achieve the research objectives (Iacobucci, 2010). To prevent being overly optimistic respondents' responses, an estimated 25% response rate based on similar construction management research was utilized for the questionnaire survey. Using sampling estimation format (Population X100)/response rate) developed by (Saunders et al., 2009). [(75X100)/25] =300. 300 questionnaires were distributed to the target population. 76 respondents were gathered from the questionnaires distributed.

- **Criteria for choosing respondents for the questionnaire.**
    - Project control and management experience. Planning, cost control/quantity surveying, project-management/controlling, procurement management/commercial management and risk management etc.
    - Experience in government owned infrastructure project execution or delivery.

- Minimum of 5years’ experience.

- **Procedures followed to ensure a high response rate**
  - The pilot study was performed prior to the dissemination of the final questionnaire to ascertain the credibility and quality. Professionals and academia in the field of construction project management were selected randomly to participate in the survey. Constructive feedback was given, and changes were made to improve the quality of the questionnaire.
  - A cover letter and Instructions provided along with the questionnaires to encourage the participants to voluntarily participate in the survey.
  - The questionnaires were clearly divided into segment to prevent clumsiness why filling it by the participants.

To answer the research questions adequately there is need to choose an appropriate sample technique and guidelines to follow. Fig 3.4 is shows Taherdoost (2016) sample process utilized for the research work.

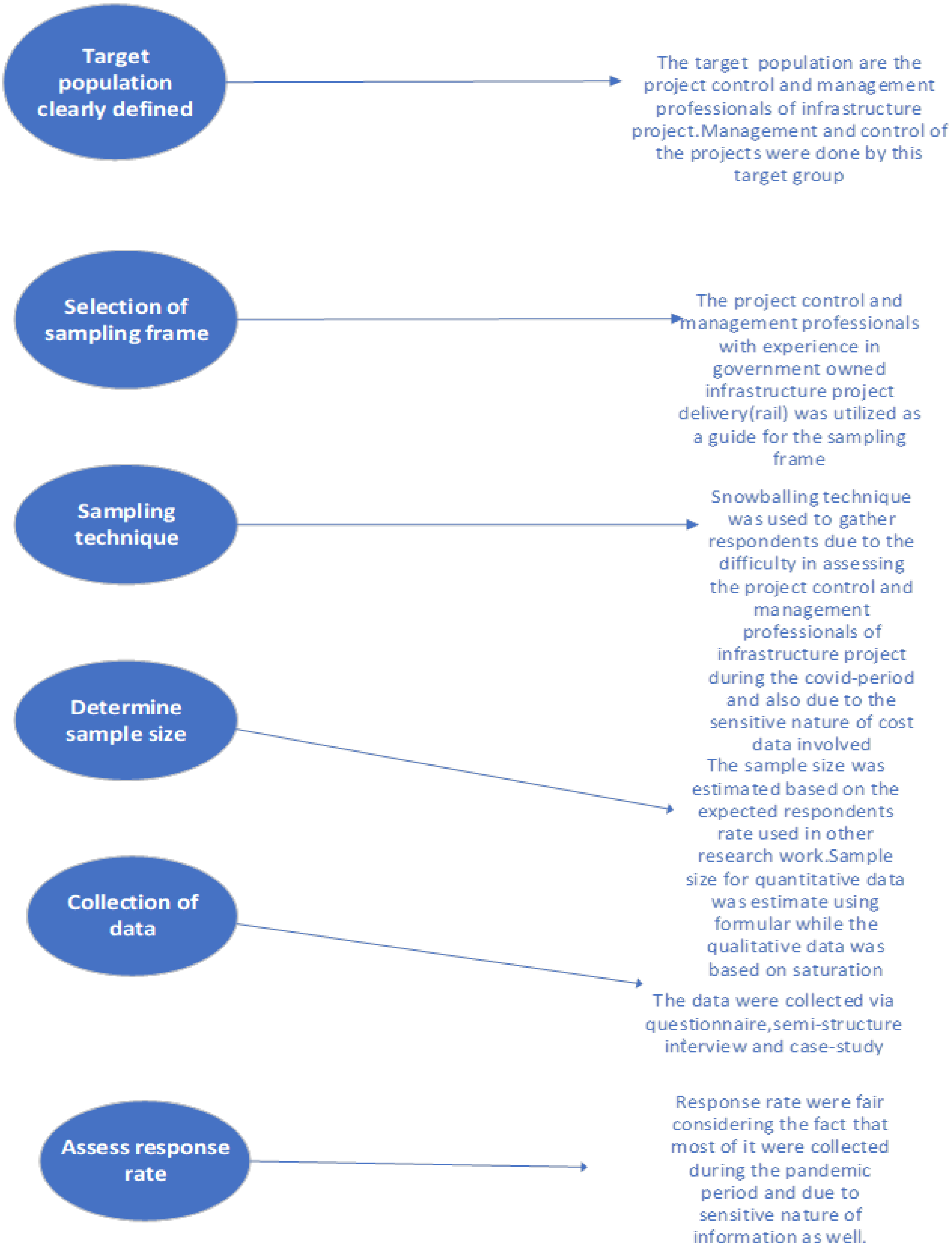


Fig-3.3 Sampling technique process used for the research work (Taherdoost, 2016)

3.3.7.4 Pilot study

The questionnaires were created for the purpose of answering the research questions to achieve the aim and objectives of this research. A preliminary investigation was conducted to ascertain the use and implementation of system thinking in the identification of uncertainties in infrastructure project so as improve the initial cost estimation during the initiation stage. The questionnaires were pilot tested with professionals and academia in the construction project management fields to improve the quality prior to final production. According to Abbott (2008), a pilot study is a meagre picture of a study used to establish procedures, materials, and parameters to be used in the full study. It can be described as the prototype of a full-scale study, or a trial run performed in preparation of the main study. In a more realistic context, it can regard as a feasibility study undertaken for the pre-testing of a specific research instruments, such as surveys and interviews (Polit, 2001). Similarly, it can be used to save considerable amount of time and resources effectively, if conducted correctly. Furthermore, a pilot study can thoroughly assist in clarifying instructions, determining appropriate levels of independent variables, as well as the reliability and validity of potential methods (Abbott, 2008). Welman (1999), further illustrated that there are core reasons and values why pilot study is necessary prior to the actual research. Additionally, it is quite needed to detect potential flaws in the measurement of procedures, for example instructions and duration as well as operationalizing independent variables

According to Nashwa (2017), if a pilot study is well conducted it can ensure the validity of the actual study and the chosen methodology. To detect and correct problems that might arise in the future a pilot study is crucial. The aim and objectives of this research must be linked to the actual potential questionnaires prior to the real study. This will eventually provide a road map in which potential methods will be built upon for effective analysis. The pilot study conducted consists of construction management professionals involved in the delivering of government owned infrastructure projects. More professionals in academia were involved to provide rigorous feedback on how the questionnaire could be improved.

- **Criteria for choosing pilot study respondents.**
  - ✓ Possession of project control and management experience, planning, cost control/quantity-survey in project-management/controlling, procurement management/commercial management and risk management etc.
  - ✓ Experience in government owned infrastructure project execution or delivery.
  - ✓ Professionals in the construction project management academia
  - ✓ Minimum 5 years' experience.

Fifteen professionals from project control and with a background in the management of infrastructure and academia were sent the questionnaires. Only six of them responded outrightly. Table 3.1 below shows the feedback comments made.

Table 3. 1 Tabulated comment from respondents

Respondent	Comment
A(Academia)	Adjustment on the Likert scale was needed to imrpove the quality of the response from the participant
B(Industry professional)	Couple of duplicate fields was observed
C(Industry professional)	Length of the survey should be shortened
D(Industry professional)	Couple of repeated questionnaires and too long as well
E(Industry professional)	Length of the survey should be shortened
F(Industry professional)	Couple of repeated questions

The feedback received from these professionals was valuable in producing the final questionnaire that was distributed to the participants. Adjustment on the Likert scale was completed as recommended whilst repeated questions were deleted. This enabled the survey to be shortened as recommended. It is always advantageous to pre-test or conduct a pilot study before administering a questionnaire so as to make sure that it can be understood and is relatively straightforward to follow (Bryman, 2016). The positive impact of the pilot study on the final questionnaires was quite immense. Hence, the positive impact of the pilot study on the final questionnaire was considerable.

3.4 Reliability

Reliability refers to the extent to which a measurement instrument yields consistent and stable results over repeated observations. Thus, reliability has to do with the amount of random error in measurement. The more reliable a measure is, the less the random error contained within. There are different types of reliability, thus, reliability can be estimated differently depending on the purpose and design of a study. Internal consistency which is a single measurement instrument administered to a group of people on one occasion to estimate reliability is utilised for this research. Individual items in an instrument measuring a single construct should deliver highly correlated results which in turn reflect the homogeneity of items (Engs,1996). Cronbach's Alpha was exploited to determine the internal consistency of the collected data. The Likert scale, system thinking and need for cognition data were used to determine the internal consistency of the data, thus ensuring the reliability.

3.5 Validity

The research's validity was increased by performing it in a precise, competent, straightforward, and systematic manner (Golafshani,2003). Basically, achieving validity entails closing the distance between fact and representation so that the study's data and findings are as similar as possible to each other (Golafshani,2003). To improve validity, theory triangulation, methodological triangulation and data triangulation were all used. Several data were used to triangulate the data while theoretical viewpoints from a variety of literatures were compared to achieve theory triangulation. The utilisation of two different data collection methods: the questionnaire and semi-structured interview, resulted in methodological triangulation.

3.6 Data analysis and findings

The primary and secondary data was analysed using statistical analysis to ensure the robustness of the findings. There are many techniques and tools for collecting and analysing data depending on the nature of the questions to be addressed in the research (Creswell and Clark, 2011). Some of the secondary data (Uncertainty factors) used for the questionnaire was further analysed using factor analysis. Additionally, the other secondary data (Cost information) was further analysed using Generalise linear model and Bayesian Hierarchical Regression Model.

3.6.1 Factor analysis

This is regarded as a procedure used to determine the extent to which shared variance exist between variables or items within the item pool for a developing measure (Gerber and Price, 2018). Factor analysis as developed by Spearman and colleagues has the essential purpose of describing the relationships among variables in terms of a few underlying, but unobservable random quantities known as factors (Wichern, 2002). The uncertainty factors were reduced to 7 by means of factor analysis using SPSS software. Reliability/internal consistency test was done on the data collated using Cronbach's Alpha.

- **Cronbach's Alpha (Reliability test)**

This was used to test the reliability/internal consistency of the data gathered for factor analysis. It is a measure employed to assess the reliability/internal consistency of a set of scales or test items (Goforth, 2015).

3.6.2 Generalized linear model (GLM)

Generalised linear models (GLM) provide a unified approach to many of the most common statistical procedures used in applied statistics (Lindsey 1997).According to Zhao (2013), the generalised linear model (GLM) extends linear regression by allowing the linear model to be linked to the response variable via a connection function and the magnitude of each measurement's variance to be a function of its predicted value. Moreover, it unifies a variety of statistical models. To produce a reliable and robust predictive model a more advanced statistical model is essential for this research. The relationship of factors impacting on the early infrastructure cost estimate was investigated using the GLM method. These factors caused the infrastructure cost estimate to overrun, established and investigated the relationships and assisted in predicting cost overrun. Cost information (UK rail projects), such as contractual cost, duration of delay, expected duration (planned duration of the project) and twenty-two uncertainty factors (identified in the literature review in chapter 2), were utilised for this predictive model. Additionally, cost information related to 31 infrastructure projects (projects that experienced cost overrun), were utilised and their associated uncertainty factors categorised using, 0=No & 1=Yes scale, respectively. The potential influence of each of the predictors or key drivers were investigated using GLM and the Bayesian Hierarchical Regression Model which is described in chapter 4.

One of the assumptions of the general linear models is stated below as follows:

$Y = X'\beta + \epsilon$ (Turner, 2004)--------Equation (3.1)

is that expected value of the response variables $E[Y|\mu] = \mu$ be a linear function of the p predictors, that is $\mu = X'\beta$**(Turner, 2004)------Equation (**3.2)

Where $X_i' = (x_{i1}, \dots, x_{ip})$ are a collection of predictors measures with respect to the ith project, and β is a vector of unknown regression parameters. However, the inclusion of the non-normal categorical variables as independent variables means that it is no longer statistically appropriate to assume that the linearity assumption still hold even when the response Y is continuous and can be assumed to follow normal distribution. Instead, a more flexible approach was utilized which allows for the nonlinearity of the expected value μ to the set of the covariates. This method known as the Generalized linear model transforms the expected value of the response using an appropriate link function $g(\mu)$ so that the linear predictor $\eta = g(\mu)$ is a linear function of the p predictors given by$\eta = g(\mu) = X'\beta$ (Turner, 2004)

So that the expected value μ is obtained as a back-transformed function of the linear

predictor, that is, $\mu = g^{-1}(X'\beta)$ (Turner, 2004). To this end, appropriate GLM's of the form

$Y = \alpha_0 + \beta_1 Contract\ Cost + \beta_2 Expected\ duration + \cdots + \beta_p StakeholderIssues + error$

Variants of the model were fitted to the dataset to allow a robust selection of the best fit model. Furthermore, given that each project is faced with some other unobserved uncertainties affecting its cost overrun, we extended the GLM model to include project-level random effect, α_i which is iid normally distributed and assumed uncorrelated so that $\alpha_i \sim Normal(0, \sigma_\alpha^2)$ and $Cov(\alpha_i, \alpha_j) = 0$ for all $i \neq j$. Then the so-called random effect model is specified as

$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_2 + \alpha_i + e$ ---------Equation (3.3)

Where the sampling error e is also iid and normally distributed with zero mean and variance of σ^2. In addition, there is often the need to quantify uncertainty in parameters estimation for a more accurate prediction. For this reason, these models were extended and implemented within Bayesian the hierarchical modelling techniques. Data preparation and cleaning, and all statistical analysis were conducted using R statistical programming software (R Core Team, 2020). Akaike Information Criterion (AIC) Date (2019) was utilized to select the best fit model for the research work. It is used to see how well models matches the data set without overfitting it (Date, 2019).

3.6.2.1 Akaike Information Criterion (AIC)

This is used to see how well frequentist models matches the data set without overfitting it. The consistency of a series of statistical models is compared using Akaike's knowledge criterion (AIC). A model with the lower AIC score is supposed to achieve a better balance between its ability to match the data set and its ability to avoid overfitting (Sachin, 2019). The frequentist models utilized in this research work is selected based on the goodness-of-fit score. A lower AIC score denotes good model compared to other formulated models.

3.6.3 Bayesian Hierarchical Regression Modelling (BHRM)

In a statistical data model based on observations y, the bayesian approach to inference focuses on updating information about the unknowns,Θ, with revised knowledge represented in the posterior density,p(Θ/y). The sample of observations being analysed provides new information about the unknowns, while the prior density,p(Θ) of the unknowns reflects prior knowledge about them before observing or an analysis (Congdon, 2010). In contrast to the frequentist method, there is a lot more versatility in how prior evidence about parameters can be integrated into a study, and using insightful priors (to convey cumulative knowledge) can minimise confounding and provide a natural basis for evidence synthesis (Congdon, 2010). This statistical approach makes it suitable for the identified uncertainty factors quantification in this research work. Like the frequentist GLM specification above, the BHGLM can be specified as

$\eta = \alpha_0 + \beta_1 X_1 + \cdots + \beta_p X_p$Where the α_0, $\boldsymbol{\beta} = (\beta_1, \ldots, p)$ and p are the intercept, the regression coefficients and the number of predictors in the model Usually, the intercept α and regression parameters $\boldsymbol{\beta}$ are assigned normal prior distributions of the form

$$\beta^* \sim Normal(\mu^*, \sigma^*)$$

Where β^*=$\alpha_0, \boldsymbol{\beta}$(Jeffrey, 2005}, and where μ^* and σ^* are the mean and variance parameters, respectively (Jeffrey, 2005). Parameter estimation is based on Markov chain Monte Carlo

(MCMC) algorithms implemented within the stan framework.It is a type of iterative sampling method that falls under the monte-carlo-method umbrella.Also,it provides a simple,intuitive way to simulate values from an unknown distribution and then use those simulated values in subsequent analyses.As a consequence,they can be used in a wide range of fields (Speagle,2020). Model selection and model diagnostics were based on the Akaike Information Criterion, AIC (Akaike, 1998) and the Rhat statistics (Gelman, et al., 2013), as well as the visual inspection of the trace plots and autocorrelation function (ACF) plots (Green, 2001). Results from the top models are presented as tables and graphs in chapter-4 section of this research work. The predictive models were produced based on both final cost and cost overruns as response variables, respectively.6 models were produced each and the best fit models were chose based on the goodness for fit score. Table 3.2 shows the predictive models produced after performing the GLM and BHRM analysis in chapter 4 as well.

Table 3. 2 GLM and BHRM predictive models.

Inference	Model	Specification	Link
Frequentist	Model 1; m_1	$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + e$	Identity
Frequentist	Model 2; m_1	$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + e$	Identity
Bayesian	Model 3 m_3	$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \alpha_i + e$	Identity
Bayesian	Model4 m_4	$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \alpha_i + e$	Identity
Bayesian	Model 5 m_5	$Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + e$	Identity
Bayesian	Mode6 m_6	$Y = \alpha_0 + \beta_1 X_1 + +e$	Identity

Where $\alpha_i \sim Normal(0, \sigma_\alpha^2)$ is the project-level random effect?

3.6.3.1 Caterpillar Plot

In Bayesian inference, caterpillar plots are often used to summarize the quantiles of posterior samples. A caterpillar plot is like a horizontal boxplot but without the quantiles, allowing the consumer to analyse several distributions in one plot (Cabral,2021). It is used to produce a plot of posterior distribution from an object either of class etc. The mean posterior predictive distribution of the outcome variables is displayed in this plot as well. This is quite useful in understanding confidence level interval of parameter estimates.

3.6.3.2 Rhat Plot

This generates the R-hat convergence diagnostic, which compares model parameter and other univariate quantities of interest estimates between and within chains (Jiqiang et al.,2020). R-hat is >1 if chains have not blended well (the between and within chain figures do not agree). This is used in Bayesian statistics to check for model efficiency and selection.

3.6.4 Binary data

This research work converted the identified uncertainty factors from each of the project into binary data, respectively. The project uncertainty factors were collated randomly from articles and project documents. Binary data has only two possible states, usually labelled as 0 and 1 in the binary numeral scheme and Boolean algebra (Claudia et al ., 2014). A tabulated coded uncertainty factors were carried out using this method. This was used to enable statistical analysis on categorical data.

3.6.5 Z-Score

Standard deviations from the mean are used to calculate Z-scores. As a result, the distributions of these z-scores have mean of O and standard deviation of 1(Adam, 2020). It describes the position of a raw score in terms of its distance from the mean, when measured in standard deviation units. This can be regarded as standard score because standardizing the distribution allows for comparison of scores on various types of variables (Saul, 2019). Cost information gathered for this research work varies in values which needs standardization to fit-in adequately for the GLM and BHRM analysis. Below is the mathematical representation of Z-Score: $Z = \frac{(x-\mu)}{\sigma}$ (Hayes,2021)- ------------------Equation (3.4)

3.6.6 System thinking scale measurement

System thinking scale measurement was captured using likert-type scale that has been designed to assess system thinking as a distinct cognitive paradigm and not just a set of specific skills.It contains a 20-item instrument that uses 5 point-likert scale.These are described as follows:0= Never,1= Seldom,2=Some of the time,3=Often and Most of the time =4 (Moore et al., 2010a). The total score is computed by adding-up the response for each item. Scores range is dependent on the Likert scale utilized. In this research work the range of scores is from 0-80. The highest score is 4 X Nos of ITEMS (20) =80. A reliability test was undertaken using Cronbach Alpha.

This is done to ensure that robust data were collated for the system thinking scale measurement.

Below are the lists of the system thinking scale items

Table 3.3 System thinking Scale Item

1	I seek everyone's view of the situation
2	I look beyond a specific event to determine the cause of the problem
3	I think understanding how the chain of events occurs is crucial.
4	.I include people in my work unit to find a solution.
5	I think recurring patterns are more important than anyone specific event.
6	I think of the problem at hand as a series of connected issues
7	I consider the cause and effect that is occurring in a situation.
8	I consider the relationships among coworkers in the work unit.
9	I think that systems are constantly changing.
10	I propose solutions that affect the work environment, not specific individuals.
11	I keep in mind that proposed changes can affect the whole system.
12	I think more than one or two people are needed to have success
13	I keep the mission and purpose of the organization in mind.
14	I think small changes can produce important results.
15	I consider how multiple changes affect each other
16	I think about how different employees might be affected by the improvement.
17	I try strategies that do not rely on people's memory.
18	.I recognize system problems are influenced by past events.
19	I consider the past history and culture of the work unit.
20	I consider that the same action can have different effects over time, depending on the state of the system.

3.6.7 Need for cognition scale

It is an assessment instrument that measures quantitative tendency for an individual to engage in and enjoy thinking (Bost, 2007). Thisscalecontains 8items which isutilised by investigators in assessing the cognitive scale.The project control and management professionals are being assessed with these 18 Items of Need for Cognition scale in this research work and it is scored using reverse scoring method. A 6 point likert scale was utilised for this research which are as follows:Strongly disagree=-1, Disagree=-2, Slightly disagree=-3, Slightly agree =1, Agree =2 & Strongly Agree =3.The total score for each participants is dependent on the type of Likert scale used (Bost, 2007).The range of scores will be from -1 to 3. In this research work the range of scores cane from 0-80. The highest score is 3 X Nos of ITEMS (18) =54. A reliability test was undertaken using Cronbach Alpha. This is done to ensure that robust data were collated for the system thinking scale measurement. Below are the items for the Need for cognition

Table 3.4 Need for cognition scale item

1	I would prefer complex to simple problems.
2	I like to have the responsibility of handling a situation that requires a lot of thinking.
3	Thinking is not my idea of fun.
4	I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
5	I try to anticipate and avoid situations where there is likely a chance I will have to think in depth about something.
6	I find satisfaction in deliberating hard and for long hours.
7	I only think as hard as I have to.
8	I prefer to think about small, daily projects to long-term ones.
9	I like tasks that require little thought once I've learned them.
10	The idea of relying on thought to make my way to the top appeals to me.
11	I really enjoy a task that involves coming up with new solutions to problems.
12	Learning new ways to think doesn't excite me very much
13	I prefer my life to be filled with puzzles that I must solve.
14	The notion of thinking abstractly is appealing to me.
15	I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
16	I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
17	It's enough for me that something gets the job done; I don't care how or why it works.
18	I usually end up deliberating about issues even when they do not affect me personally.

3.7 Model development and validation

The model development was based on the findings obtained from the survey data analysis, vital information from the literature review and cost information from case study firms. This is divided into two sections as follows: infrastructure project uncertainties identification using system thinking and cost overrun prediction using the Generalised linear model and Bayesian hierarchical regression model respectively. The predicted cost overrun is used by the key stakeholders to make an informed decision in producing a robust infrastructure project early cost estimate during the initiation stage.According to Roman and Hartmann (2008) models are acknowledged to be anything from physical objects, fictional objects, set-theoretic structures, descriptions and equations but what matters is the value in regard to learning about the world. Learning from the previous research models in regard to infrastructure projects, development, building and validatiing requires rigorous and enthusiastic study which this research has completed effectively.Fig-3.4 is the diagramatic illustration of the conceptual infrastructure project cost estimating model.

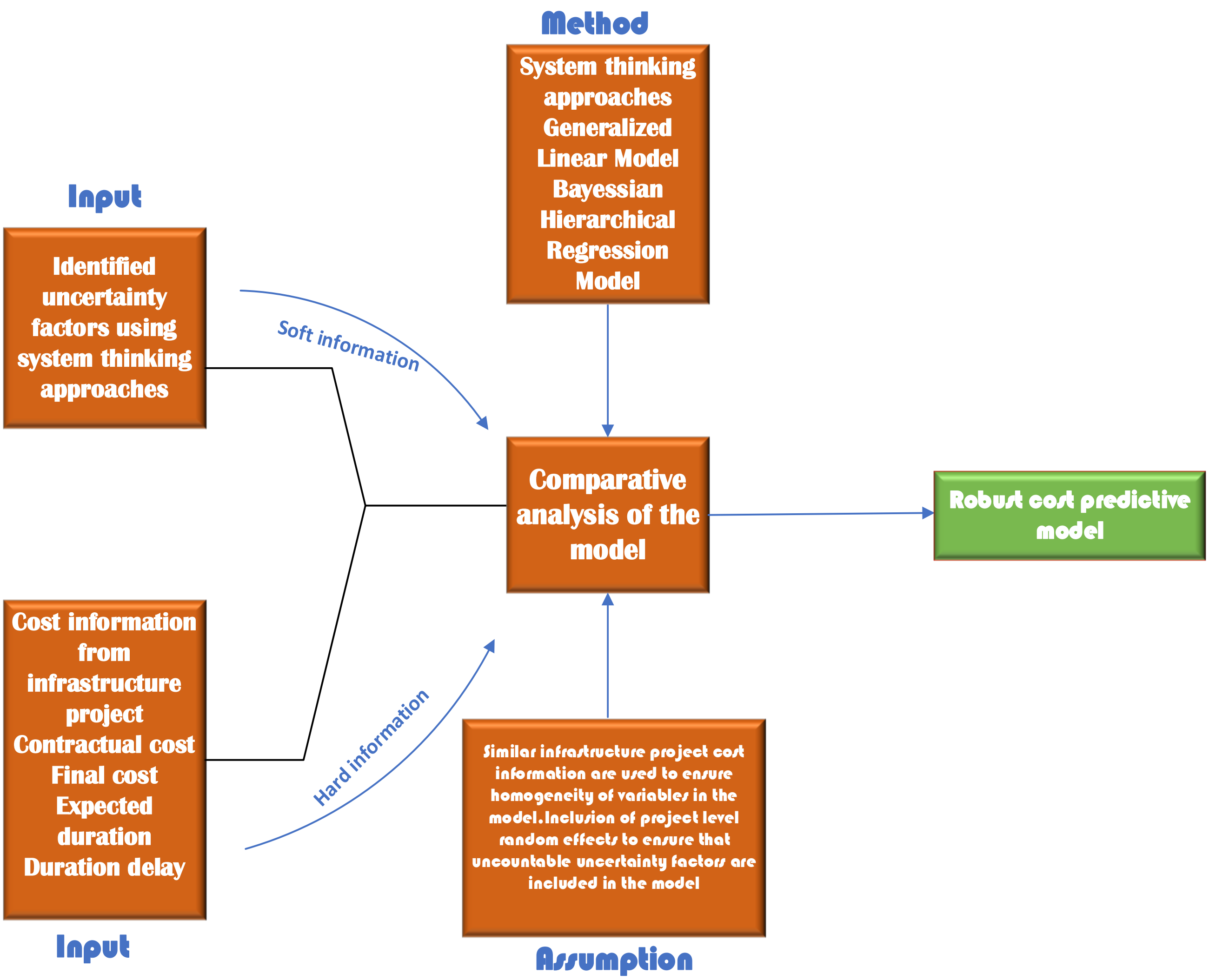


Fig 3.4 Diagrammatical illustration of Robust cost model framework for infrastructure project.

- **Model Validation**

The first validation of the predictive cost model was done by the same infrastructure programme where all the cost information were derived from using the GLM and BHRM respectively. Second validation was done using two different projects. One of the project is at the bidding stage and the other one is an ongoing UK railway infrastructure project. This predictive cost estimate model is expected to accommodate future uncertainties which may lead to increase in cost of the infrastructure project. This model,if applied carefully it will improve the rough-order of estimate during project cost estimate. Also,it will enable the key project stakeholders(client) estimate careful their initial project estimate during pre-tender stage to screen out any ambiguous project estimate from subcontractors.

3.8 Chapter Summary

This chapter has discussed a detailed account of methodology adopted for this study,the rationale for choosing the research approach,the procedures,design involved in the data collection and analysis. A mix-method of quantitative and qualitative research methods were chosen as the most appropriate ways to achieve and address the study objectives and questions because they are the primary reasons for selecting the most appropriate research method. A literature review was used as research tools to identify gaps in the field, present challenges, and effective solutions for these difficulties. A case study was used to understand the cost esimation,risk/uncertainty management techniques utilized in the infrastructure project and also used to validate the generated models.Explanatory semi-structured interviews were used as part of the qualitative approach to create a comprehensive picture of existing methods for cost estimating,risk analysis,uncertainty management and system thinking application in infrastructure project. Additionally, questionnaire surveys were chosen for the quantitative portion of data collection. A Generalized linear model and Bayessian hierachical Regression model were used for statistical analysis (using project cost data & uncertainty factors) for the generated predictive models to quantify and analyse infrastructure project uncertainties. The use of GLM & BHRM approach has assisted in the improvement of model produced by (Mohammed, 2011). The cost model was built on the assumption of a liner relationship between the studied variables and the project cost. The GLM and BHRM takes cognizance of the non-linearity of the response variable and the covariates.The model was used to give early cost advice on school project.To satisfy the requirement of this study it is required to show the frequentist (GLM) and Bayessian method (BHRM) method respectively. Also,system thinking and need for cognition scale were analysed using regression method. The next chapter presents the findings of the study after the data collection and analysis of the quantitative and qualitative data.

Chapter 4 Data analysis.

4.1 Introduction

This chapter discusses the semi-structure interview, cost information from UK infrastructure project delivery firms and system thinking approaches analysis. The first section delves into the qualitative analysis of the transcribed data from the semi-structure interview using NVIVO software, followed by document analysis of the project file. The second section involves quantitative analysis of cost information derived from the project file. It contains information about the project costs, cost overruns, delays and description of the issues encountered by the infrastructure project. Based on the documentation reviewed, thorough understanding of the uncertainty factors that influence or impact on early infrastructure project cost estimate was identified using system thinking. Predictive models that take cognizance of uncertainties were produced. The analysis and results are explained below as follows:

4.2 Semi-structured interview

The semi-structured interview involves interviewing project control and management professionals involved in the delivery of government infrastructure projects. Due to the non-disclosure agreement, the professional disciplines and projects handled by the interviewees will be utilized for description throughout the research work. They are tabulated on Table-4.1

Table 4.1 Tabulated format of positions and infrastructure project handled by interviewees

Professional Position	Infrastructure Project handled
Head of Project	Civil works and Railway Project
Commercial Manager-A	Railway Infrastructure Enhancement Project
Head of PMO	Highway Project
Scopebaseline and EVM mgr	Railway Project
Commercial Manager-B	Defence Project
Commercial Manager-C	Rail Electrification Project
Commercial Manager	Civil Works
Cost Engineer	Project Management consultancy firm
Planning Engineer	Project Management consultancy firm
Planner	Rail Electrification Project
Programme Manager	Civil Works
Project Control Engineer	Rail Project
Project Engineer	Rail Electrification Project
Project Engineer-B	Rail Electrification Project
Project Engineer-C	Project Management consultancy firm
Project Manager	Project Management consultancy firm
Project Manager-D	Civil Works
Quantity Surveyor-F	Civil works and Railway Project
Senior Project Manager	Project Management consultancy firm
Risk Manager	Project Management consultancy firm

The purpose of carrying out this semi-structured interview is to understand the familiarity of infrastructure project management professionals on system thinking application in the aspect of uncertainty identification during initiation stage. It was used to collect open-ended data, to explore participant thoughts, feelings, and beliefs about the impact of risk/uncertainties on infrastructure project cost estimation (DeJonckheere and Vaughn, 2019). Since the system thinking application for the identification of uncertainties in infrastructure project is still nascent and has not gained adequate recognition amongst project control and management professionals a need to gain an early insight into it becomes inevitable. Semi-structured interview method of qualitative data collection method provides the interviewer a clarity or more details when needed (Abbas and Teddlie, 2010). It also provides means through which questions naturally flow from the informal conversation during interview (Abbas and Teddlie, 2010). The semi-structured interview questions were carefully designed in relation to this study's research questions derived from literature reviews. NVIVO software was used to analyse the transcribed interviews to generate themes for further thematic analysis. The respondents were carefully selected randomly to cater for the infrastructure project control and management team population.

The main purpose of sampling is to ensure a practical means of enabling the data collection and processing components of research to be carried out while making sure the sample is a representative of the intended population

4.2.1 Sampling technique

The method of data collection was based on the intention of this interview, which is to get the expert opinion on cost estimation and identification of infrastructure project uncertainties utilising system thinking. The planned sample for this study was to define the target population which is the project control and management professionals of government owned infrastructure project institutions as stated above previously.

Project control and management team: The project manager's role has the responsibilities of managing day-to-day activities of the project and delivering the capabilities that allows the benefit to be realised (APM, 2006). PMI (2013) stipulates that the project management office is a management structure responsible for the standardisation of the project related governance process and facilitates the sharing resources, tools, and techniques. Also, their responsibilities vary, and it can involve providing support functions and directing project as well. Project management office staffs (Project control) involved the planning /scheduling/Cost engineer, Quantity surveyor, commercial manager, project officers, risk engineers, quality engineers and procurement managers etc

A snow balling sampling technique was used for the purpose of qualitative data collection. It is a non-random sampling which uses a few cases to encourage other potential participants to participate respectively in the study (Taherdoost, 2016). This method of sampling was used due to the nature of accessibility to cost information in infrastructure project institution which are quite sensitive. To have a good representation of the professionals involved in the delivery of infrastructure project, a government owned infrastructure project institution was chosen directly using snow-balling sampling technique. According to Fellows (1997), sampling is utilised to provide practical means of making data collection and processing components of research to be carried out while ensuring the sample connotes a good representation of the population.

Olive (2014), states that interview research that has an idiographic aim generally seeks a small sample size that is adequately small for individual cases to have a locatable voice within the study and for an intensive analysis for each to be conducted. The target respondent was between 6-10. The interview questions presented to respondents are available on the appendix table lists. Prior to conducting this interview, a cover letter was sent to potential respondents, explaining the purpose of the research work and all ethical issues that guaranty non-disclosure agreement, respectively. These letters are listed on the appendix table as well. The participants involved in this semi-structured interview are quite vast in their respective areas of profession. The 20 participant's total budget of the infrastructure project undertaken are more than £55 Billion. This shows the samples from the population of the infrastructure project professionals collated is quite robust in terms of budget and years of experience, respectively. The interview time was on average of 40mins which made the interviewees to express their experiences in the management and execution of government owned infrastructure project firms. It also permits open-ended questions and response related to the study. The interview questions are in the Appendix D-section. Below is the interview analysis of the collated data from respondents.

4.2.2. Interview analysis

This section explains both the univariate and thematic analysis of the data collated during the semi-structured interview. Interviews data was later transcribed and coded using NVIVO-12 for analytical purpose. Tables and graphs were used to illustrate the results and trends. They are underlisted below as follows:

A. **Project demographic profile**

The demographic profile of the respondents involved in the management and delivery of government owned infrastructure project firms were quite robust in terms of experience, project types and project cost value handled, respectively. The below **Fig 4.1** illustrates that the sample gathered is characterised with project control and management professionals of high level of experience in infrastructure delivery and management. More than 80% of the respondents have >10years of experience in infrastructure project management and delivery. Possessing such experience in the sample is considered potentially valuable in providing insightful views on risk, uncertainties, system thinking and cost estimation during initiation stage.

Fig 4.1 Infrastructure project control & management professionals' years of experience

A-2 The average of the total budget handled by the respondents is £2,749,950,000 and this shows a reasonable representation of project cost values across the samples collated.

Table 4.2 Illustrating the respondent's project budget handled.

Position	Budget handle
Head of Project	200000
Commercial Manager A	10,000,000
Head of PMO	200,000,000
Scopebaseline and EVM Mgr	55,000,000,000
Commercial Manager B	200,000,000
Commercial Manager C	10,000,000
Construction Manager	10,500,000
Cost Engineer	20,000,000
Planning Engineer	15,000,000
Planner	13,750,000
Programme Manager	10,000,000
Project Control Engineer	23,000,000
Project Engineer	42,000,000
Project Engineer B	7,000,000
Project Engineer C	32,000,000
Project Manager	19,000,000
Project Manager D	33,000,000
Quantity Surveyor	1,000,000
Senior Project Manager	64,500,000
Risk Manager	39,000,000

A-3 The respondent's firm sizes are quite reasonable for the purpose of this exploratory study. Up to 50% of the respondent's firm have more than 5,000 employees. Less than 20% are below 1000Fig 4 2 Respondent's firm size

A-4 Project types handled by all the respondents are 100% infrastructure projects which is quite advantageous for the respondents in providing valuable and meaningful into the areas of study. The infrastructure projects with highest representation are the rail project which is used as a case-study for the produced model validation as well.

The sample for the semi-structured interview is suitable and directed composition of sample for the purposes of this study across profile demographics such as years of experience, firm size, and project types, respectively. Below are the description and analysis of other transcribed data collated during this interview. Prior to the robust analysis the interviewees are represented alphabetically. This is to accommodate the non-disclosure agreement. They are underlisted as follows:

Interviewee-A (Commercial Manager-A

Interviewee-B (Commercial manager B

Interviewee-C (Head of Project).

Interviewee-D (Head of Project Management Office).

Interviewee-E (Quantity Surveyor-).

Interviewee-F (Scope baseline and Earned Value Management Manager)

Interviewee-G (Commercial Manager)

Interviewee-H (Quantity Surveyor)

Interviewee-I (Planning Engineer)

Interviewee-J (Planner)

Interviewee-K (Programme Manager)

Interviewee-L (Project Control Engineer)

Interviewee-M (Project Engineer)

Interviewee-O (Project Engineer B)

Interviewee-P (Project Engineer C)

Interviewee-Q (Project Manager)

Interviewee-R (Snr Project Manager)

Interviewee-S (Project Manager D)

Interviewee-T (Risk Manager)

4.2.3 Thematic Analysis

The recorded semi-structured interviews were transcribed and coded using NVIVO-12 software to generate the themes. The generated themes were further analysed using thematic analysis. The graphical representation of the codes is displayed on the appendix. The themes are as follows: Infrastructure project, risk, uncertainty, unknown/unknown, cost estimation, cost overrun, stakeholders, scope and system thinking. Below is the graphical illustration of the themes formed from the coding in NVIVO software. It describes the percentage of occurrence of the themes in each of the transcribed interviews.

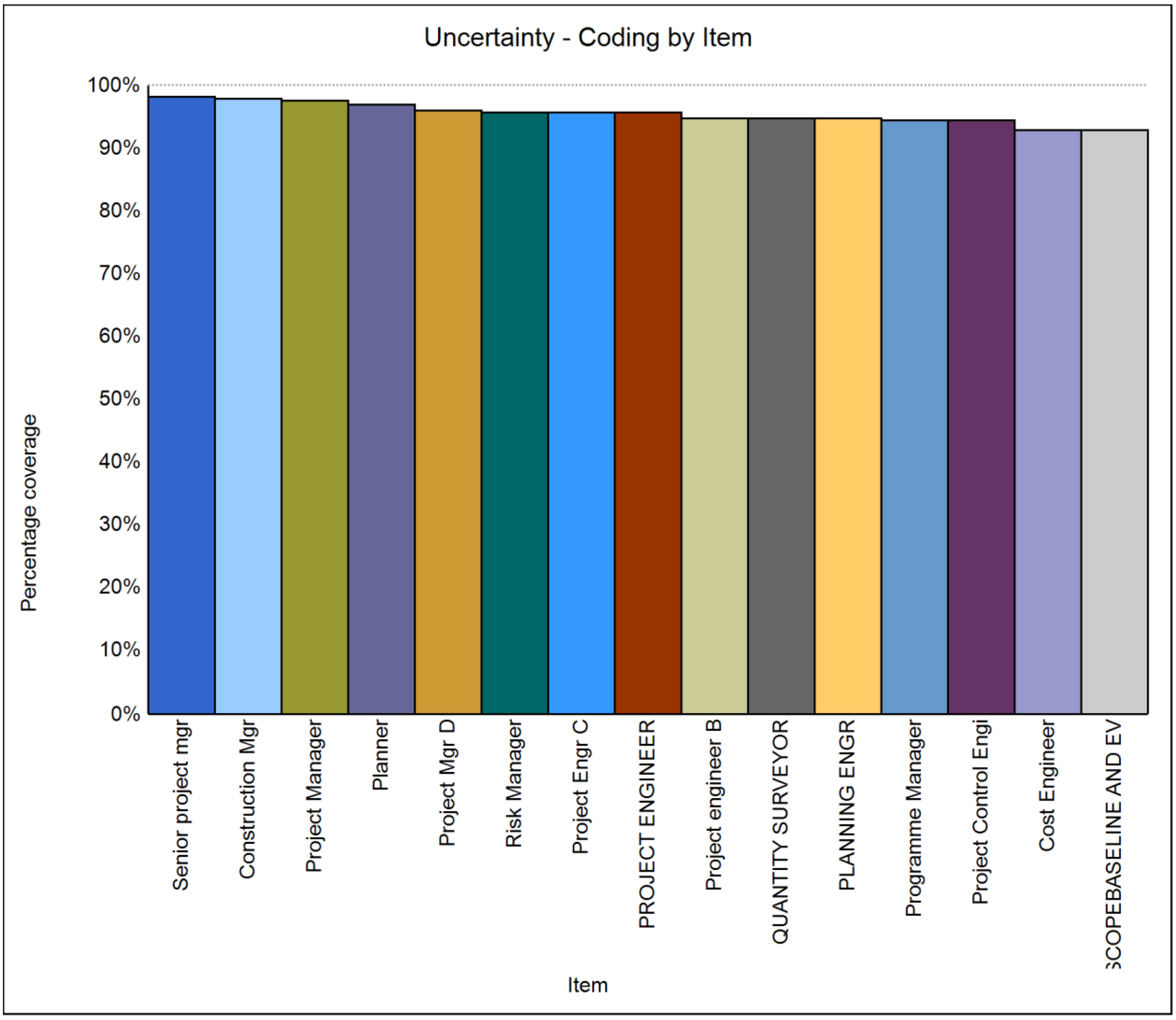


Fig 4.2 Formed Uncertainty theme

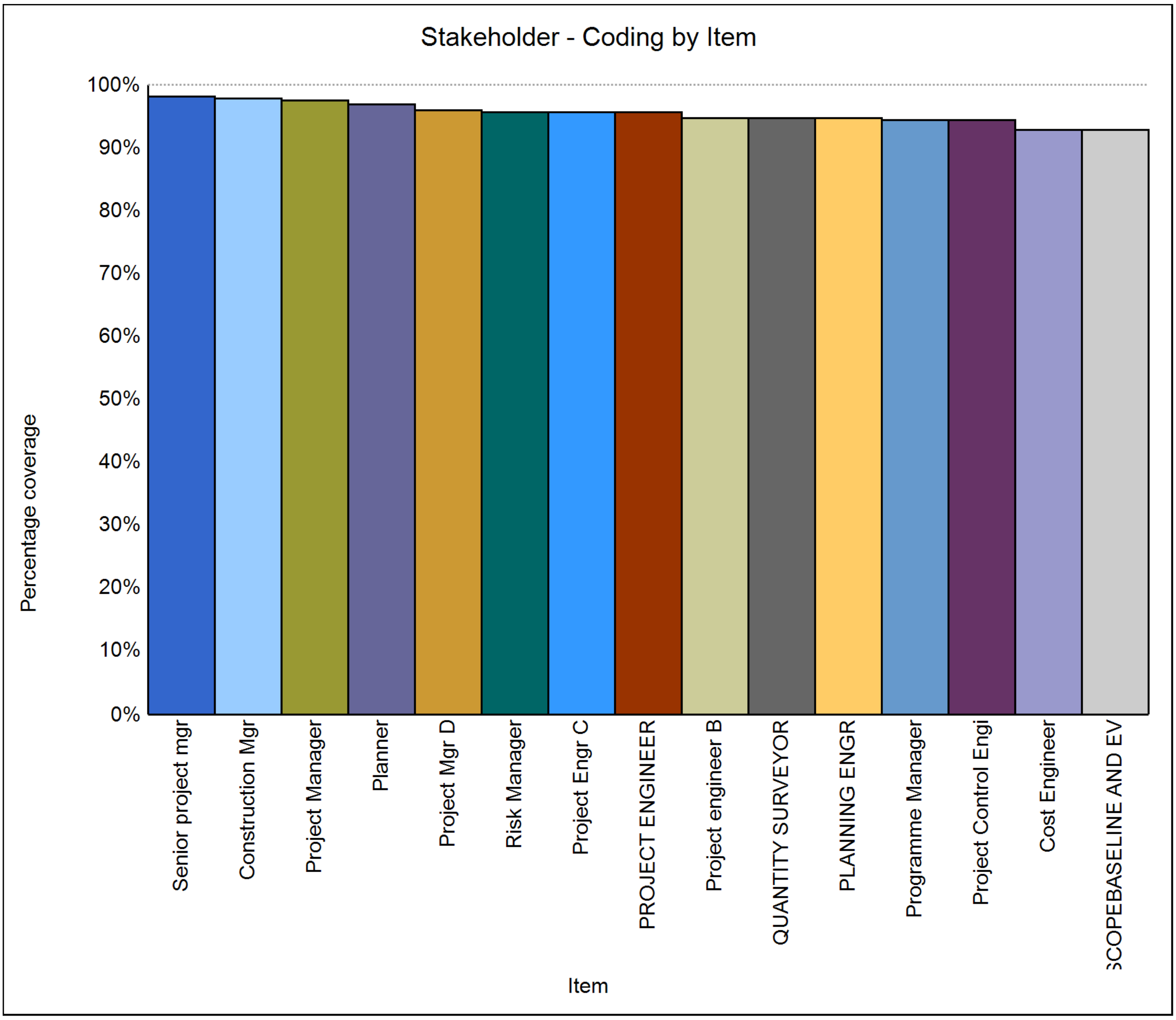
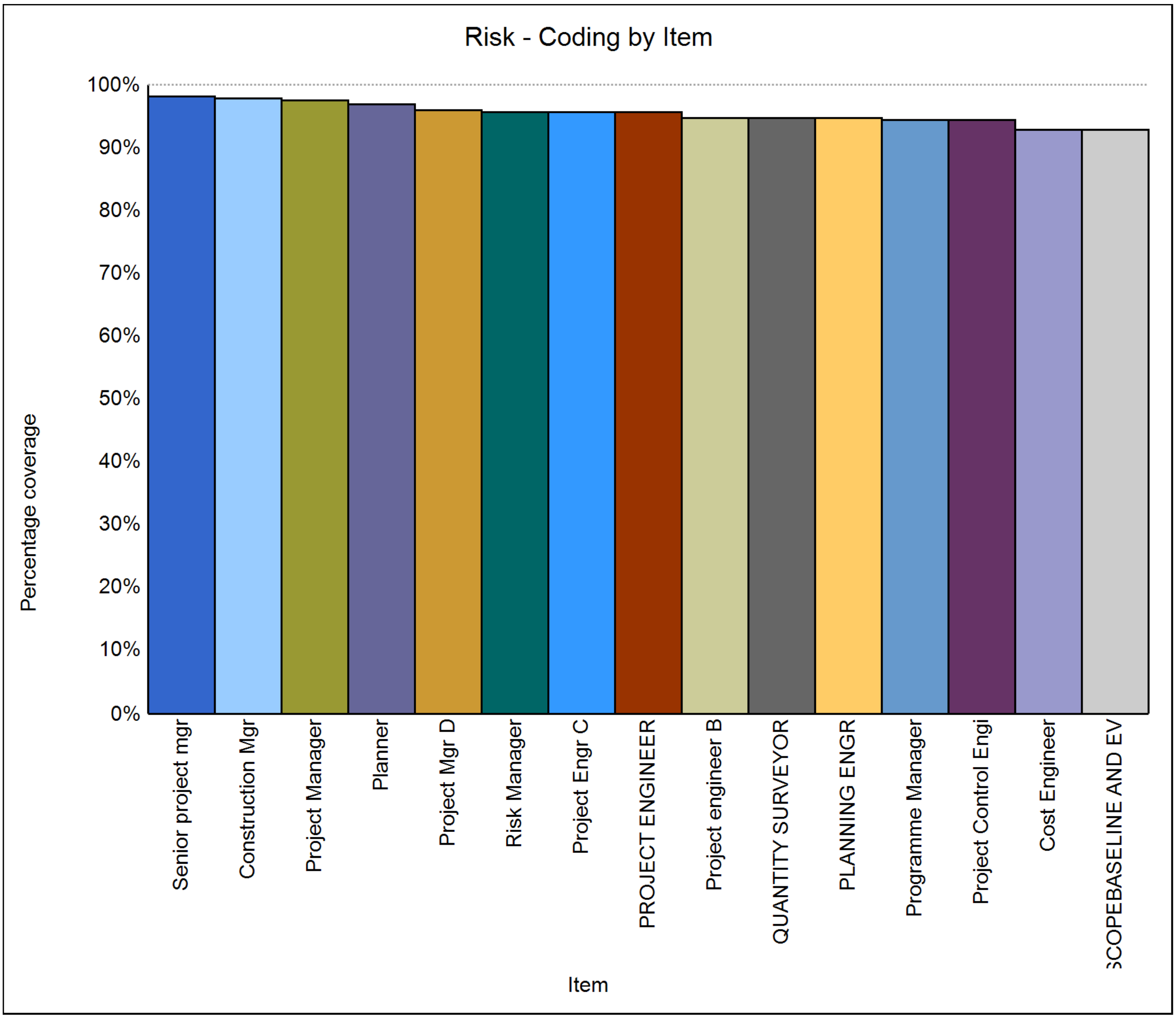


FIG-4.3 FORMED STAKEHOLDER THEME



Risk - Coding by Item
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage coverage
Senior project mgr
Construction Mgr
Project Manager
Planner
Project Mgr D
Risk Manager
Project Engr C
PROJECT ENGINEER
Project engineer B
QUANTITY SURVEYOR
PLANNING ENGR
Programme Manager
Project Control Engi
Cost Engineer
SCOPEBASELINE AND EV
Item

Fig-4.4 Formed risk theme

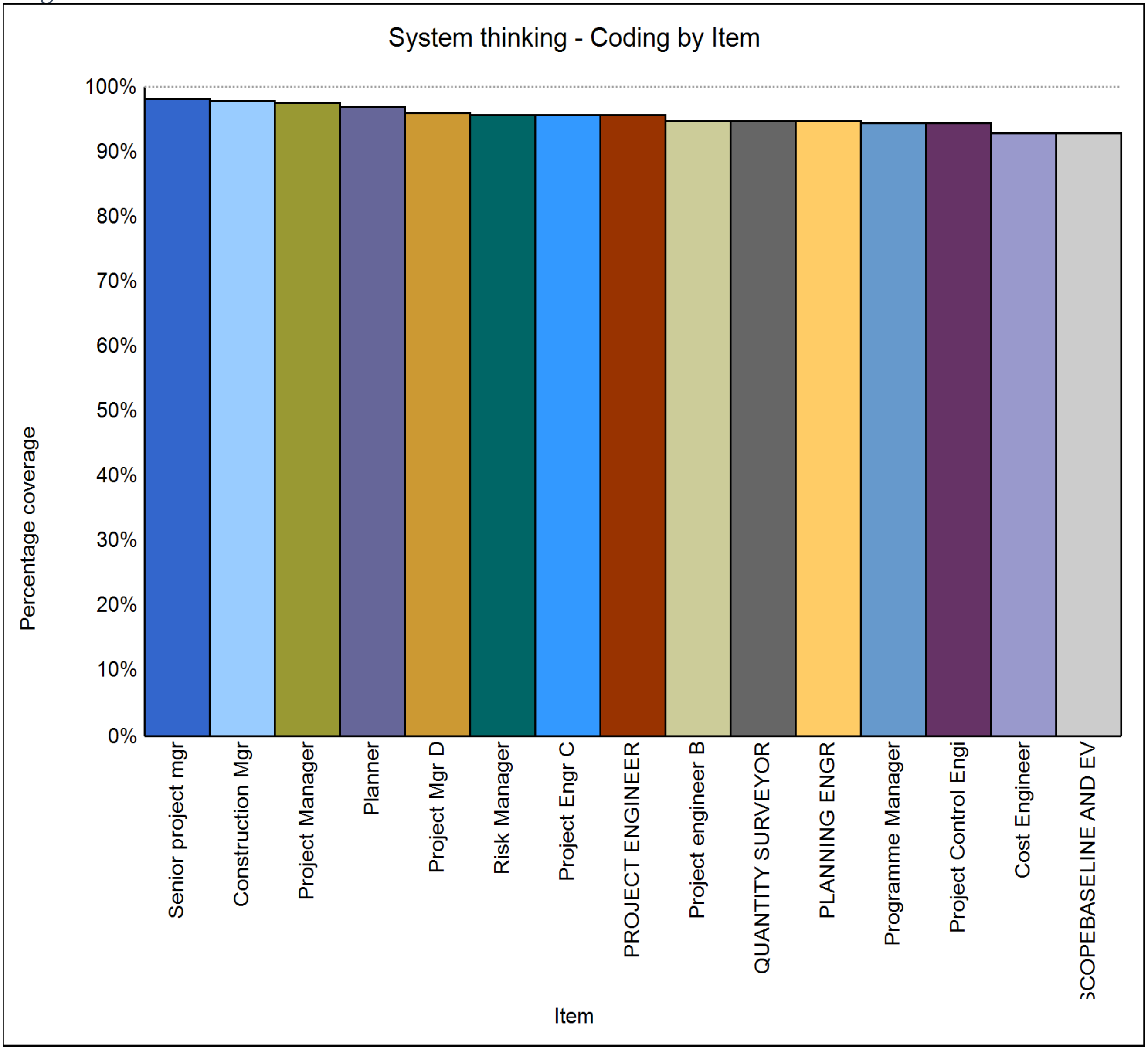


Fig 4.5 Formed system thinking theme

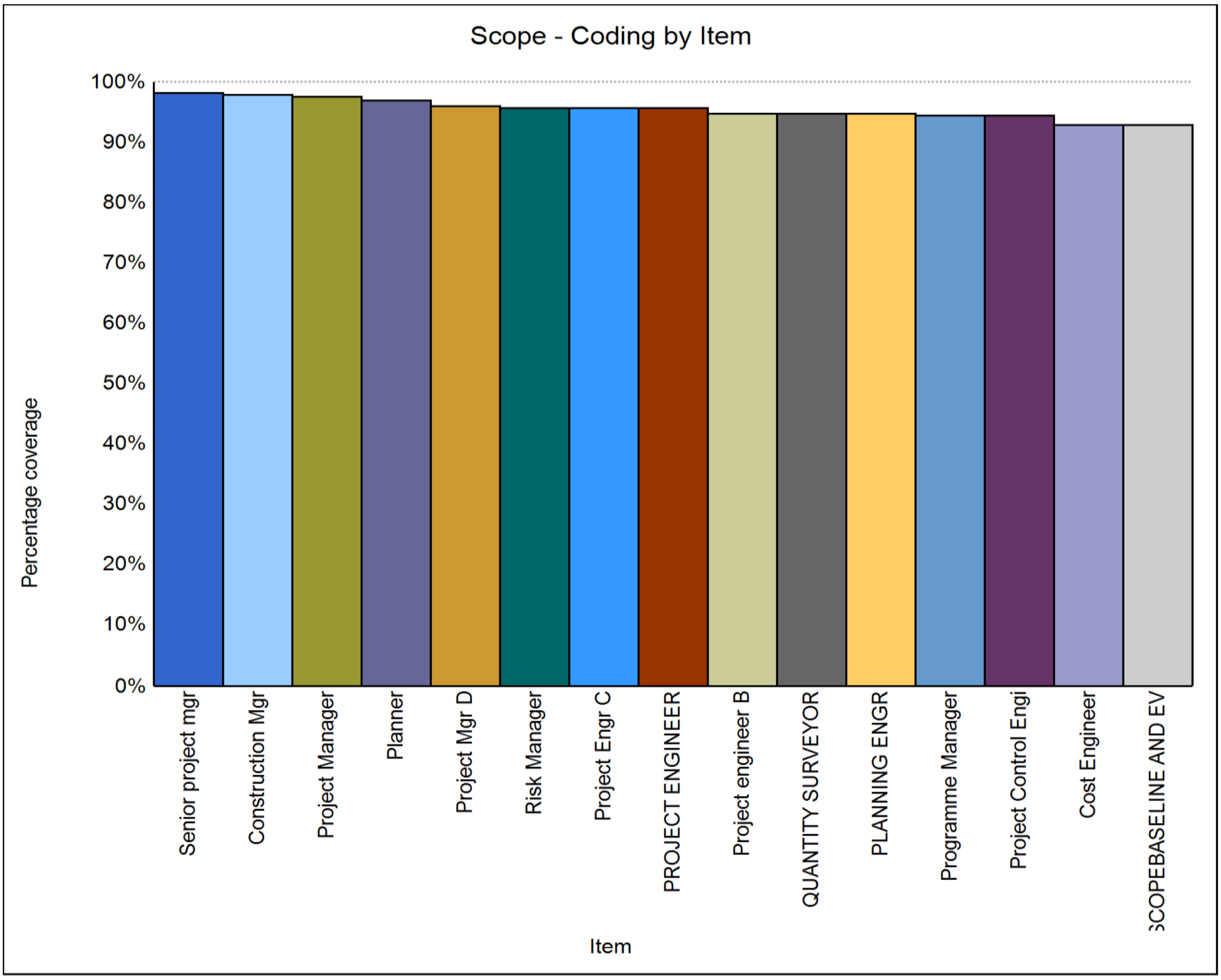


FIG 4.6 FORMED SCOPE THEME

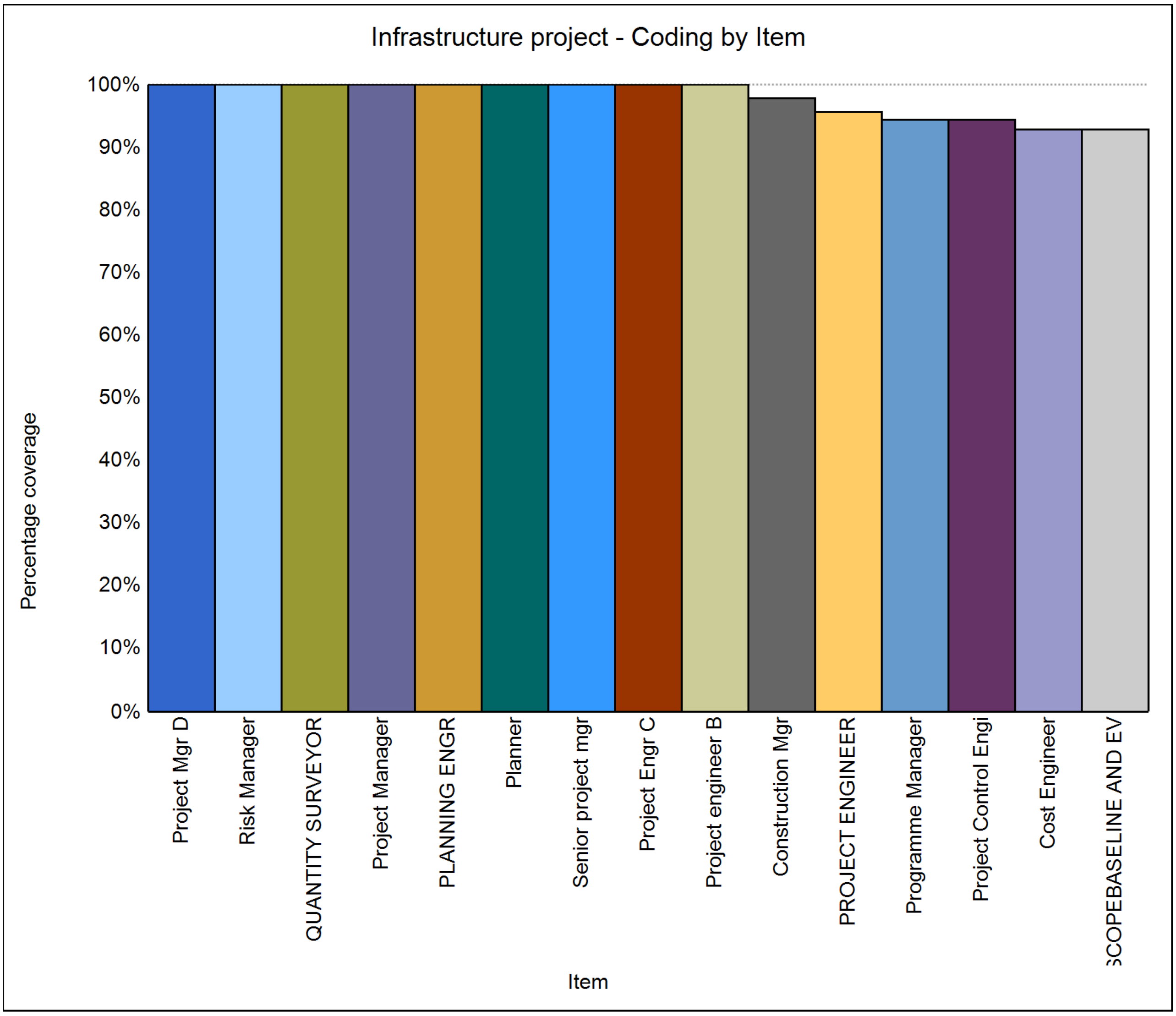


FIG-4.7 FORMED INFRASTRUCTURE PROJECT THEME

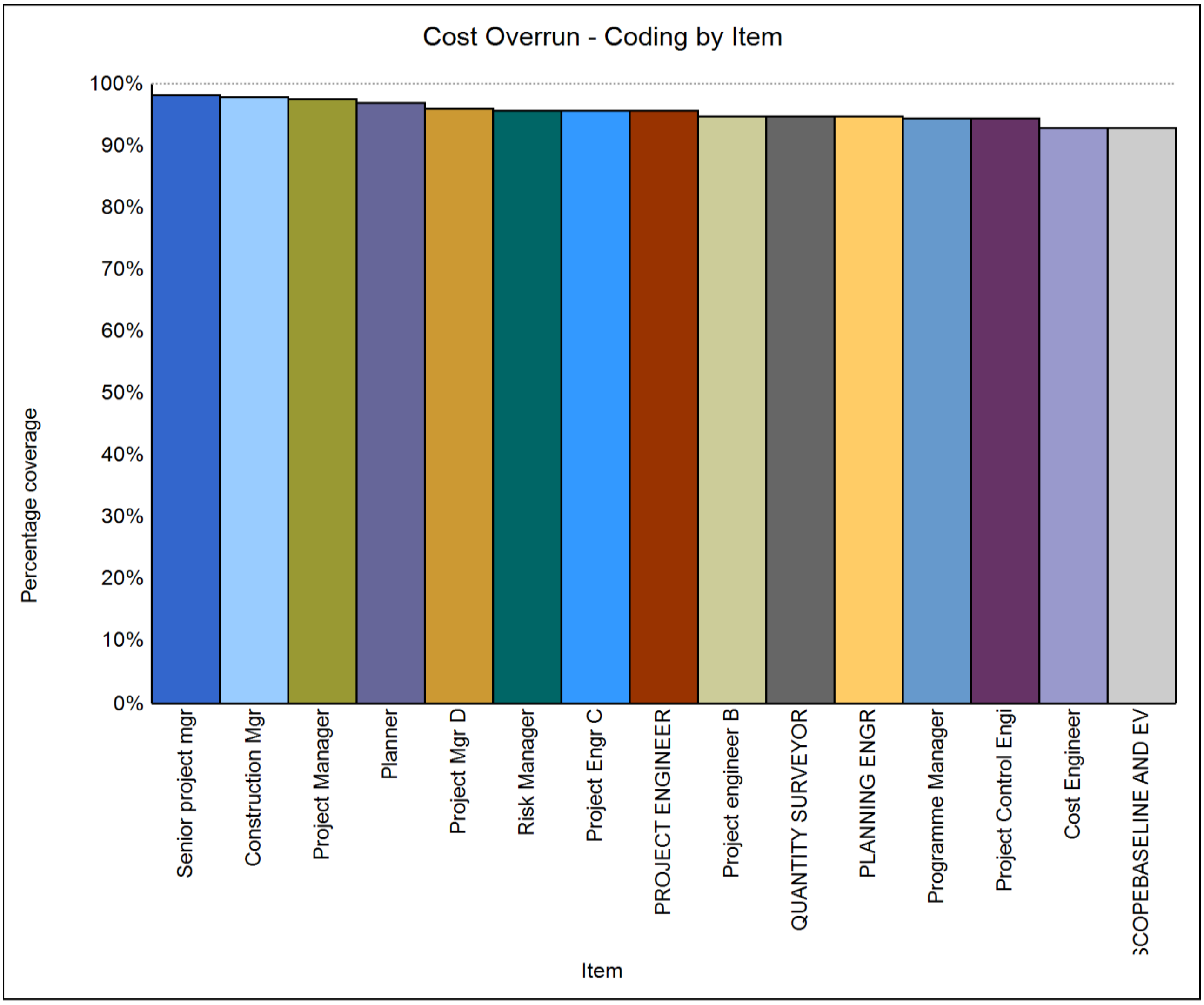


FIG-4.8 FORMED COST OVERRUN THEME

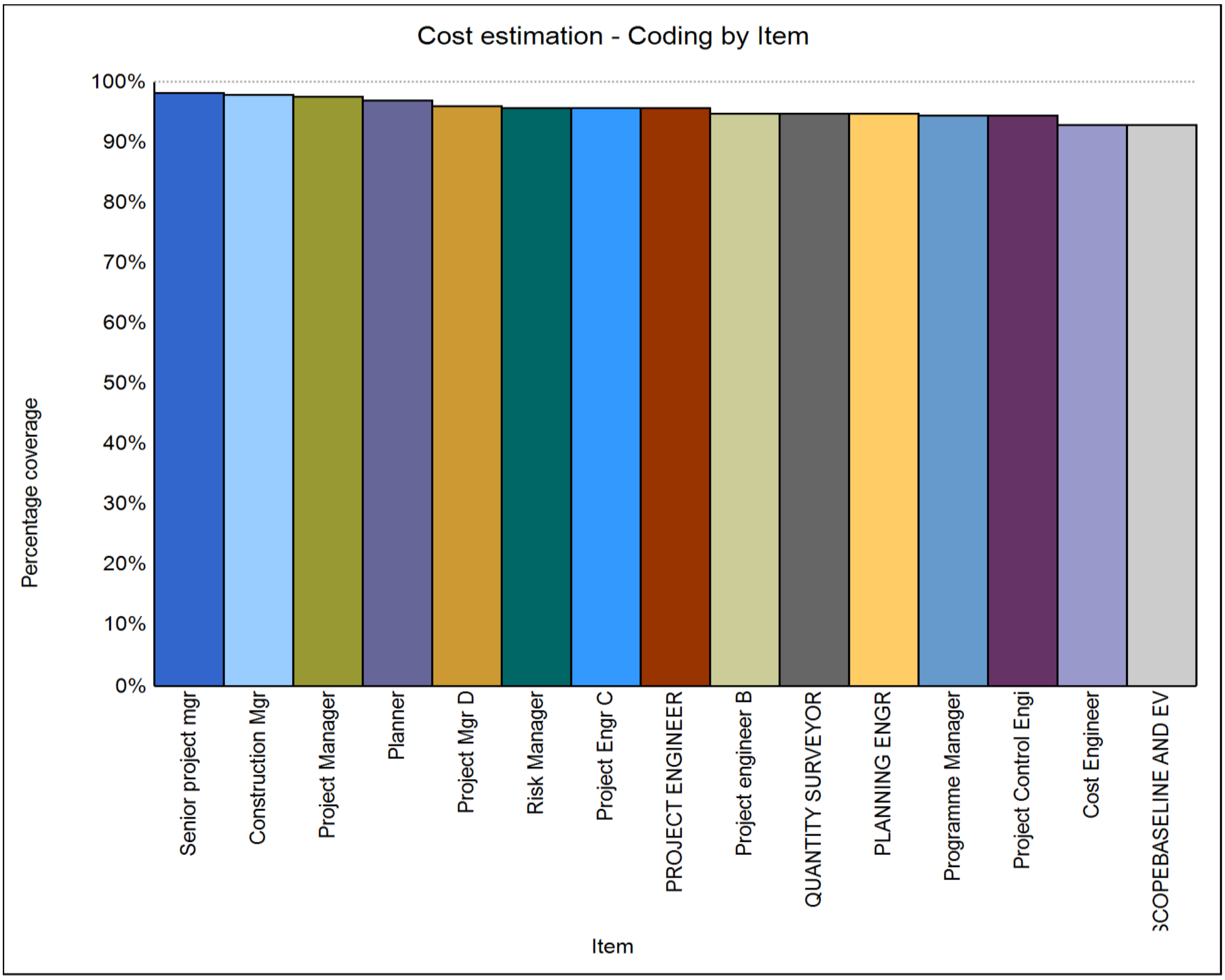


FIG 4.9 FORMED COST ESTIMATION THEME

The cost of infrastructure projects can range from a few thousand dollars to millions of dollars. According to Flyvbjer et al. (2003), there is little information available about how these significant expenditures performed in terms of true cost, benefits, and hazards. The claims of the interviewees (C, D, M&J) support this assertion which claim that the robust risk management in their respective organization is still nascent and most of the key stakeholders' struggle to implement it into the project management structure. It is expected that investment (Infrastructure project) of this magnitude should be properly executed by carrying out a robust risk and uncertainty management to mitigate the impact of cost overrun. Major infrastructure project institutions are still struggling to put in place appropriate management to execute the risk and uncertainty process adequately. It has been observed in the transport infrastructure project that there is inadequate preparation in terms of planning and implementation, respectively. This leads to cost escalation towards project completion (Flyvbjer et al., 2003). Construction professionals generally agree that the traditional cost estimation method is inadequate given the complexity of the projects being undertaken now. (Doloi, 2011). Understanding the key influences on the traditional cost estimation process is necessary to enhance it. According to Doloi (2011), size of projects, availability of reliable resources, market condition, risk and uncertainty are some major factors that impact on cost estimation process. This statement was supported by Interviewee **D & E** and government legislation was also regarded as a major factor considered during project cost estimation process. It is pertinent now to consider project cost estimation holistically rather than as an isolated process. System thinking approach will improve the traditional method(reductionism) of project cost estimation and this assertion is supported by all the interviewees **(A, B, C, D, M, N &E)** respectively. Interviewee **A, B & C** believed that human factors play a vital role during the project cost estimation process due to subjective nature of experience and expert opinion. The conventional method of cost estimating does not account for these aspects (Reductionism). Cost estimates are made during the project's commencement stage using the project's limited knowledge and hazy scope and needs. This cost estimate serves as the foundation for creating project budgets. Most often, throughout the planning and implementation stages, important stakeholders find a mistake in this estimate. The early impact of these errors on the cost estimation process may have been reduced with a holistic approach. It involves the exploration of problems in the context of holistic system by viewing the interactions between components of systems and integrating the perceptions of individuals as well. Infrastructure project structures and implementation conditions are complicated, necessitating a thorough examination of the implementation hazards (Pirogova et al., 2022). This is corroborated by interviewees **(P,R,S,T**

& V) that projects are complicated and contains inherent uncertainties which needs to be uncovered prior to execution. The field of investment development for infrastructure project is extremely risky and susceptible to the effects of shifting external and internal environmental conditions (Pirogova et al., 2022). There is need for a nascent approach that takes cognizance of both internal and external that impact on a project prior to execution.

4.2.4 Findings

Most participants agree that improved infrastructure project cost estimation is necessary. There is not enough investigation done to ascertain collation of uncertainties and risk as speculated by **Interviewees-B, C, L, M,O,P,Q & D.** This will then be useful in estimating a robust contingency budget for the project.

Uncertainty and risk are quite misunderstood by project control and management professionals. As specified by **Interviewee-E, V, N, T** which states categorically the term risk is the preferred context to use while carrying out infrastructure project estimation. Most of the participants cannot differentiate between Risk and uncertainties which is quite absurd due to the nature of the sensitive role played in management of infrastructure project. Chapman (2001) argues that most of the present project risk management processes result to restricted focus on project uncertainty management. He further stipulates that if project control and management professionals focus more on uncertainty rather than risk, it could enhance the project risk management process outrightly. This goes back to the concept of unknown/Unknown where infrastructure project professionals allocate arbitrarily management reserve to a cost estimate by mere expert opinion which certainly subject to biases. **Interviewee-C** further confirms that during the initial cost estimation determination, all the risk is identified and passed to the estimators who are not directly involved in the process of risk management in their organisation. This leaves a gap of human-error where most of the decision taken on the infrastructure project risk management is solely based on expert opinion (excluding the estimators) who are not privy to first class realities on the risk management process and only rely on the information passed to them thus making decision based on it.

It was also discovered that there is no known strategic framework used in determining the yardstick for contingency estimate (In terms of risk allocation). According to the participants most of the estimate carried out are completely subjective based own historical data, benchmarking & expert opinion and this concept are prone to human errors due to inconsideration of soft skills involved in the estimation process. All the interviewees agreed that holistic consideration using system thinking approach is required during project cost estimation to improve its performance adequately. Also most have them have not applied the system thinking approaches in infrastructure project delivery.

Aside these findings during the interview, some of the respondents guaranteed case study firm. This was very beneficial for the overall research work.

4.3 Survey Questionnaire

The survey was adequately designed in relation to this study research questions taking cognizance of the statistical data analysis.

This was done in addition to the data collected through semi-structure interview and secondary data collected via literature reviews. It contains 72 questions which are divided into Demographics, Infrastructure project uncertainty management, Infrastructure project risk management, Infrastructure project cost estimation and system thinking scale, respectively. The questionnaire was distributed to random samples of infrastructure project management professionals who have experience managing government owned infrastructure project institution in the UK. Only 76 responses were obtained. Prior to the actual survey, pilot study was carried out to ascertain the validity and effectiveness of the questions asked. The findings were reported and tabulated in Chapter-3. To ensure the privacy of the respondents, a non-disclosure agreement and research summary letter was sent to explain the contents of the research work. The questionnaire was placed on www.bristolonline.com and distributed via email to respective respondents using snowballing sampling technique.

4.3.1 Sampling.

The sample was made of 76 respondents selected using snow-balling technique. This type of technique was selected due to the nature of the data to be collected and the duration of the whole process. It is a non-probability sampling technique in which existing subjects provide referrals to recruit samples required for a research study (Bhat, 2020). This is used to access difficult population due to the closed nature of their operation (Taherdoost, 2016). The population target is the project control and management professionals of government owned infrastructure project institutions in the UK.IBM SPSS statistical software package was used for descriptive and inferential statistics of the questionnaires.

4.3.2 Descriptive Analysis

All the data from the questionnaires were entered into the IBM SPSS statistics 26 software package. All the items were transformed to relevant variables and the answers/alternatives were also coded using value labels. Also, the variables were entered for analysis. The descriptive analysis enabled frequency tables, standard deviation, and rankings to be established. The presentation of the data was done by the inbuilt graphs as well.

4.3.2.1 Respondents Demographic

- **Infrastructure project types**

Participants were asked the type of infrastructure project institutions they worked for and 34% responded to be working for government owned infrastructure project institutions while 66% responded to be working for private owned infrastructure project institutions. This was done to effectively capture well experienced project control and management professionals involved in the execution of infrastructure projects in the UK. The distribution is shown in **Fig-4.10** below

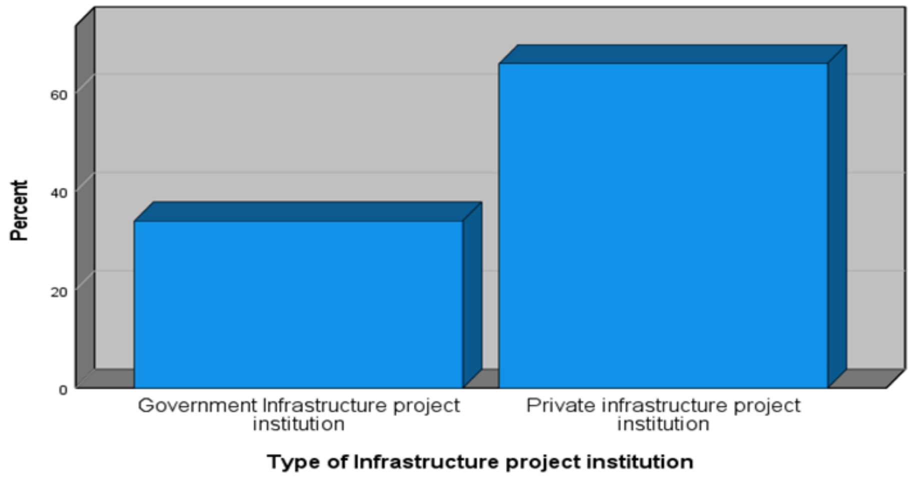


Fig 4.10 Percentage types of infrastructure project firms

Due to the inadequate project control and management professionals of government owned infrastructure project institutions, private owned infrastructure project institution professionals were involved in this research work. Most of them have experience in government infrastructure projects.

- **Respondent's professional positions**

The participants involved in this survey are quite vast and well experienced in managing infrastructure projects in the UK. Most of the selected positions are key stakeholders in managing infrastructure projects which makes the research work more reliable. The distribution is shown in **Fig-4.11.**

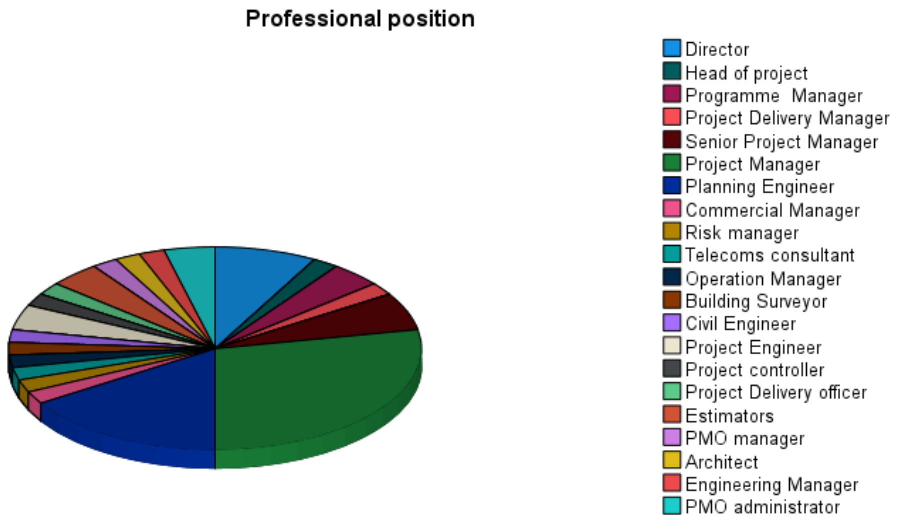


Fig 4.11 Professional positions of the respondents

The participants in this survey are well experienced in the delivery of various infrastructure; the target participants for this research work are the rail and transportation sector, respectively. Due to the inadequate availability of infrastructure project control and management professionals in the rail sector/transportation sector, other infrastructure project sectors were solicited for the participation. The distribution is shown in **Fig-4.12.**

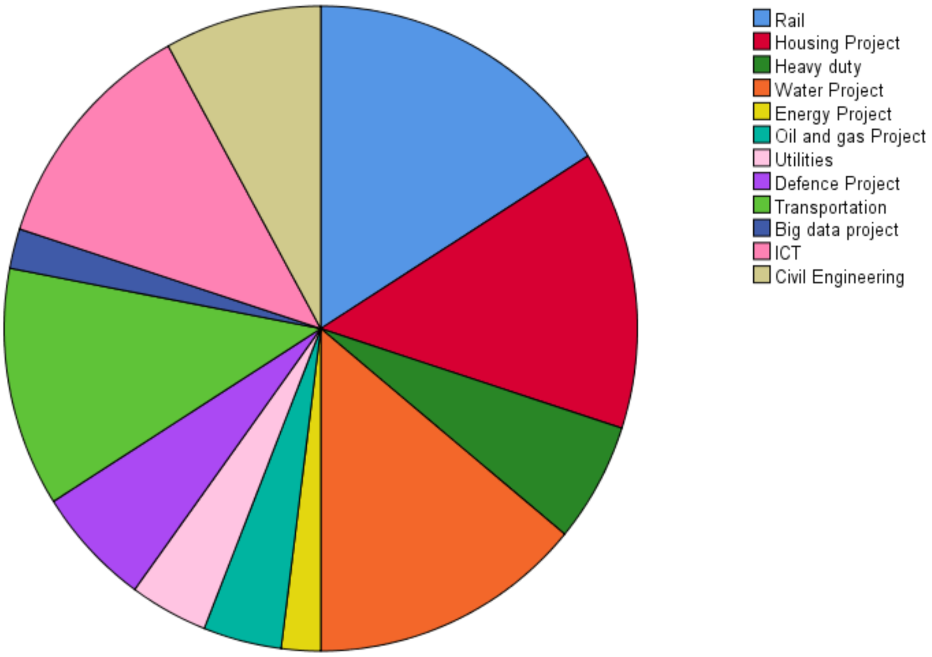


Fig 4.12 Types of infrastructure project involvement.

- **Respondents Infrastructure project experience**

Participants were asked years of experience in delivering infrastructure projects and close to 40% have between 5-10years of experience which surpasses the target of minimum of 5% target within the stipulated range. All the participants have combined total of more than 50years of experience in delivering infrastructure project which makes the survey results robust and reliable. The distribution is shown in **Fig-4.13.**

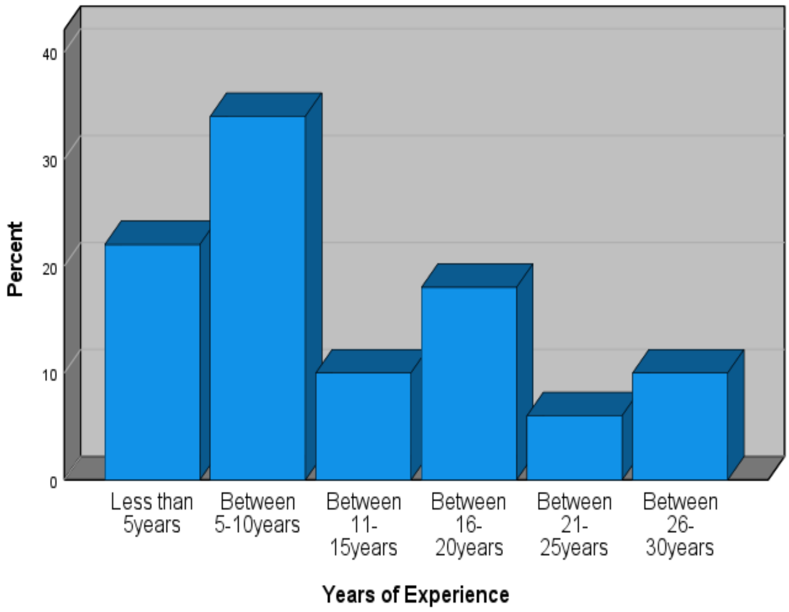


Fig-4.13 Years of experience in delivering infrastructure projects.

- **Respondents' infrastructure project budget handled**

The participants infrastructure project budgets handled are quite impressive in terms of size. More than 15% of the participants handled project budget worth close to £100billion. The combined total of the budgets handled by the participants are more £100 billion, which makes the survey reliability robust. The distribution is shown in **Fig-4.14**

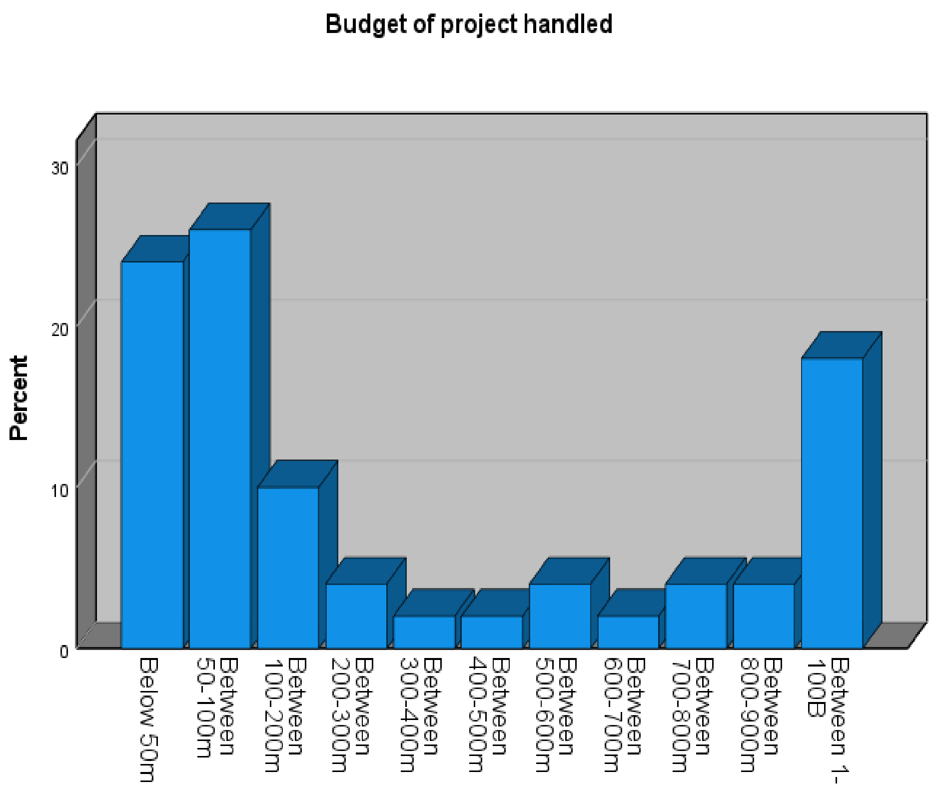


FIG 4.14 INFRASTRUCTURE PROJECT BUDGET SIZE.

- **Respondent company's staff size**

Respondents were asked about the employees' population in their respective organizations. 20% of the respondent's staff size is < 5000 in numbers while 80% are > 50,000 in numbers. This shows that most of the participants work with large organization involved with appreciable size of infrastructure projects**.** The distribution is shown in Fig-4.15.

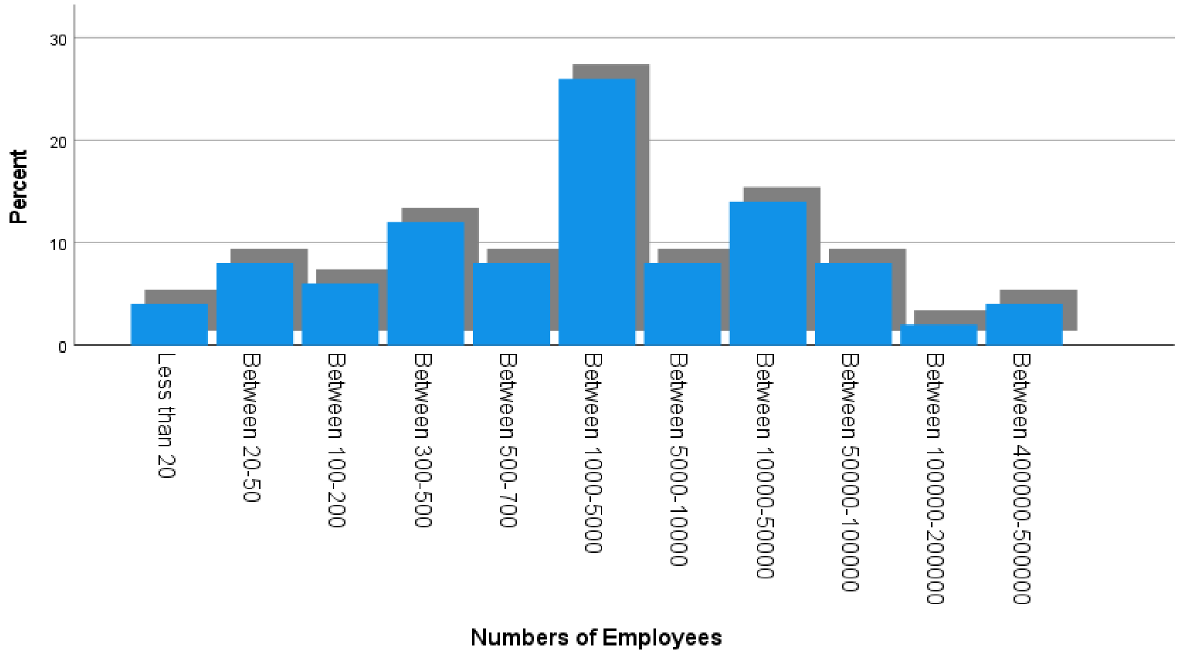


Fig 4.15 Respondent staff size.

4.3.3 Factor Analysis

This is carried out on the uncertainty factors identified by the respondents according to their impact level on initial cost estimate. It is quite necessary to derive the uncertainty factors with the relevant impact on the cost estimate. There is need to check for the reliability of the data to be factored in this research work. Internal consistency within the data set is required and Cronbach Alpha will be utilized to determine it.

4.3.4 Cronbach Alpha (Reliability test)

The internal consistency of the responses needs to be checked for reliability to ensure the uncertainty factors become robust for further analysis in the research work. Below is the result generated from the Cronbach Alpha using SPSS software.

Table 4.3 Showing the Alpha Coefficients of the 22 items

Cronbach Alpha	Item
0.87	22

It is recommended in the social research society that Cronbach Alpha coefficient should be higher than 0.7 (UCLA, 2020). The Cronbach Alpha result in Table-4.3 shows that items have relatively high level of internal consistency. This in turn proof that data generated for further factor analysis are very reliable. The items statistics depicting summary and correlation are shown on the appendix section of this thesis.

4.3.5 Principal Component Analysis

This was utilized to derive the most significant uncertainty factors from the samples of the project control and management professionals. KMO and Bartlett's test was done to show that the samples collated are appropriate. The sample adequacy is quite significant according to the KAISER-MEYER-OLKIN MEASURE (0.675). The correlation between the variables is significant as the P-Value is lower than 0. 005. Below is the Table 4.4 showing the tabulated result of the KMO and Bartlett's test, respectively.

Table 4.4 Showing the KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.675
Bartlett's Test of Sphericity	Approx. Chi-Square	490.199
	df	231
	Sig.	0.000

4.3.6. Total Variance Explained

Kaiser criterion was used to extract the most significant uncertainty factors according to the conducted Principal component analysis. It is a criterion utilized in factor analysis to determine the number of components or factors for consideration. Eigenvalues is used for the selection criteria which should be greater than 1 (Howitt, 2004). The **Table-4.5** showing the minimal test of the statistical significance of the factor.

The number of factors to retain and the issue of factor loading are normally subjective to the criteria used. The correlation coefficient for the variable and factor is known as factor loading. The variance explained by the variable on that factor is shown by factor loading. As a rule of thumb in structural equation modelling (SEM) approach, factor loading of 0.4 or greater indicates that the factor extracts enough variance from the variable (Christ of Schuster and Yuan, 2016). To select factors to keep based on the factor loading and common variability, the minimum factor loading for this study was 0.4. The extracted factors are displaced on **Table-4.7**. Based on this minimum factor loading criterion, the seven factors are interpreted on **Table-4.7.** The green section of the table shows the classification of the all the extracted factors.

Table 4.5 Extracted factors based on Eigen Values >1

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.747	21.58	21.58	4.747	21.58	21.58	2.455	11.16	11.16
2	2.616	11.892	33.471	2.616	11.892	33.471	2.441	11.096	22.256
3	1.746	7.937	41.408	1.746	7.937	41.408	2.066	9.391	31.646
4	1.41	6.408	47.816	1.41	6.408	47.816	2.012	9.144	40.79
5	1.32	6.001	53.817	1.32	6.001	53.817	1.817	8.261	49.052
6	1.049	4.767	58.585	1.049	4.767	58.585	1.76	7.998	57.05
7	1.015	4.612	63.197	1.015	4.612	63.197	1.352	6.147	63.197
8	0.99	4.501	67.698						
9	0.969	4.406	72.104						
10	0.875	3.978	76.082						
11	0.767	3.485	79.567						
12	0.684	3.109	82.675						
13	0.581	2.639	85.314						
14	0.551	2.504	87.818						
15	0.497	2.261	90.079						
16	0.436	1.981	92.06						
17	0.408	1.855	93.915						
18	0.336	1.528	95.443						
19	0.331	1.504	96.947						
20	0.264	1.2	98.146						
21	0.21	0.955	99.101						
22	0.198	0.899	100						
Extraction Method: Principal Component Analysis.									

Table 4.6 Rotated estimated factor loadings for uncertainty factors

UNCERTAINTY FACTORS	1	2	3	4	5	6	7
Unforseen site construction	0.418	0.299	0.205	-0.020	-0.257	0.336	-0.170
Design error omission	0.202	0.324	0.274	0.061	0.049	-0.032	-0.431
Contractor caused delays and coordination issues	0.206	0.208	0.584	-0.265	-0.003	-0.008	0.188
Owner driven changes	0.207	0.021	0.114	0.088	-0.449	-0.441	-0.200
Accelerated schedules	0.374	-0.064	-0.352	0.268	0.237	0.290	0.417
Construction coordination issues	0.430	0.028	0.489	-0.292	0.133	-0.329	-0.018
Project Delivery Method	0.433	-0.242	0.201	-0.368	0.184	-0.161	0.154
Team formation process	0.286	-0.570	-0.048	-0.479	0.454	-0.217	0.002
Regulatory permitting process	0.318	0.018	-0.029	-0.345	0.134	0.591	0.185
Miscommunication between teams	0.395	-0.042	-0.148	-0.532	0.351	0.133	-0.398
Unclear project requirements	0.470	0.203	-0.602	0.068	0.040	-0.095	0.200
Scope gaps	0.485	0.460	-0.268	-0.116	-0.265	-0.240	0.067
Project complexity	0.540	0.232	-0.131	-0.129	-0.159	-0.138	0.033
Underperforming Unqualified inexperienced staff	0.264	0.295	-0.063	0.489	0.005	-0.183	-0.133
Lack of thoroughness of preconstruction planning, estimating	0.237	0.231	0.043	0.420	0.554	-0.047	0.225
Weather condtion	0.383	0.431	0.393	0.346	0.127	-0.008	-0.088
Government policies	0.140	-0.105	0.239	0.133	-0.019	0.447	0.265
Resources availability	0.235	-0.200	-0.195	-0.449	-0.158	0.111	-0.169
Quality assurance control	0.659	-0.189	-0.258	-0.046	-0.116	-0.128	-0.296
Adaption of advance technology	0.372	-0.405	0.014	0.059	0.139	-0.210	0.504
Socio-economic condition	0.290	-0.630	0.225	0.392	-0.199	0.092	0.151
Stakeholders issues	0.626	-0.069	0.089	0.144	-0.274	0.140	-0.196

Table 4.7 Extracted factors classification

FACTOR	EXTRACTED FACTORS						Classification
FACTOR-1	Project Complexity	Scope Gap	Project Complexity	Unforseen Site construction Condition	Unclear Project requirement	Stakeholder Issues	Project related factor
FACTOR-2	Weather condition	Socio-economic condition					External factor
FACTOR-3	Contractor caused delays and coordination issues	Construction Coordination issues					Consultant factor
FACTOR-4	Team formation process	Miscommunication between teams	Underperforming Unqualified inexperienced staff	Resource availability			Organizational issues
FACTOR-5	Owner driven changes	Lack of thoroughness of preconstruction planning, estimating					Factors related to client
FACTOR-6	Regulatory permitting proce	Government policies					Legal issues
FACTOR-7	Accelerated schedules	Adaptation of advance technology					Technical issues

4.4 System thinking analysis

There is need to assess the reliability and internal consistency of the items of the system thinking questionnaire generated. Below is the Cronbach Alpha of 0.703 generated which shows a good reliability. This analysis was done using SPSS software.

Table 4.8 System thinking analysis Cronbach Alpha test

Cronbach's Alpha	N of Items
0.703	20

Sample adequacy for the variables is quite needed to justify the internal consistency of the data collated. This analysis was done using SPSS software. Below is Table 4.9 showing the Kaiser-Meyer-Olkin Measure Test

Table 4.9 Showing System thinking scale of KMO and Bartlett Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.651
Bartlett's Test of Sphericity	Approx. Chi-Square	277.765
	df	210
	Sig.	0.001

KMO measure shows 0.651, this indicates internal consistency for the system thinking scale estimation for the respective respondents. The system thinking scales of the respondents are calculated using Likert scale of 0= Never,1= Seldom,2=Some of the time,3=Often and Most of the time =4. **Table-4.10** is the calculation procedures for the system thinking scale of the respondents.

Table 4.10 System thinking scale score calculation

Director of project	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.		1				1
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.		1				1
.I recognize system problems are influenced by past events.		1				1
I consider the past history and culture of the work unit.		1				1
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
Score						53

Table 4.11 System thinking scale score of all respondents

NO	Professional	SYST	Years of Experience
1	Director of project	53	30
2	Project controller	62	9
3	Project Manager	53	6
4	Planner	58	10
5	Commercial Mgr	60	20
6	Snr Planning Engr	52	8
7	Head of Project	53	6
8	Engineering Director	67	20
9	Project Manager	65	10
10	Project deliver officer	63	5
11	Project Delivery Manager	64	10
12	Building Surveyor	58	5
13	Project Planner	58	7
14	Project Manager	59	6
15	Quantity Surveyor	52	8
16	Snr Project Mgr	64	18
17	Snr Project Mgr	68	6
18	Snr Project Planner	60	5
19	LeadProject Mgr	58	25
20	Project Mgr	66	18
21	Project Mgr	70	15
22	PMO mgr	58	11
23	Project Mgr	64	5
24	Project Mgr	60	30
25	Project Engineer	74	20
26	PLANNER	39	10
27	PROJECT MGR	40	10
28	COST ENGINEER	23	8
29	PM	35	12
30	PM	36	7
31	QS	29	8
32	QS	34	8
33	PM	32	7
34	QS	39	7
35	RISK MGR	32	7
36	PLANNER	34	12
37	COMMERICAL MGR	32	6
38	COST CONTROL	27	6

39	PM	33	8
40	PROJECT COORDINATOR	33	7
41	PLANNER	25	8
42	PM	39	8
43	PROJECT ENGR MGR	34	7
44	PROJECT DIRECTOR	29	16
45	PROJECT CON ENGR	41	13
46	COMMERCIAL MGR	36	8
47	QS	35	7
48	COMMERCIAL MGR	23	8
49	PROGRAMME MGR	40	8
50	RISK MGR	39	9
51	PM	52	4
52	Project Engineer	62	7
53	Planner	52	10
54	Project Engineer	55	10
55	PMO Director	61	30
56	PROGRAMME MGR	59	16
57	Engineering Mgr	67	10
58	PMO Administrator	71	7
59	Project Manager	12	6
60	Project Manager	10	8
61	Project support officer	60	5
62	Project Manager	53	7
63	Project Enginner	53	6
64	Planning Mgr	68	11
65	Project Director	65	30
66	Project Engineer	64	8
67	Snr QS	57	9
68	Planning Mgr	73	30
69	Project Manager	72	25
70	Project Manager	57	12
71	Project Manager	41	6
72	PROGRAMME MGR	45	22
73	Senior Planning Engineer	44	9
74	Operation Mgr	43	20
75	Risk Mgr	32	9
76	Project Mgr	41	14

4.4.1 Need for cognition

There is need to assess the reliability and internal consistency of the need for cognition items of the questionnaire generated. Table 4.12 showing the Cronbach Alpha of 0.672 generated which shows a good reliability. This analysis was done using SPSS software.

0.672 generated which shows a good reliability. This analysis was done using SPSS software.

Table 4.12 Need for Cognition Cronbach's Alpha

Cronbach Alpha	Item
0.627	18

KMO measure shows 0.719, this indicates internal consistency for the need for cognition estimation for the respective respondents.

Table 4.13 KMO and Bartlett Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.719
Bartlett's Test of Sphericity	Approx. Chi-Square	288.63
	df	123
	Sig.	0

Table-4.14 showing the calculation of the Need for cognition.

Table 4.14 Need for cognition calculation

Director of Project	Strongly Agree	Agree	Slightly agree	Slightly disagree	Disagree	Strongly disagree	Reverse Score	Total
ITEM								
I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.					-2		2	2
I like to have the responsibility of handling a situation that requires a lot of thinking.			1					1
I would prefer complex to simple questions					-2		2	2
I try to anticipate and avoid situations where there is likely a chance I will have to think in depth about something.					-2		2	2
I find satisfaction in deliberating hard and for long hours.					-2		2	2
Thinking is not my idea of fun.						-3	1	1
I really enjoy a task that involves coming up with new solutions to problems.		2						2
Learning new ways to think doesn't excite me very much.*					-2		2	2
I usually end up deliberating about issues even when they do not affect me personally.				1				1
It's enough for me that something gets the job done; I don't care how or why it works.*						-2	2	2
The notion of thinking abstractly is appealing to me.				1				1
I only think as hard as I have to.*						-2	2	2
I prefer my life to be filled with puzzles that I must solve.						-2	2	2
I like tasks that require little thought once I've learned them.*						-2	2	2
The idea of relying on thought to make my way to the top appeals to me.				1				1
I prefer to think about small, daily projects to long-term ones.*				1				1
I feel relief rather than satisfaction after completing a task that required a lot of mental effort.*		2						2
I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.		2						2
Score								30

Table 4.15 Respondents need for cognition scores

NO	PROFESSIONAL POSITION	NCG	Years of Experience
1	Director of project	30	30
2	Project controller	26	9
3	Project Manager	37	6
4	Planner	40	10
5	Commercial Mgr	35	20
6	Snr Planning Engr	27	8
7	Head of Project	33	6
8	Engineering Director	29	20
9	Project Manager	37	10
10	Project deliver officer	40	5
11	Project Delivery Manager	36	10
12	Building Surveyor	41	5
13	Project Planner	37	7
14	Project Manager	32	6
15	Quantity Surveyor	32	8
16	Snr Project Mgr	32	18
17	Snr Project Mgr	35	6
18	Snr Project Planner	33	5
19	LeadProject Mgr	31	25
20	Project Mgr	34	18
21	Project Mgr	35	15
22	PMO mgr	33	11
23	Project Mgr	40	5
24	Project Mgr	42	30
25	Project Engineer	50	20
26	PLANNER	26	10
27	PROJECT MGR	58	10
28	COST ENGINEER	45	8
29	PM	31	12
30	PM	38	7
31	QS	25	8
32	QS	31	8
33	PM	31	7
34	QS	31	7
35	RISK MGR	34	7
36	PLANNER	41	12
37	COMMERICAL MGR	42	6
38	COST CONTROL	23	6

39	PM	37	8
40	PROJECT COORDINATOR	25	7
41	PLANNER	33	8
42	PM	28	8
43	PROJECT ENGR MGR	34	7
44	PROJECT DIRECTOR	47	16
45	PROJECT CON ENGR	32	13
46	COMMERCIAL MGR	29	8
47	QS	32	7
48	COMMERCIAL MGR	46	8
49	PROGRAMME MGR	49	8
50	RISK MGR	32	9
51	PM	32	4
52	Project Engineer	32	7
53	Planner	43	10
54	Project Engineer	33	10
55	PMO Director	35	30
56	PROGRAMME MGR	28	16
57	Engineering Mgr	37	10
58	PMO Administrator	37	7
59	Project Manager	27	6
60	Project Manager	28	8
61	Project support officer	47	5
62	Project Manager	37	7
63	Project Enginner	37	6
64	Planning Mgr	34	11
65	Project Director	36	30
66	Project Engineer	33	8
67	Snr QS	34	9
68	Planning Mgr	34	30
69	Project Manager	35	25
70	Project Manager	35	12
71	Project Manager	37	6
72	PROGRAMME MGR	41	22
73	Senior Planning Engineer	40	9
74	Operation Mgr	33	20
75	Risk Mgr	41	9
76	Project Mgr	33	14

4.4.1 System thinking scale score and need for cognition relationship

There is need to ascertain the relationship between the system thinking scale score, need for cognition and years of experience, respectively. A correlation analysis was carried out to establish the relationship between the system thinking scale score, need for cognition and years of experience. Below is Table-4.16 showing the variables.

Table 4.16 System thinking scale score, Need for Cognition and Years of experience

NO	Professional	NCG	SYST	Years of Experience
1	Director of project	30	53	30
2	Project controller	26	62	9
3	Project Manager	37	53	6
4	Planner	40	58	10
5	Commercial Mgr	35	60	20
6	Snr Planning Engr	27	52	8
7	Head of Project	33	53	6
8	Engineering Director	29	67	20
9	Project Manager	37	65	10
10	Project deliver officer	40	63	5
11	Project Delivery Manager	36	64	10
12	Building Surveyor	41	58	5
13	Project Planner	37	58	7
14	Project Manager	32	59	6
15	Quantity Surveyor	32	52	8
16	Snr Project Mgr	32	64	18
17	Snr Project Mgr	35	68	6
18	Snr Project Planner	33	60	5
19	LeadProject Mgr	31	58	25
20	Project Mgr	34	66	18
21	Project Mgr	35	70	15
22	PMO mgr	33	58	11
23	Project Mgr	40	64	5
24	Project Mgr	42	60	30
25	Project Engineer	50	74	20
26	PLANNER	26	39	10
27	PROJECT MGR	58	40	10
28	COST ENGINEER	45	23	8
29	PM	31	35	12
30	PM	38	36	7
31	QS	25	29	8
32	QS	31	34	8
33	PM	31	32	7
34	QS	31	39	7
35	RISK MGR	34	32	7
36	PLANNER	41	34	12
37	COMMERICAL MGR	42	32	6
38	COST CONTROL	23	27	6

39	PM	37	33	8
40	PROJECT COORDINATOR	25	33	7
41	PLANNER	33	25	8
42	PM	28	39	8
43	PROJECT ENGR MGR	34	34	7
44	PROJECT DIRECTOR	47	29	16
45	PROJECT CON ENGR	32	41	13
46	COMMERCIAL MGR	29	36	8
47	QS	32	35	7
48	COMMERCIAL MGR	46	23	8
49	PROGRAMME MGR	49	40	8
50	RISK MGR	32	39	9
51	PM	32	52	4
52	Project Engineer	32	62	7
53	Planner	43	52	10
54	Project Engineer	33	55	10
55	PMO Director	35	61	30
56	PROGRAMME MGR	28	59	16
57	Engineering Mgr	37	67	10
58	PMO Administrator	37	71	7
59	Project Manager	27	12	6
60	Project Manager	28	10	8
61	Project support officer	47	60	5
62	Project Manager	37	53	7
63	Project Enginner	37	53	6
64	Planning Mgr	34	68	11
65	Project Director	36	65	30
66	Project Engineer	33	64	8
67	Snr QS	34	57	9
68	Planning Mgr	34	73	30
69	Project Manager	35	72	25
70	Project Manager	35	57	12
71	Project Manager	37	41	6
72	PROGRAMME MGR	41	45	22
73	Senior Planning Engineer	40	44	9
74	Operation Mgr	33	43	20
75	Risk Mgr	41	32	9
76	Project Mgr	33	41	14

- **Correlation analysis of the system thinking scale score, need for cognition and years of experience of infrastructure project professionals.**

The correlation analysis was performed by fitting the variables into the SPSS software and the results are depicted on Table 4.17 as follows:

Table 4.17 Correlation between system thinking scale score and need for cognition

		SYST scale score	NFC scale score
SYST scale score	Pearson Correlation	1	.735**
	Sig. (2-tailed)		0.001
	N	76	76
NFC scale score	Pearson Correlation	.735**	1
	Sig. (2-tailed)	0.001	
	N	76	76

As depicted in Table 4.18, correlation between these two variables is significant. The P-Value (0.001) is less than 0.05.

Table 4.18 Correlation between Years of Experience and System thinking scale score

		SYST scale score	Years of Experience
SYST scale score	Pearson Correlation	1	-0.014
	Sig. (2-tailed)		0.907
	N	76	76
Years of Experience	Pearson Correlation	-0.014	1
	Sig. (2-tailed)	0.907	
	N	76	76

As depicted in Table 4.18, correlation between these two variables is insignificant. The P-Value is (0.907) which is greater than 0.05.

Table 4.19 Correlation between years of experience and need for cognition

		Years of Experience	NFC scale score
Years of Experience	Pearson Correlation	1	-0.002
	Sig. (2-tailed)		0.988
	N	76	76
NFC scale score	Pearson Correlation	-0.002	1
	Sig. (2-tailed)	0.988	
	N	76	76

As depicted in Table 4.19, correlation between these two variables is insignificant. The P-Value is (0.988) which is greater than 0.05.

4.4.2 Predicting system thinking scale scores

A regression analysis model is used to produce a system thinking scale score predictive model.

Table 4.20 Model summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.735[a]	0.540	0.527	1.04937
a. Predictors: (Constant), NFC scale score, Years of Experience				

As depicted in Table-4.20, there is correlation amongst the variables which is represented on R column (0.735) and the R-square shows that it can predict more than 50% of the dependent variable (STS).

Table 4.21 Anova table of the variables

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	94.403	2	47.202	42.865	<.001[b]
	Residual	80.386	73	1.101		
	Total	174.789	75			
A. Dependent Variable: SYST scale score						
B. Predictors: (Constant), NFC scale score, Years of Experience						

The regression analysis is significant at 0.01(P-Value) as indicted on Table 4.21. This is less than 0.05.

Table 4.22 Coefficient of the variables

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-0.100	0.559		-0.179	0.859
	Years of Experience	-0.014	0.089	-0.012	-0.156	0.877
	NFC scale score	1.226	0.132	0.735	9.257	0.001

The predictor coefficient constant, need for cognition are all significant with their P-values less than 0.05. While the year of experience is insignificant as shown in Table 4.22.

Multiple regression equation, $Y = \beta_o + X_1\beta_1 + X_2\,\beta_2 + e$ ----------------------Equation (4.1)

System thinking scale score (STSS)=$-0.1+1.226X_1+ e$ --------------------------Equation (4.2)

Table 4.23 Showing the predictive STSS

No	Respondent	NCG	SYST	Years of Experience	Predictive STS
1	Director of project	30	53	30	37.98
2	Project controller	26	62	9	31.72
3	Project Manager	37	53	6	45.14
4	Planner	40	58	10	48.8
5	Commercial Mgr	35	60	20	42.7
6	Snr Planning Engr	27	52	8	32.94
7	Head of Project	33	53	6	40.26
8	Engineering Director	29	67	20	35.38
9	Project Manager	37	65	10	45.14
10	Project deliver officer	40	63	5	48.8
11	Project Delivery Manager	36	64	10	43.92
12	Building Surveyor	41	58	5	50.02
13	Project Planner	37	58	7	45.14
14	Project Manager	32	59	6	39.04
15	Quantity Surveyor	32	52	8	39.04
16	Snr Project Mgr	32	64	18	39.04
17	Snr Project Mgr	35	68	6	42.7
18	Snr Project Planner	33	60	5	40.26
19	LeadProject Mgr	31	58	25	37.82
20	Project Mgr	34	66	18	41.48
21	Project Mgr	35	70	15	42.7
22	PMO mgr	33	58	11	40.26
23	Project Mgr	40	64	5	48.8
24	Project Mgr	42	60	30	51.24
25	Project Engineer	50	74	20	61
26	PLANNER	26	39	10	31.72
27	PROJECT MGR	35	40	10	42.7
28	COST ENGINEER	45	23	8	54.9
29	PM	31	35	12	37.82
30	PM	38	36	7	46.36
31	QS	25	29	8	30.5
32	QS	31	34	8	37.82
33	PM	31	32	7	37.82
34	QS	31	39	7	37.82
35	RISK MGR	34	32	7	41.48
36	PLANNER	41	34	12	50.02
37	COMMERICAL MGR	42	32	6	51.24
38	COST CONTROL	23	27	6	28.06

39	PM	37	33	8	45.14
40	PROJECT COORDINATOR	25	33	7	30.5
41	PLANNER	33	25	8	40.26
42	PM	28	39	8	34.16
43	PROJECT ENGR MGR	34	34	7	41.48
44	PROJECT DIRECTOR	47	29	16	57.34
45	PROJECT CON ENGR	32	41	13	39.04
46	COMMERCIAL MGR	29	36	8	35.38
47	QS	32	35	7	39.04
48	COMMERCIAL MGR	46	23	8	56.12
49	PROGRAMME MGR	49	40	8	59.78
50	RISK MGR	32	39	9	39.04
51	PM	32	52	4	39.04
52	Project Engineer	32	62	7	39.04
53	Planner	43	52	10	52.46
54	Project Engineer	33	55	10	40.26
55	PMO Director	35	61	30	42.7
56	PROGRAMME MGR	28	59	16	34.16
57	Engineering Mgr	37	67	10	45.14
58	PMO Administrator	37	71	7	45.14
59	Project Manager	27	12	6	32.94
60	Project Manager	28	10	8	34.16
61	Project support officer	47	60	5	57.34
62	Project Manager	37	53	7	45.14
63	Project Enginner	37	53	6	45.14
64	Planning Mgr	34	68	11	41.48
65	Project Director	36	65	30	43.92
66	Project Engineer	33	64	8	40.26
67	Snr QS	34	57	9	41.48
68	Planning Mgr	34	73	30	41.48
69	Project Manager	35	72	25	42.7
70	Project Manager	35	57	12	42.7
71	Project Manager	37	41	6	45.14
72	PROGRAMME MGR	41	45	22	50.02
73	Senior Planning Engineer	40	44	9	48.8
74	Operation Mgr	33	43	20	40.26
75	Risk Mgr	41	32	9	50.02
76	Project Mgr	33	41	14	40.26

4.5. Cost information analysis

The cost information used for this analysis were derived from 31 infrastructure project firms involved with rail projects. The cost information used are between the control period 3-9 of the UK infrastructure project programme. Control period is the Network rail control cycles are the 5-year time frames in which Network rail, the owner and operator of many of the rail networks in the United Kingdom, prepares for financial and other purposes (Transport, 2019). To correspond with the financial year, each Control period starts April-1 and ends on March-31. Due to the non-disclosure agreement, the real names of the infrastructure project cannot be revealed. They are denoted with Alphabets (Project-A, B &C etc). A constellation of statistical techniques was utilized to explore the roles of key covariates and uncertainty factors on project likelihood/magnitude of cost overrun (COR) and final cost (FC) using R'programming software (R Core Team, 2019). Data coding, categorization and standardization using Z-score was done prior to the statistical analysis. Data were fitted into the Generalized linear model (GLM) (McCullagh and Nelder,1989) and Bayesian hierarchical regression models, BHRM (Gamerma,1997) across the 31 principal projects using R 'programming software (R Core Team,2019).

Markov chain Monte Carlo (MCMC) techniques was used to obtain samples from the posterior distribution of the parameters (Green,2001). Model selection and model diagnostics were based on the Akaike Information Criterion, AIC (Akaike,1998) and the Rhat statistics (Gelman et al., 2013) as well as the visual inspection of the trace plots and autocorrelation function (ACF) plots (2001). Below are the descriptive statistics of the cost information prior to the inferential statistics.

Fig-4.16 indicates the result on the project cost information was collected from variety of initial costs of the rail infrastructure projects in the UK.

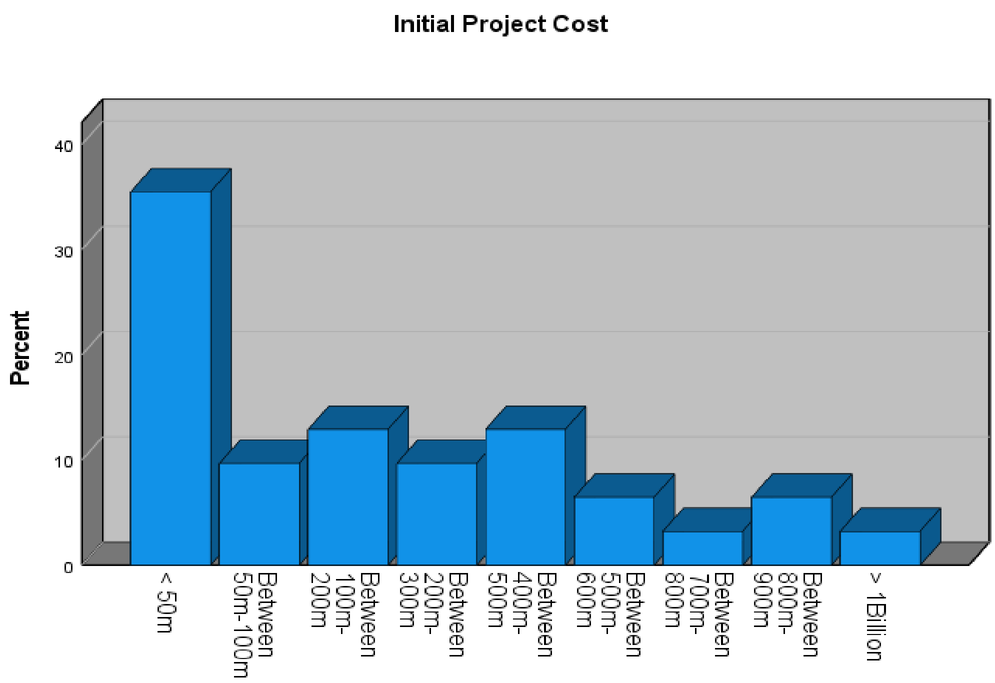


Fig-4.16 Showing initial project cost information

The average cost of the initial project cost for this analysis is £250,218,146 and the sum is £7,756,762,539.

Fig-4.17 below is graphical illustration of the project final cost percentage.

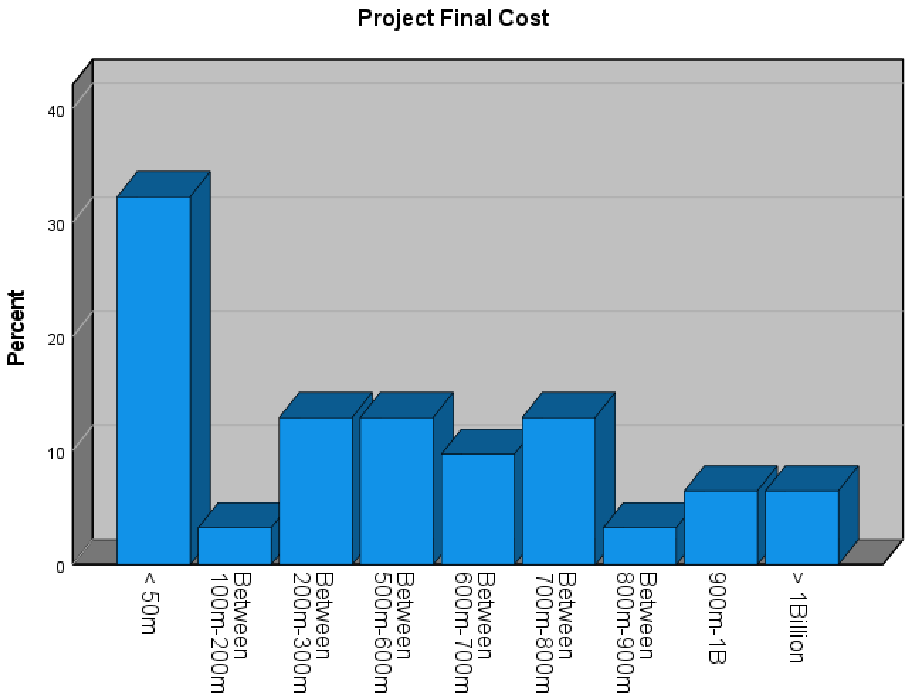


Fig 4.17 Rail infrastructure project final cost

The average cost of the final project cost for this analysis is **£487,352,275** and the sum is **£15,107,920,512.** The difference between the initial project cost and final cost £7,351,157,973 which equals the sum of cost overrun of 31 projects in the UK. Project with <£50million has the highest cost overrun while the >£I Billion project has lesser percentage.

Fig-4.18 depicts the percentage of cost overruns of the 31 rail infrastructure projects in the UK.

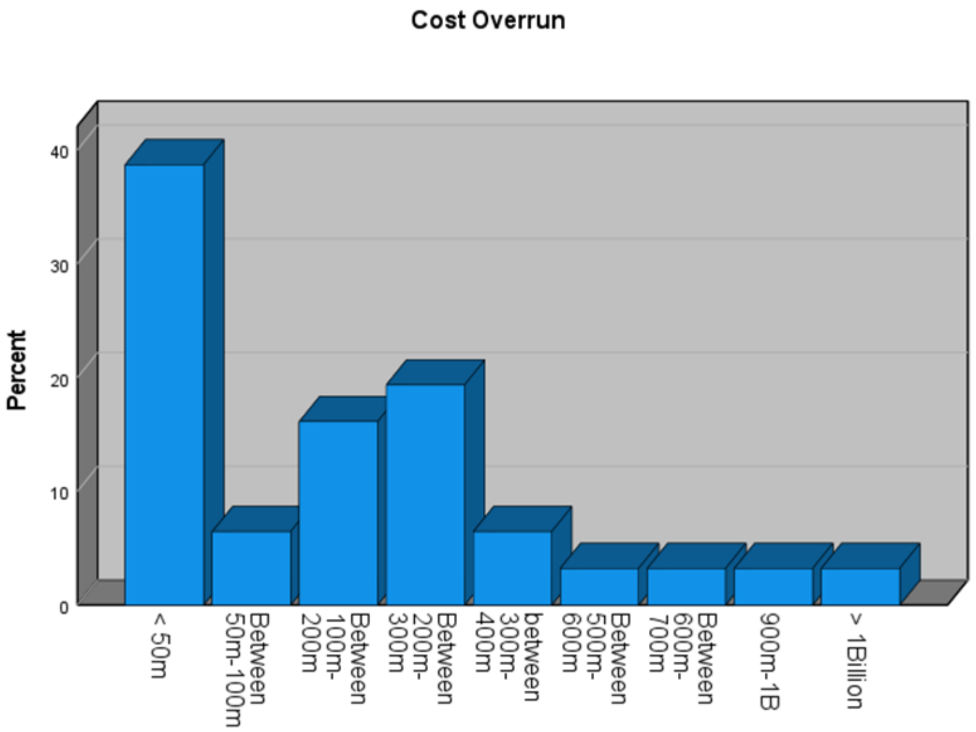


FIG 4.18 RAIL INFRASTRUCTURE PROJECT COST OVERRUN

The percentage duration of the 31 rail infrastructure projects is depicted on **Fig-4.19**.

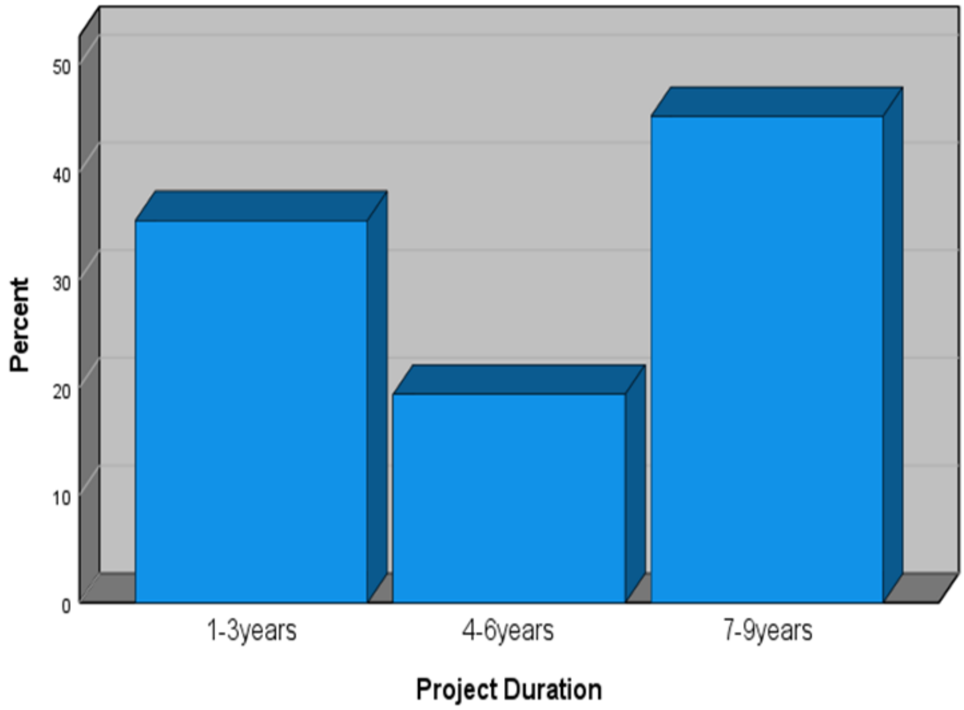


FIG 4.19 RAIL INFRASTRUCTURE PROJECT DURATION PERCENTAGE

Rail infrastructure projects with the highest duration is between 7-9years while the lowest is between 1-3years, respectively. This shows that this research has been able to take cognizance of medium to large duration projects, respectively.

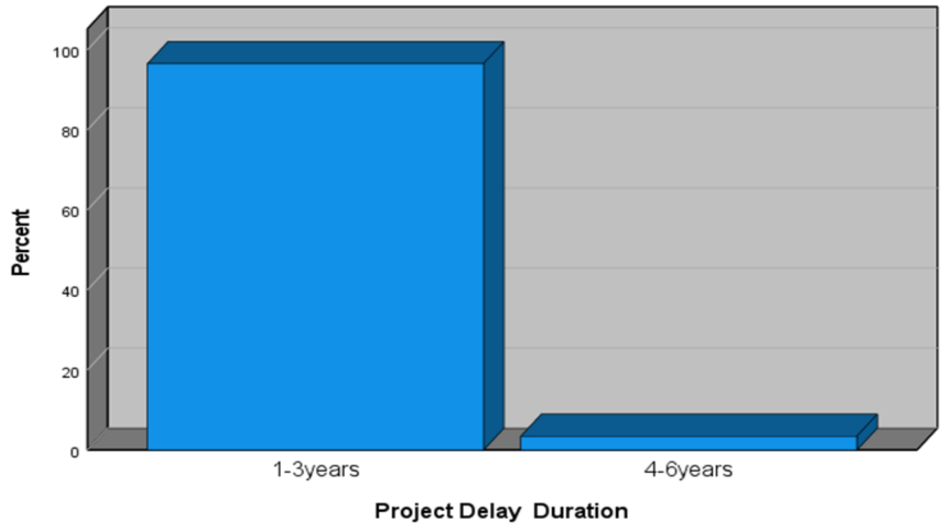


FIG-4.20 PROJECT DELAY DURATION PERCENTAGE

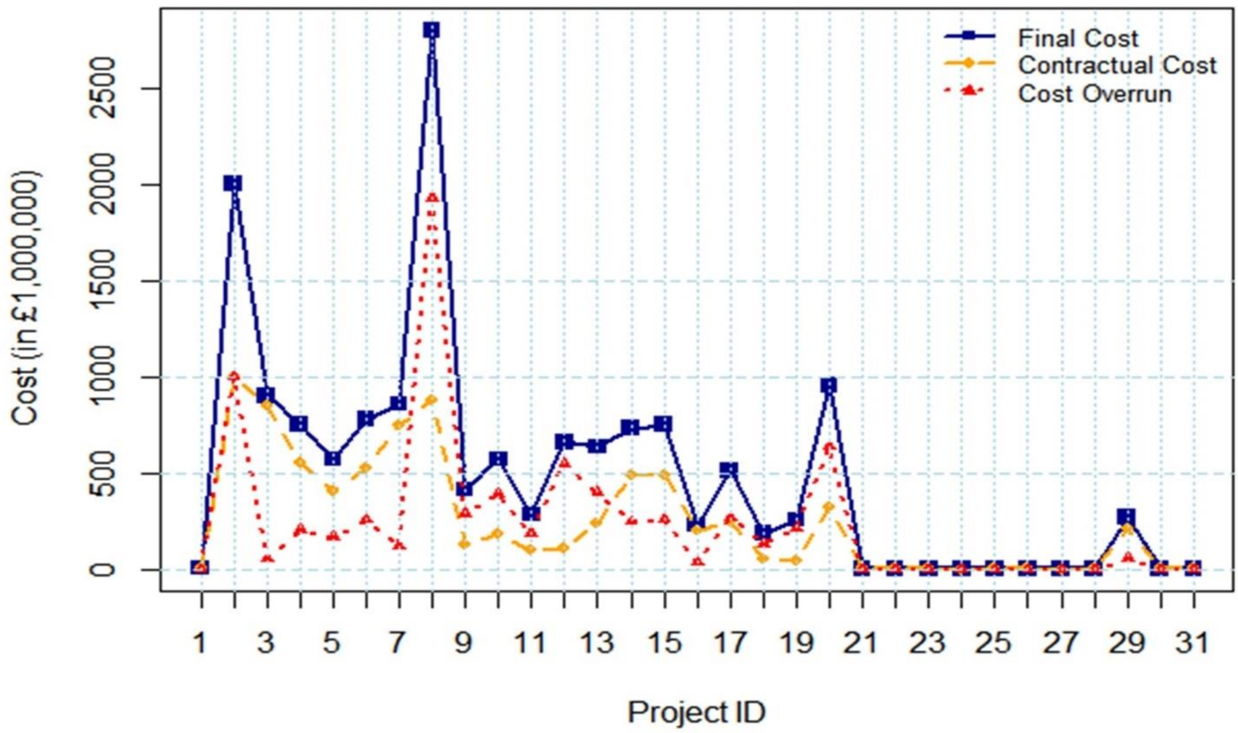


Fig 4.21 Comparative description of final cost, contractual cost and cost overrun

The Fig-4.21 shows comparative description of the collated final cost, contractual cost, and cost overrun, respectively. Data normalization was done prior to plotting of the line plot. This is to ensure that all the cost information is in common scale without distorting the differences in the ranges of values. The project-8(H) as indicated in appendices 2-J appears to be an outlier in the collated data and this was removed from the final analysis.

4.5.1 Data standardization

The project cost data of 31 rail infrastructure projects in the UK ranges from <£50million->£1Billion.Data were first checked for outliers and multicollinearity before being included in the modelling, mainly using visual inspection (boxplots, line graphs, etc). The data were normalized by dividing it by 1,000,000 to fit in accurately into the R'programming software for the statistical analysis. This assisted in eliminating outliers to generate roust results All continuous variables were standardized using the z-score to ensure meaningful easier interpretations. Specifically, the Z score is denoted with this formular below as follows: $\mathbf{Z} = \frac{(x-\mu)}{\sigma}$ (Hayes, 2021)------(Equation 4.3)

Where Z is the transformed data (that is, CC or COR) so that has a standard normal distribution or $Z \sim N(0,1)$; x are the observed data with standard deviation of σ and population mean of μ (Hayes, 2021).

. The project cost data used for the description and inferential statistics are located in the appendices section 2A-2J, respectively. Below are the further inferential statistics carried out to generate the Generalised linear model and Bayesian hierarchical regression models. Two predictive models were generated from this analysis which are as follows:

I- Predicting the cost overrun of a given projects by taking cognizance of the covariates (Uncertainty factors, project duration, contractual cost). Cost overrun is the response variable.

II- Predicting final cost of a given project by taking cognizance of the covariates (Uncertainty factors, contractual cost, expected duration, duration delay).

The categorical variables (identified project uncertainty factors) were coded 1 if yes or 0 if not. Out of the 22 uncertainty factors 11 variables were excluded from the model as they returned 'NA' due to the existence of only one level of the two factors within the variable. General Linear Model (GLM) was fit to the data sets first and all non-significant covariates were removed from subsequent runs. Same modelling structures were adopted for the Bayesian model and six models generated. This was adequately examined for goodness of fit using appropriate statistical fit indices (AIC-GLM and Rhat-Bayesian Model). In total,4-chains were run simultaneously for 4000 iterations each. Convergence of the Markov Chain Monte-Carlo algorithms (MCMC) were based on Trace-plot and Rhat statistics. The MCMC algorithms implemented was within the stan framework. The total numbers of predictive models created are 12 in numbers.

These analyses are divided according to the utilized response variables which are cost overrun and final cost. Each of the predictive models has 6 analyses. Two Generalized liner model analysis with all the covariates and only significant factors. Four Bayesian hierarchical Regression model analysis with all the covariates and significant factors. The impact of project level random effects on the response variables was investigated as well. Below is the various analysis carried out for the predictive model.

4.5.2 Correlation of cost-time relationship

The relationship between actual cost, final cost, cost overrun, duration delay and expected duration in the UK construction industry is statistically examined in this section. The association and significance between cost overrun, final cost and expected duration were tested using correlation plot. The response variables utilised in this analysis are Cost overrun & Final cost of the project. The independent variables considered in this study are described in **Table-4.24.**

Table-4.24 Shows variables for the predictive model using GLM &BHRM

Variable	Description	Scale
Contact cost(CC)	Initial cost of the project	Continous
Expected duration(ED)	Initial duration of the project	Continous
Duration Delay	The difference between the expected duration and project final duration	Continous
Stakeholder issues	Uncertainty factor	Binary
Unforeseen site condition(USC)	Uncertainty factor	Binary
Weather condition (WC)	Uncertainty factor	Binary
Team formation (TF)	Uncertainty factor	Binary
Designers Omission(DO)	Uncertainty factor	Binary
Contractor Caused Delay(CCD)	Uncertainty factor	Binary
Accelerated schedules(AS)	Uncertainty factor	Binary
Construction Coordination Issues(CCI)	Uncertainty factor	Binary
Project Delivery Method	Uncertainty factor	Binary
Regulatory permitting process(RPP)	Uncertainty factor	Binary

Miscommunication between team(MBT)	**Uncertainty factor**	**Binary**
Unclear Project Requirment(UPR)	**Uncertainty factor**	**Binary**
Scope Gap(SG)	**Uncertainty factor**	**Binary**
Project Complexity	**Uncertainty factor**	**Binary**
staff (UUIS)	**Uncertainty factor**	**Binary**
Lack of thoroughness of preconstruction planning & estimating(LTPPE)	**Uncertainty factor**	**Binary**
Government policies(GP)	**Uncertainty factor**	**Binary**
Resource availability	**Uncertainty factor**	**Binary**
Quality Assurance(QA)	**Uncertainty factor**	**Binary**
Adaptation of advance technology(AAT)	**Uncertainty factor**	**Binary**
Socio-Economic Condition(SEC)	**Uncertainty factor**	**Binary**

Prior to the correlation plot, an outlier was identified using line plot shown in **Fig-4.21.** The final cost of Project-H (**appendices 2-J)** was dropped. The correlation plot **(Fig-4.22)** shows the relationships among the continuous variables. There was strong positive correlation between Contract cost & cost overrun and final cost & contract cost. There are two correlation plots for continuous variable excluding final cost and cost overrun, respectively. The **Fig 4.22** shows correlation plot for continuous variable excluding final cost. The **Fig 4.23** correlation plot for continuous variable excluding cost overrun. This plot was generated using R'programming software (R Core Team,2019).

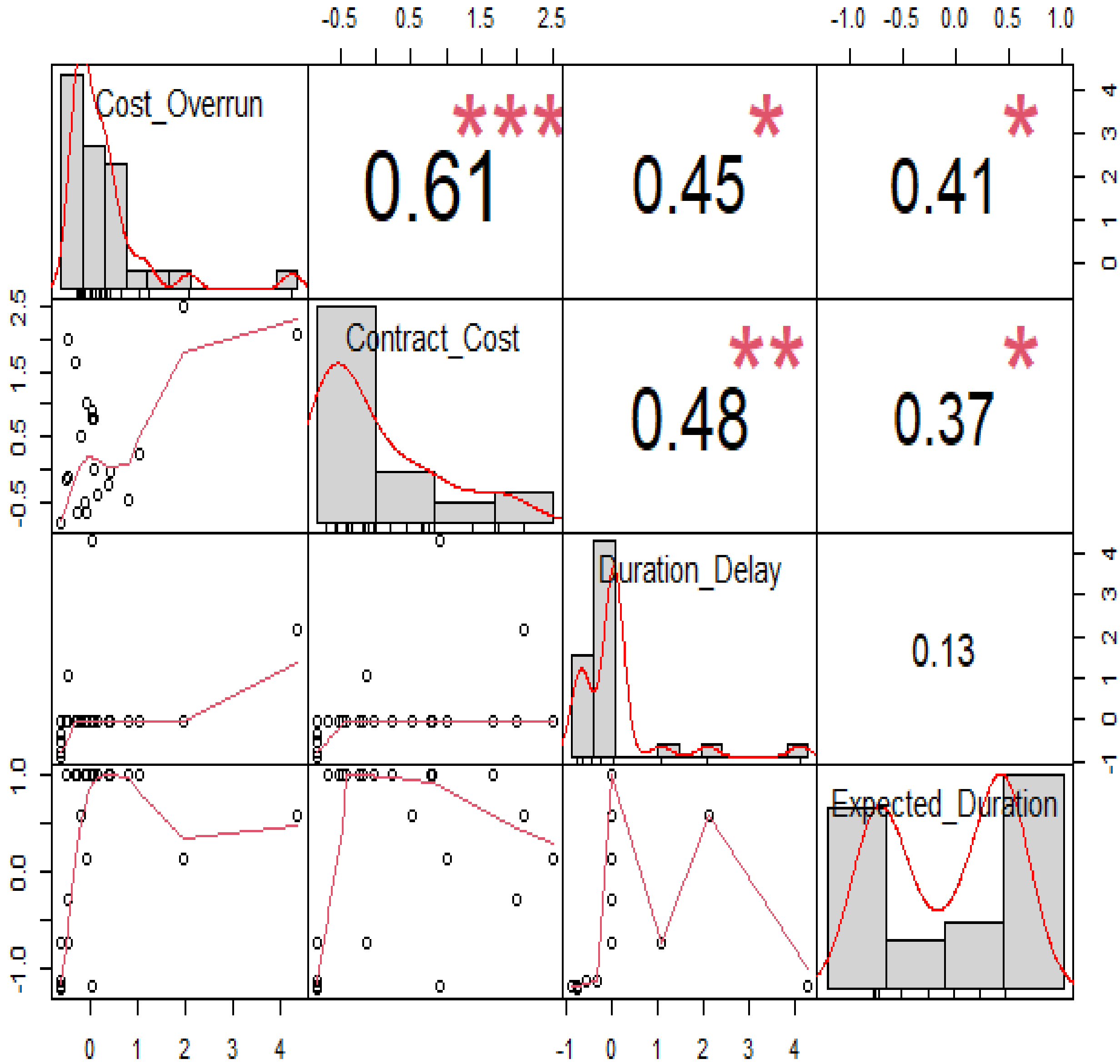


Fig-4.22 Correlation plot for continuous variable excluding final cost

The correlation plot shows a strong correlation between Cost overrun and Contract cost with a significance at 0.61. The 3 stars show that it is significant at all levels, meaning that P-Value is less than 0. 001.There is a correlation between the cost overrun and duration delay at 0.45 significance. One star shows it is significant at 10 percent level. Also, there is a correlation between cost overrun and expected duration at 0.41 significance. One star shows it is significant at 10 percent level. There is a correlation between contract cost and Duration delay.

It shows 0.48 significance at 5 percent level (2 stars indicates moderate correlation). There is 0.37 correlation between the contract cost and expected duration at 10 percent level. This correlation is weak. There is no correlation between delay duration and expected duration, respectively. The results of these correlation were used to produce predictive Generalized Linear models and Bayesian hierarchical regression models using final cost as response variable.

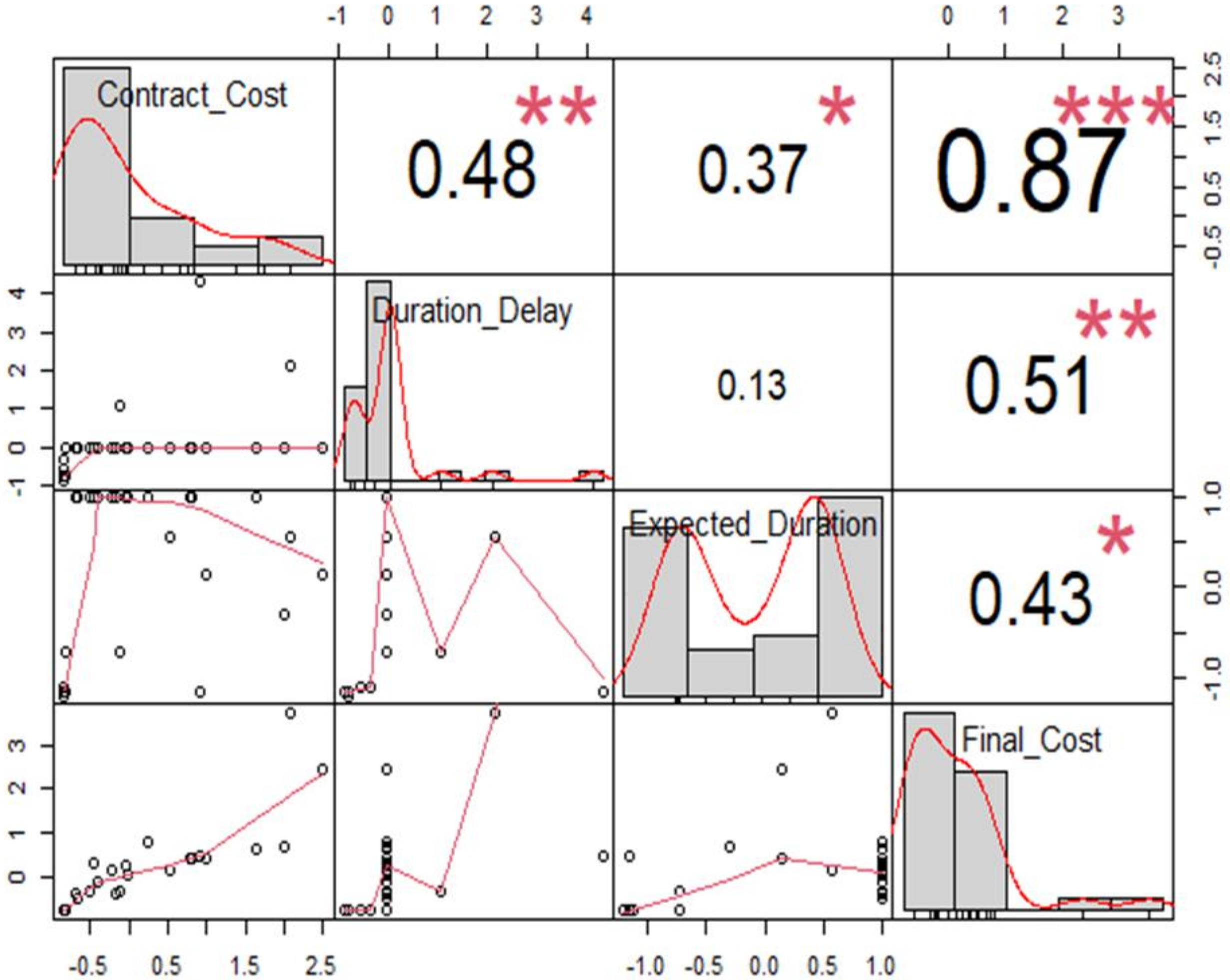


Fig 4.23 Correlation plot of continuous variables excluding cost overruns.

As shown in Fig 4.23 there is correlation between the final cost and contract cost. It is significant 0.87***. The 3 stars indicate it is significant at all levels. The final cost and duration delay is significant at 0.51**. The 2 stars indicate it is significant at 5% level. There is 0.43 significant correlation between the final cost and expected duration. One star indicate significance at 10% level. These results were used for the predictive model's production using GLM and BHRM, respectively.

4.5.3 Generalized linear model (GLM) of all covariates using cost overrun as response variable.

The GLM was fitted into the R Core Team (2019) and tested with all the covariates excluding the final cost. All nonsignificant covariates were removed from subsequent runs only 15 covariates functioned properly in the analysis. This is used to produce Model-1A using GLM. The result is depicted in **Table 4.25** as follows:

- **Model-1A**

Table 4.25 GLM analysis of Model-1A

Coefficient	Estimate	Std.Error	T.Value	Pr(>|t|)
Intercept	-1.1235	0.9232	-1.217	0.2424
CC	0.1926	0.136	1.416	0.1772
DD	0.3235	0.552	0.586	0.5666
ED	0.7197	0.3187	2.258	0.0393
Designer omission	0.5246	0.733	0.716	0.4852
Unforseen site construction	0.3123	0.7877	0.396	0.6973
Owner Driven Changes	0.1693	0.7169	0.236	0.8165
Contractor Caused Delay	0.3238	0.5937	0.545	0.5936
Regulatory permitting process	3.5314	3.5314	2.005	0.0633
Unclear project requirement	0.4649	0.4649	0.48	0.6378
Lack of thoroughness of preconstruction planning & estimating	0.441	0.441	0.699	0.495
Weather Condition	0.4962	0.4962	0.559	0.5846
Resources Availability	-1.3895	-1.3895	-0.409	0.0496
Quality Assurance Control	0.3821	0.3821	0.52	0.6104
Stakeholder Issues	1.0656	1.0656	2.136	0.0496
Construction Coordination issues	0.2295	0.6361	0.361	0.7233

Akaike information Criterion **(AIC)**=60.852.

Note: CC (Contract Cost), DD (Duration Delay) & ED (Expected Duration)

As depicted in Table 4.25 only Regulatory permitting process, stakeholders 'issue and resources availability are statistically significant. The Values are lesser than 0.005.

The Model IA resultant formular is depicted below as follows:

Model-1A Formular

Cost overrun = Intercept+ CC + DD + ED + DO + USC + ODC + CCD +

CCI + RPP + UPR + LOTOPPE + WC+RA+ QAC+SI-----Equation (4.4)

Other covariates are very close to be statistically significant as well. To ascertain the statistical significance a second model was tested using these covariates to generate a robust model.

- **Model-2A**

The GLM is fitted with all the covariates in Model-1A (Significant and almost significant) to generate a more robust model. Only the statistically significant covariates were inputted into Model-2. Depicted in the **Table-4.26** is the GLM analysis of the Model-2A

Table 4.26 GLM analysis of Model-2A

Coefficient	Estimate	Standard.Error	T-Value	Pr(>ItI)
Intercept	-0.46748	0.16771	-2.787	0.00980 **
Contract Cost	0.23659	0.09118	2.595	0.01535 *
Expected Duration	0.23659	0.09118	3.461	0.00187 **
Stakeholder Issues	0.7492	0.09118	2.325	0.02816 *

AIC:40.117

The generated formular for Model-2 is stated below as follows:

Cost overrun = Intercept + CC + ED + Stakeholders Issues. --------(**Equation 4.4)**

4.5.4 Bayesian hierarchical regression model of all covariates using cost overrun as response variable.

BHRM analysis is needed to account for the inherent uncertainties in the project cost estimation. Caterpillar plots were used for graphical illustration of the credible intervals of the estimates. Rhat plots were also used to show the robustness of the predictive models produced. Below are all the predictive models' analyses:

- **Model-3A**

This involves using the Bayesian Hierarchical Regression Modelling (BHRM) by inculcating the project random effects to estimate uncertainties. All the covariates (significant and non-significant) and project random effects are fitted into this analysis to produce a predictive model. Table 4.27 shows the BHRM analysis which include the project random effects.

Cost overrun = Intercept + CC + ED + DO + USC + ODC+CCD+ CCI+ UPR+LOTOPPE+WC+ RA+ QAC+S—Equation (4.5).

The functioned covariates from the BHRM analysis were used to formulate the model-3A equation shown on equation 4 above. The covariates appear to be significant at 80% confidence level interval. Some of the project random effects are significant as depicted in Fig-4.24 (Caterpillar plots).

Table 4.247 BHRM of Model 3A

Estimates:	Mean	SD	10%	50%	90%
(Intercept)	-1.2	0.8	-2.2	-1.2	0
CC	0.2	0.1	0	0.2	0.4
ED	0.7	0.3	0.3	0.7	1.1
Designer.omission	0.6	0.7	-0.3	0.6	1.4
Unforseen_site_construction	0.4	0.7	-0.4	0.4	1.3
Owner Driven Changes	0	0.7	-0.9	0	0.9
Contractor_Caused.delays	0.1	0.5	-0.5	0.1	0.8
Construction Coordination Issues	0.1	0.6	-0.7	0.1	0.9
Unclear Project Requirements	0.5	0.9	-0.6	0.5	1.7
Lack of thoroughness of Preconstruction Planning & Estimating	0.3	0.6	-0.5	0.3	1.1
Weather Condtion	0.5	0.9	-0.6	0.5	1.6
Resources Availability	0.4	1	-0.8	0.4	1.6
Quality Assurance Control	0.2	0.7	-0.7	0.2	1
Stakeholders Issues	0.9	0.5	0.3	0.9	1.5
b[(Intercept) ProjectID:1]	0	0.3	-0.4	0	0.3
b[(Intercept) ProjectID:2]	0.3	0.4	0	0.2	0.9
b[(Intercept) ProjectID:3]	0	0.3	-0.4	0	0.3
b[(Intercept) ProjectID:4]	-0.2	0.3	-0.7	-0.1	0.1
b[(Intercept) ProjectID:5]	0	0.3	-0.3	0	0.4
b[(Intercept) ProjectID:6]	0	0.3	-0.4	0	0.4
b[(Intercept) ProjectID:7]	-0.3	0.3	-0.7	-0.2	0.1
b[(Intercept) ProjectID:9]	0	0.2	-0.2	0	0.3
b[(Intercept) ProjectID:10]	0.1	0.2	-0.1	0.1	0.4
b[(Intercept) ProjectID:11]	0	0.2	-0.3	0	0.2
b[(Intercept) ProjectID:12]	0.3	0.3	-0.1	0.2	0.7
b[(Intercept) ProjectID:13]	0.1	0.2	-0.2	0.1	0.4

b[(Intercept) ProjectID:14]	-0.1	0.2	-0.4	0	0.2
b[(Intercept) ProjectID:15]	-0.1	0.2	-0.4	0	0.2
b[(Intercept) ProjectID:16]	-0.2	0.3	-0.6	-0.1	0.1
b[(Intercept) ProjectID:17]	0	0.2	-0.3	0	0.3
b[(Intercept) ProjectID:18]	-0.1	0.2	-0.4	0	0.2
b[(Intercept) ProjectID:19]	0	0.2	-0.3	0	0.3
b[(Intercept) ProjectID:20]	0.3	0.3	-0.1	0.2	0.8
b[(Intercept) ProjectID:21]	0	0.3	-0.3	0	0.4
b[(Intercept) ProjectID:22]	0	0.3	-0.3	0	0.3
b[(Intercept) ProjectID:23]	0	0.3	-0.4	0	0.4
b[(Intercept) ProjectID:24]	0	0.3	-0.3	0	0.4
b[(Intercept) ProjectID:25]	0	0.3	-0.4	0	0.3
b[(Intercept) ProjectID:26]	0	0.3	-0.3	0	0.4
b[(Intercept) ProjectID:27]	0	0.3	-0.4	0	0.3
b[(Intercept) ProjectID:28]	0	0.3	-0.4	0	0.4
b[(Intercept) ProjectID:29]	0.1	0.3	-0.3	0	0.4
b[(Intercept) ProjectID:30]	0	0.3	-0.4	0	0.4
b[(Intercept) ProjectID:31]	0	0.3	-0.4	0	0.3
sigma	0.4	0.1	0.3	0.4	0.6
Sigma[ProjectID:(Intercept),(Intercept)]	0.1	0.1	0	0.1	0.3

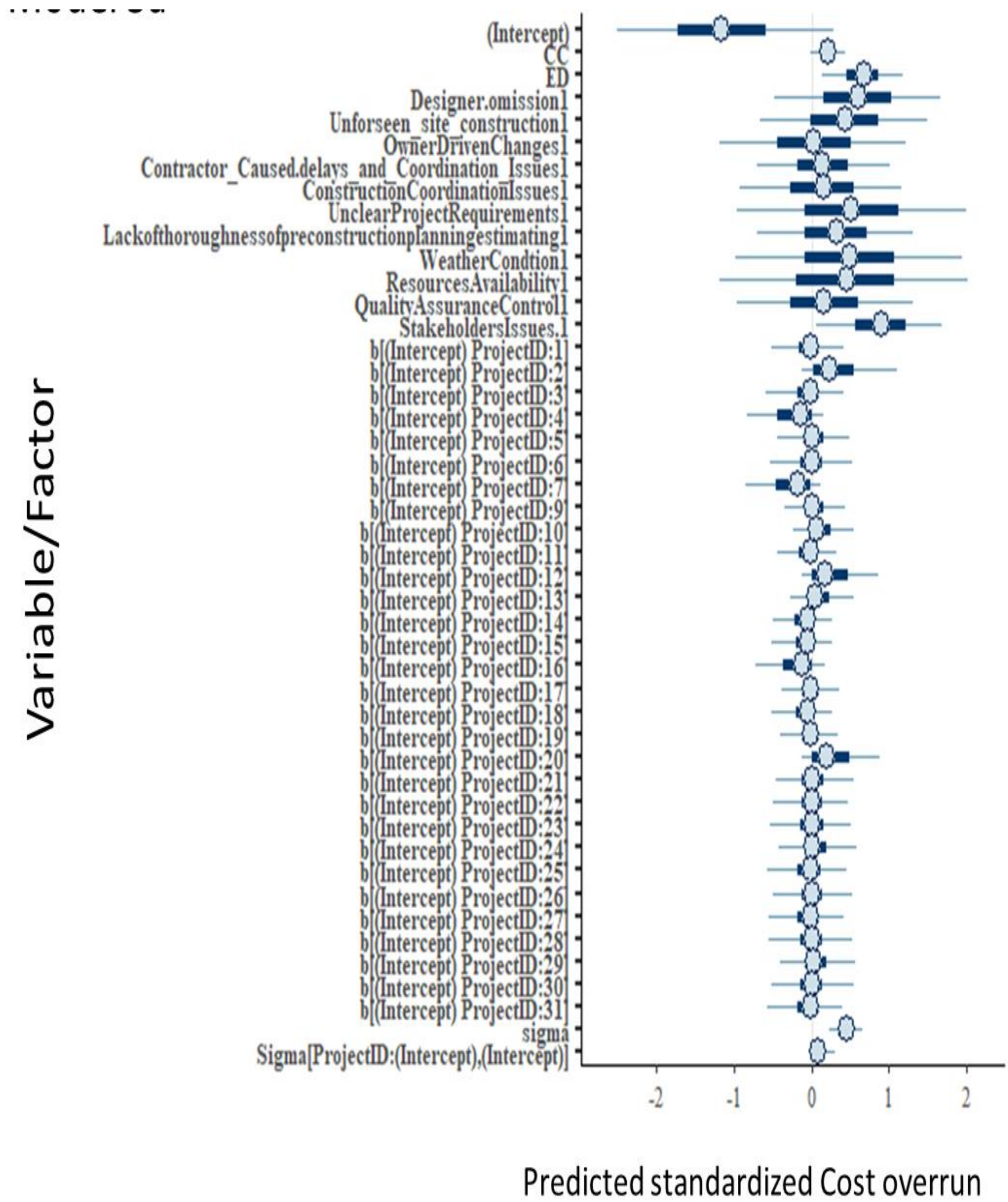


FIG 4.24 CATERPILLAR PLOT OF BHRM-3A

The Intercept is significant at 80% credible interval while CC, ED & SI are all significant at both 80% & 95% credible intervals as shown in **Fig 4.24.** The blue dots are the medians; the thick black lines are the 80% credible interval while the light blue lines are the 95% credible interval. The vertical axis contains all the estimated covariates with estimates of project level random effect balances. To ascertain the robustness of this model all the covariates including the project random effects were used to formulate the 4-model.

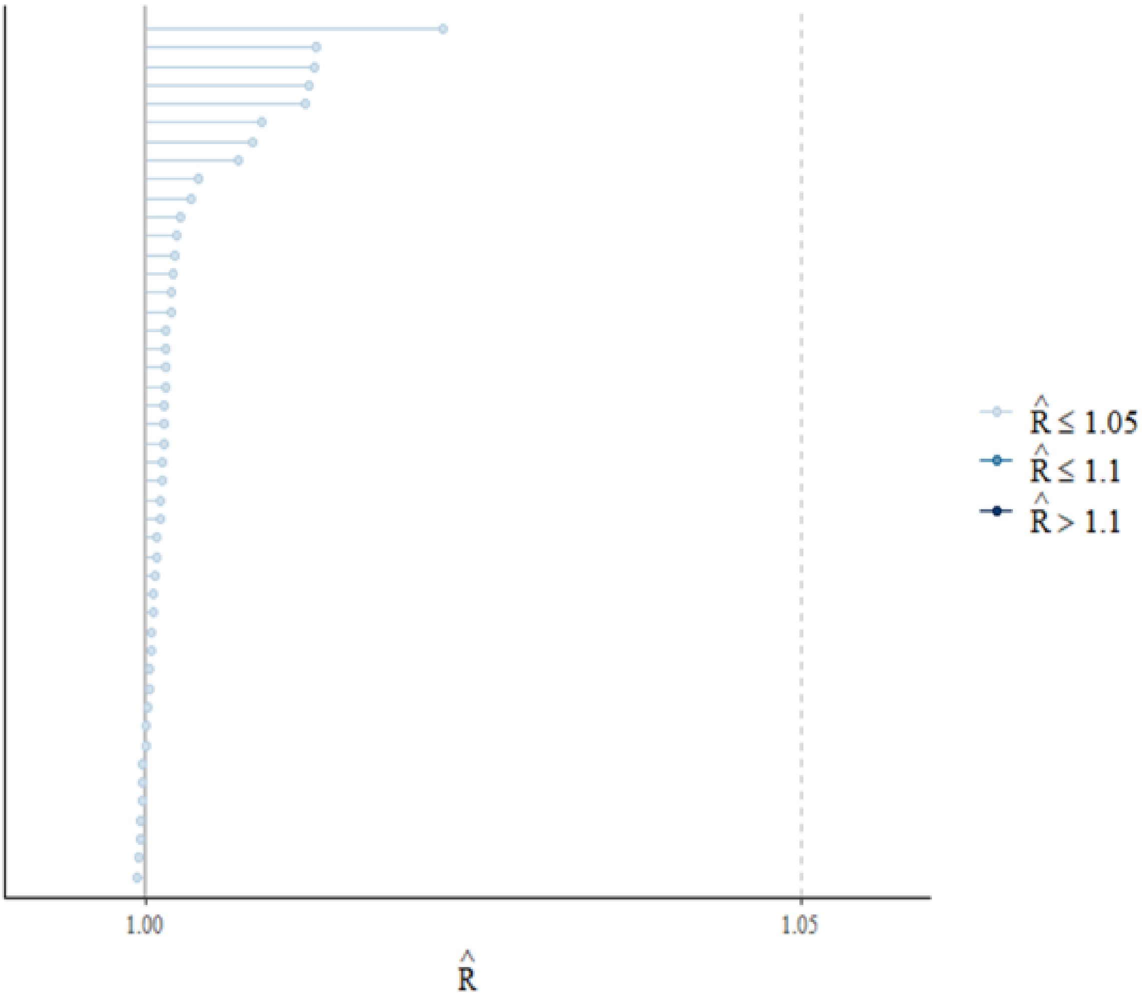


Fig 4.25 Rhat Plot of Model-3A

The Rhat plot is a convergence diagnostic which compares model parameter and other univariate quantities of interest estimates between and within chains. Rhat is greater >1 if chains are not blended well (Jiqiang et al., 2020). The above plots in Fig 4.25 indicates the MCMC chains did not perform so well for some parameters requiring further investigation.

Model 4A

The covariates from the model-3A excluding the project level random effects were fitted into the BHRM analysis to generate model 4A. Table 4.28 below shows the significant covariates of the BHRM analysis.

Table 4.28 BHRM Analysis of 4A

Estimates:	Mean	SD	10%	50%	90%
(Intercept)	-0.5	0.2	-0.7	-0.5	-0.3
CC	0.2	0.1	0.1	0.2	0.4
ED	0.6	0.2	0.4	0.6	0.8
Stakeholder issues	0.7	0.3	0.3	0.7	1.2
b[(Intercept)	-0.1	0.2	-0.3	-0.1	0.1
b[(Intercept) ProjectID:2]	0.3	0.4	0	0.3	0.9
b[(Intercept) ProjectID:3]	-0.1	0.2	-0.4	-0.1	0.1
b[(Intercept) ProjectID:4]	-0.2	0.3	-0.7	-0.2	0
b[(Intercept) ProjectID:5]	-0.1	0.2	-0.3	0	0.1
b[(Intercept) ProjectID:6]	0.1	0.2	-0.1	0	0.3
b[(Intercept) ProjectID:7]	-0.3	0.3	-0.7	-0.2	0
b[(Intercept) ProjectID:9]	0	0.2	-0.2	0	0.3
b[(Intercept) ProjectID:10]	0.1	0.2	-0.1	0.1	0.4
b[(Intercept) ProjectID:11]	0	0.2	-0.3	0	0.2
b[(Intercept) ProjectID:12]	0.3	0.3	0	0.2	0.7
b[(Intercept) ProjectID:13]	0.1	0.2	-0.1	0.1	0.4
b[(Intercept) ProjectID:14]	-0.1	0.2	-0.4	-0.1	0.1
b[(Intercept) ProjectID:15]	-0.1	0.2	-0.3	-0.1	0.1
b[(Intercept) ProjectID:16]	-0.2	0.2	-0.6	-0.1	0.1
b[(Intercept) ProjectID:17]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:18]	-0.1	0.2	-0.3	0	0.1
b[(Intercept) ProjectID:19]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:20]	0.3	0.3	0	0.2	0.8
b[(Intercept) ProjectID:21]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:22]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:23]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:24]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:25]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:26]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:27]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:28]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:29]	0.2	0.2	-0.1	0.1	0.5
b[(Intercept) ProjectID:30]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:31]	0	0.2	-0.2	0	0.2
sigma	0.3	0.1	0.2	0.4	0.5
Sigma[Project ID:(Intercept),(	0.1	0.1	0	0.1	0.2

The covariates (Intercept, CC, ED & stakeholder issues) are all significant at 80% confidence level while the project level random effects are not as shown in **Table 4.28.** To reinforce these findings caterpillar plot is used to illustrate the level of the significance. These covariates are used to generate the predictive model-4 which is stated below as equation 4.6.

Cost overrun=Intercept + CC + ED + SI-----**Equation (4.6)**

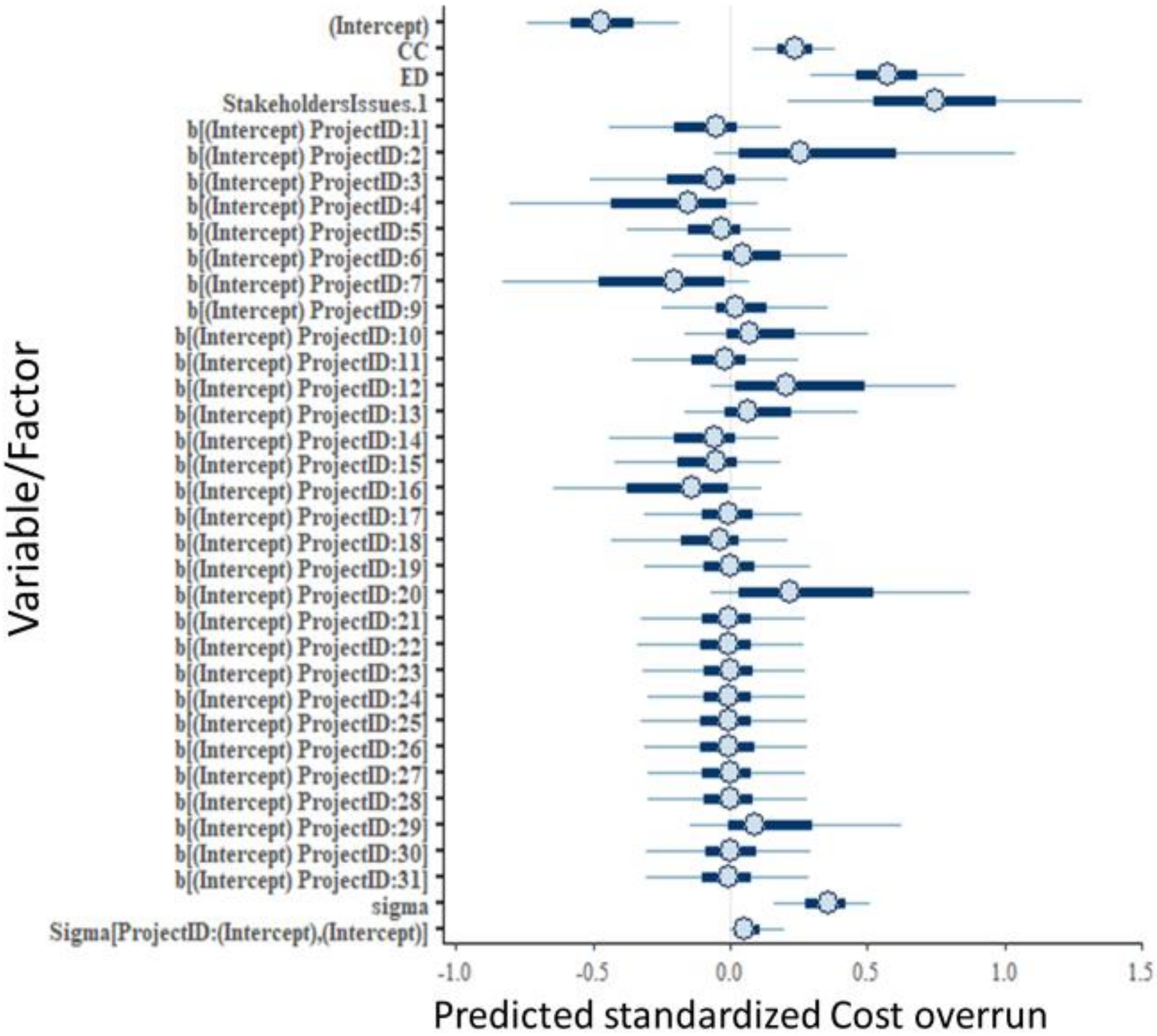


FIG 4.26 CATERPILLAR PLOT OF MODEL-4A

The intercept, contract cost, expected duration and stakeholder issues appears to be significant at 80% & 95% credible interval while the project level random effects are insignificant.

Rhat plot is used to test for the robustness of the predictive model. The **Fig 4.27** below is a Rhat Plot for Model-4

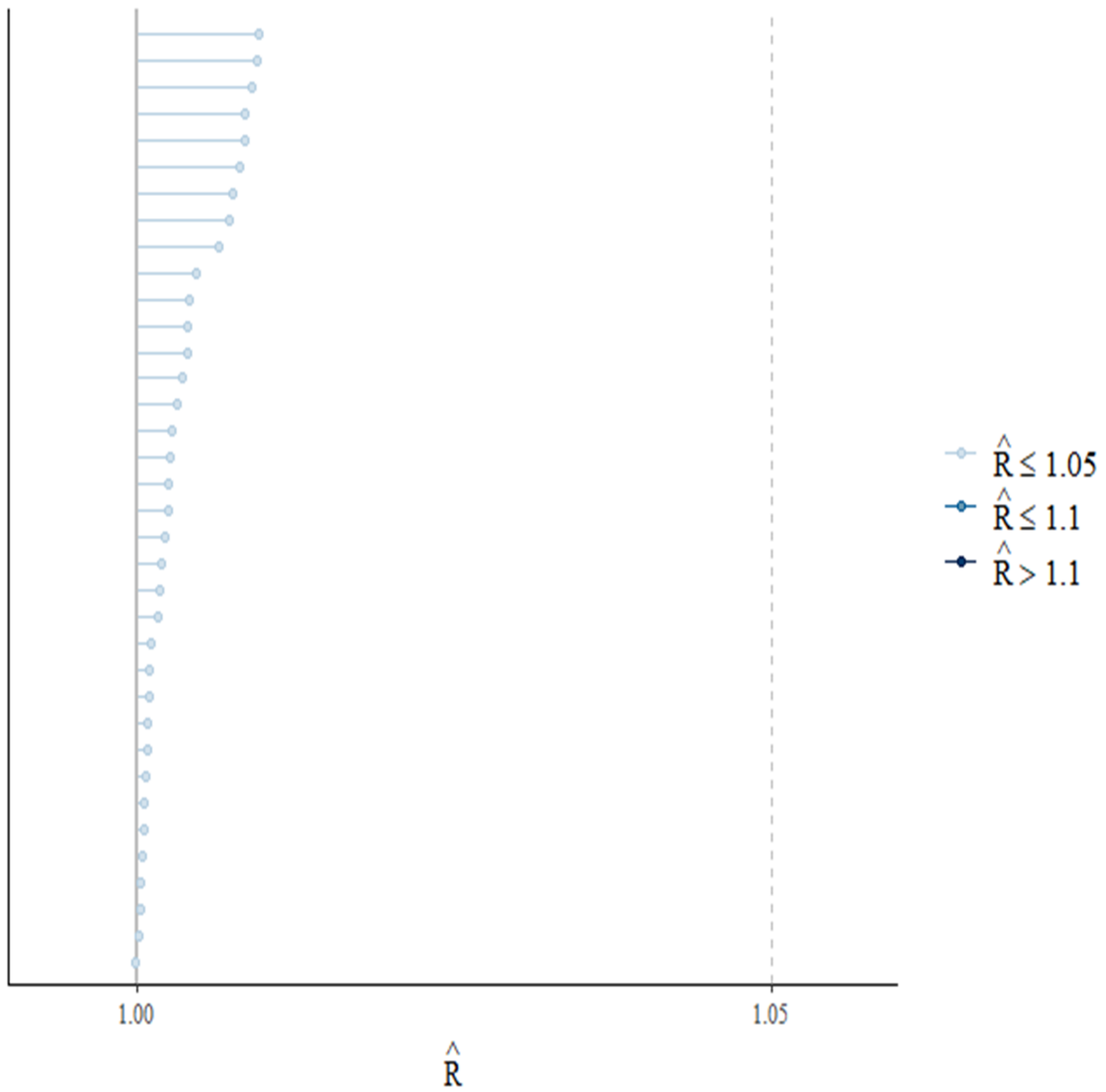


Fig 4.27 Rhat Plot for Model-4A

The Rhat is > 1 as shown on the Fig 4.27 above. The above plots indicate the MCMC chains did not perform so well for some parameters requiring further investigation.

- **Model-5A**

This model is tested with all the covariates (Significant and Non-significant variables) to produce a predictive model. Below is Table.4.29 which depicts the Bayesian Hierarchical Regression Model (BHRM) analysis.

Table 4.29 BHRM analysis of Model 5A

Estimates:	Mean	SD	10%	50%	90%
(Intercept)	-1.1	0.8	-2.1	-1.1	-0.1
CC	0.2	0.1	0	0.2	0.4
ED	0.7	0.3	0.3	0.6	1
Designer.omission	0.6	0.6	-0.3	0.6	1.4
Unforseen_site_construction	0.4	0.6	-0.4	0.4	1.2
Owner Driven Changes	0	0.7	-0.9	0	0.9
Contractor_Caused.delays	0.1	0.5	-0.5	0.1	0.8
Construction Coordination Issues	0.1	0.6	-0.7	0.2	0.9
Unclear Project Requirements	0.5	0.9	-0.6	0.5	1.6
Lack of thoroughness of Preconstruction Planning & Estimating	0.3	0.6	-0.5	0.3	1
Weather Condtion	0.4	0.9	-0.7	0.5	1.5
Resources Availability	0.4	1	-0.8	0.4	1.6
Quality Assurance Control	0.2	0.7	-0.7	0.2	1
Stakeholders Issues	0.9	0.5	0.3	0.9	1.5
sigma	0.5	0.1	0.4	0.5	0.7

Some of the covariates appears to be significant at 80% credible interval. The caterpillar plot is used to illustrate the statistical significance of the covariates. To ascertain the robustness of this predictive model another analysis is done with the same covariates. Fig 4.28 below is the caterpillar plot of Model-5.

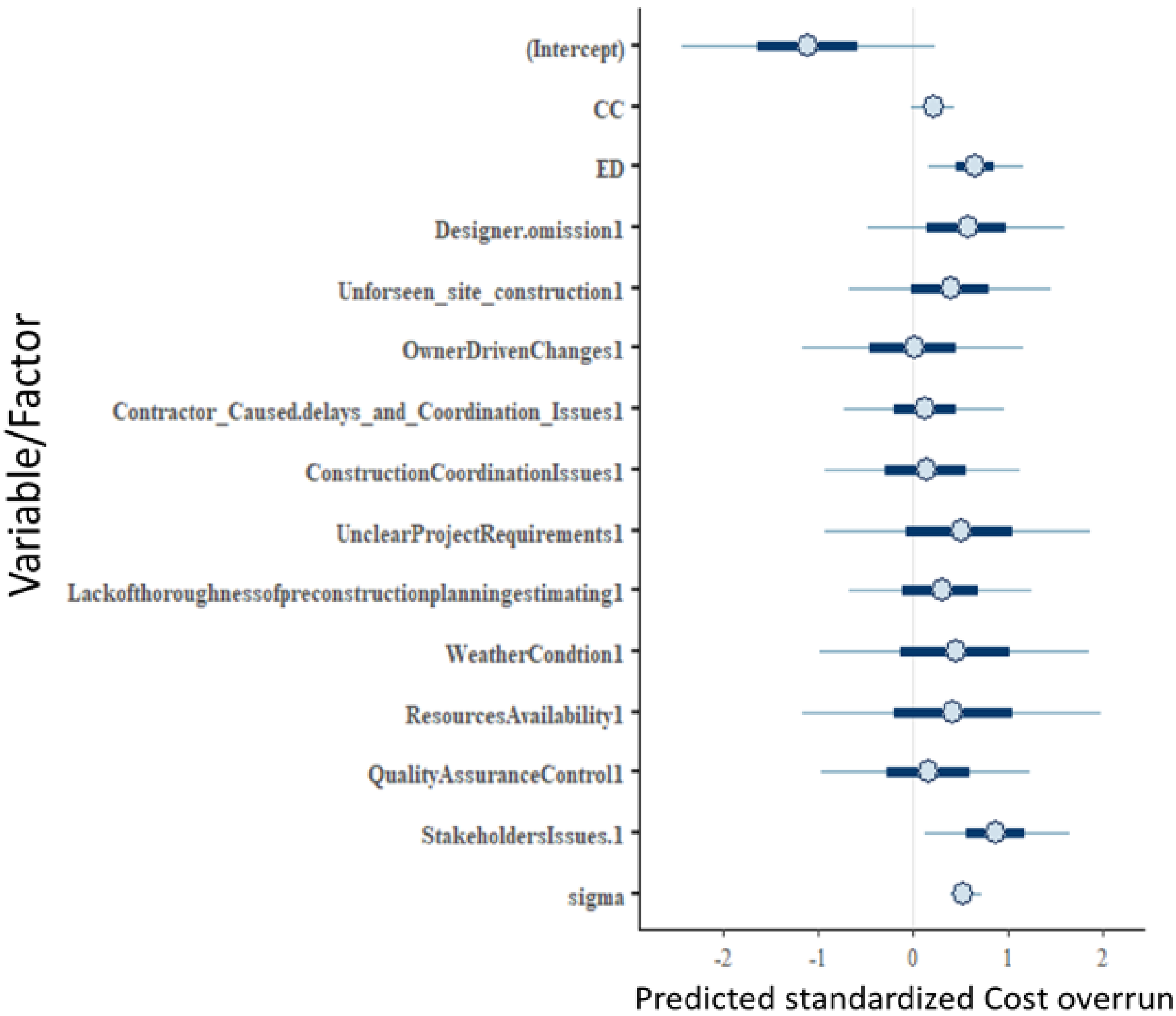


Fig-4.28 Caterpillar Plot of BHRM-5A

The intercept is significant at 80% credible interval, while the CC, ED and stakeholders are significant at both 80% & 95% confidence intervals. The project level random effects are insignificant. A Rhat is needed to ascertain the robustness of the predictive model. Fig 4.29 is the Rhat plot of the Model-5A

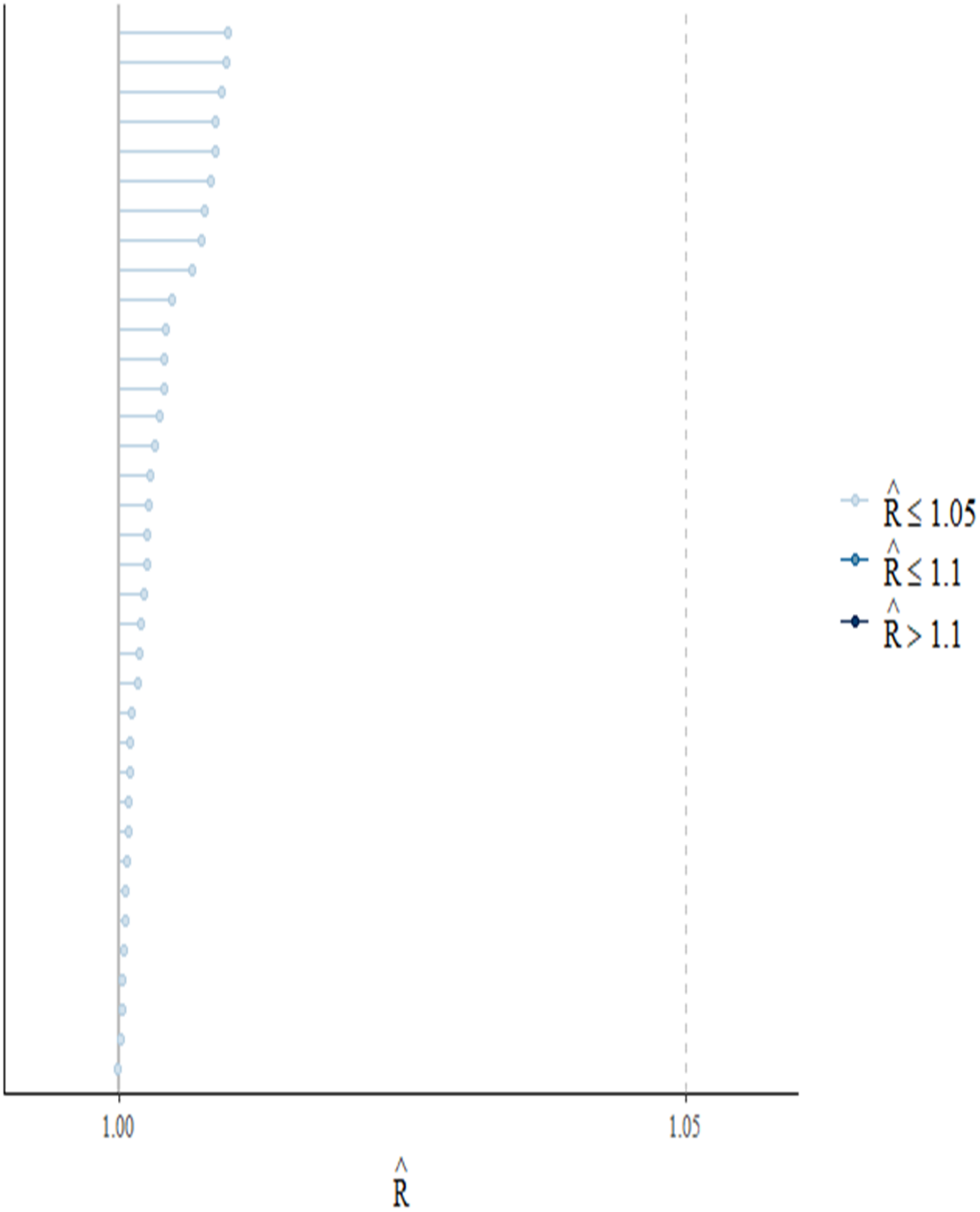


FIG 4.29 RHAT PLOT OF MODEL-5A

The Rhat is > 1 as shown on the Fig 4.29. The above plots indicate the MCMC chains did not perform so well for some parameters requiring further investigation.

The equation 6 below is derived from the BHRM analysis of Model-5A

Cost overrun =Intercept+CC+ED+DO+USC+ODC+CCD+CCI+ UPR+LOTOPPE+WC+RA +QAC+SI---Equation (**4.7)**

The significant covariates are used for further BHRM analysis to produce a robust predictive model.

Model-6A

This model is tested with all the covariates (Significant variables) to produce a predictive model. Below is Table.4.30 which depicts the Bayesian Hierarchical Regression Model (BHRM) Analysis.

Table 4.30 BHRM analysis of Model-6A

Estimates:	Mean	SD	10%	50%	90%
(Intercept)	-0.5	0.2	-0.7	-0.5	-0.2
CC	0.2	0.1	0.1	0.2	0.4
ED	0.6	0.2	0.3	0.6	0.8
StakeholdersIssues	0.7	0.3	0.3	0.7	1.2
sigma	0.4	0.1	0.4	0.4	0.5

The Intercept, CC, ED, stakeholder issues & sigma are all significant at both 10% and 90% level of confidence. The caterpillar plot was used to ascertain the significance of these covariates. Fig 4.30 is the caterpillar plot of the model-6A.

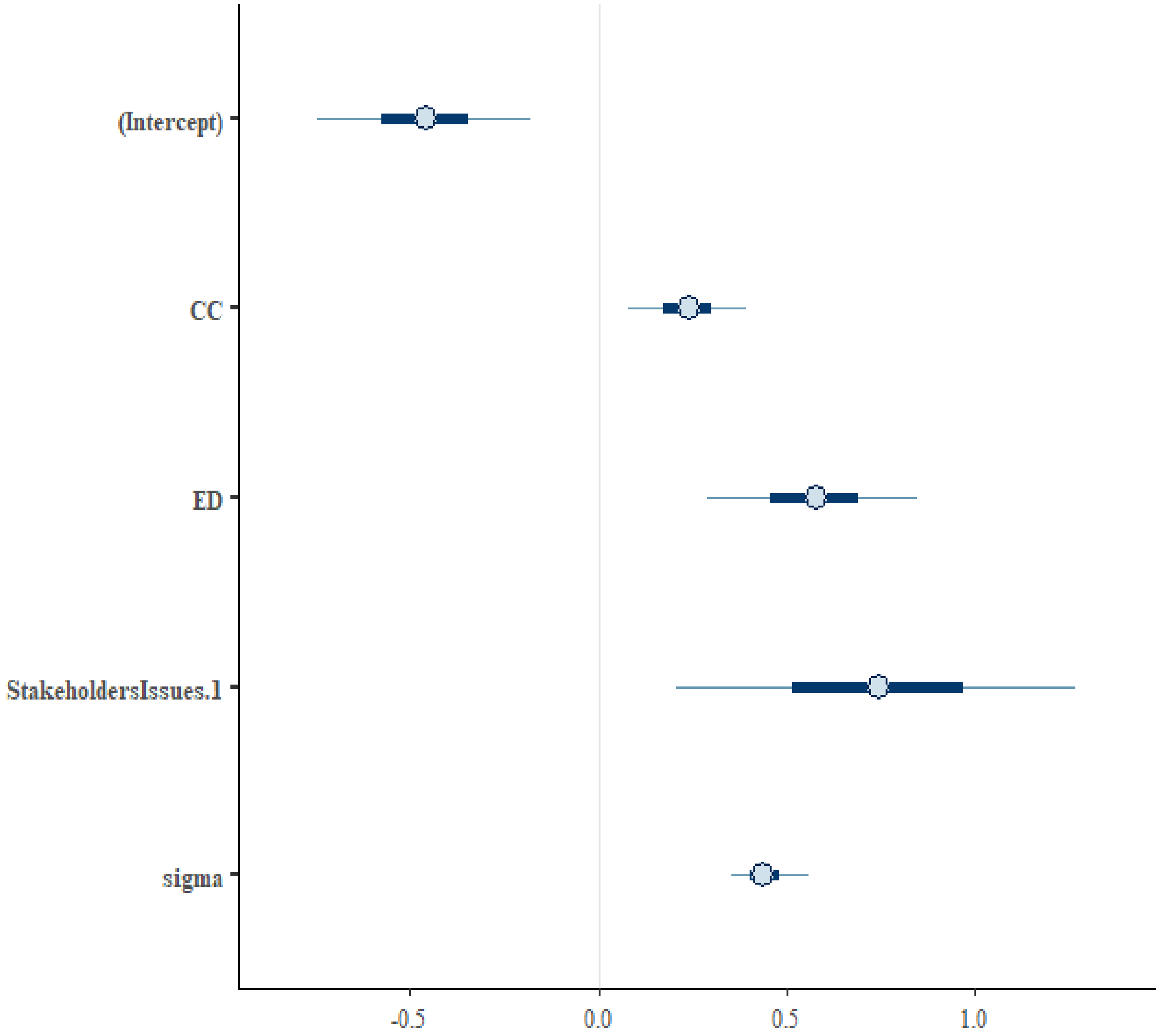


Fig 4.30 Caterpillar Plot of Model-6A

The Intercept, CC, ED & Stakeholder issues are all significant at both 80% and 95% confidence level. The Rhat plot is used to test for the robustness of the model-6A. Fig 4.31 Below is the Rhat plot of the model-6A.

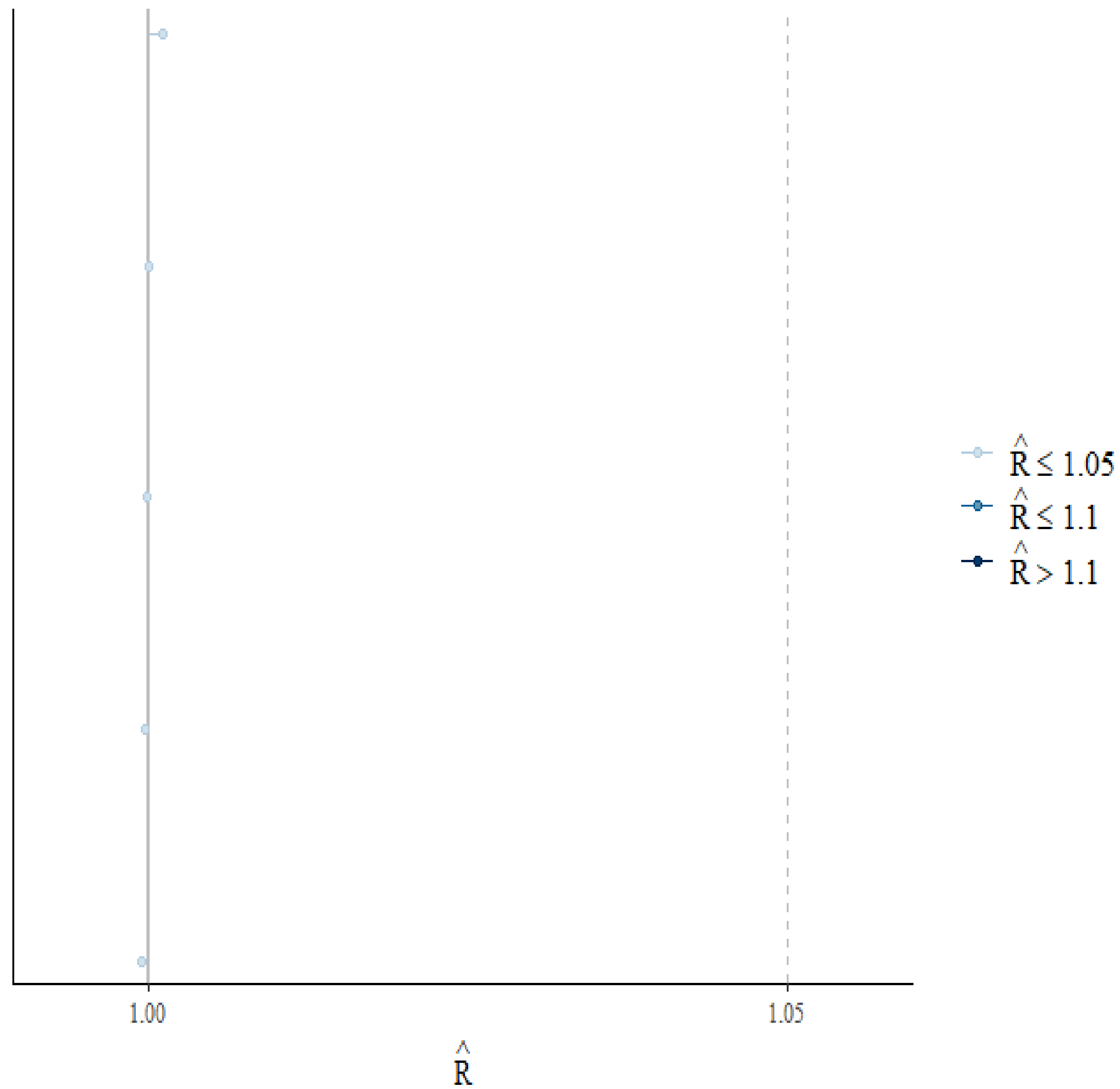


Fig 4.31 Rhat Plot of Model-6A

The Rhat =1 shown on Fig-4.31. The above plots indicate the MCMC chains did performed well with majority of the parameters. Equation 4.8 is the predictive model generated from this analysis.

Cost overrun= Intercept + CC + ED + SI…. **Equation (4.8).**

4.5.5 Generalized linear model of all covariates using final cost as response variable.

The GLM was fitted into the R Core Team (2019) and tested with all the covariates excluding the cost overrun. All nonsignificant covariates were removed from subsequent runs only 15 covariates functioned properly in the analysis. This is used to produce Model-1B using GLM. The result is depicted in **Table 4.31** below as follows:

Table 4.31 GLM analysis of Model-1B

Coefficients:	Estimate	Std. Error	T value	Pr(>|t|)
(Intercept)	-0.70586	0.57982	-1.217	0.2423
CC	0.60632	0.08544	7.096	0.00000365***
DD	0.203	0.34667	0.586	0.5669
ED	0.45202	0.20016	2.258	0.0393*
Designer.Omission	0.32969	0.46038	0.716	0.4849
Unforseen_site_construction	0.19637	0.49471	0.397	0.697
Owner Driven Changes	0.10626	0.45027	0.236	0.8166
Contractor_Caused.delays	0.20326	0.3729	0.545	0.5937
Construction Coordination Issues	0.14406	0.3995	0.361	0.7234
Unclear Project Requirements	0.29218	0.60762	0.481	0.6376
Lack of thoroughness of Preconstruction Planning Estimating	0.27723	0.39607	0.7	0.4947
Weather Condtion	0.31189	0.55776	0.559	0.5843
Resources Availability	-0.87192	2.1326	-0.409	0.6884
Quality Assurance Control	0.23988	0.46115	0.52	0.6105
Stakeholder Issues	0.6693	0.3134	2.136	0.0496*

Akaike information Criterion **(AIC)=31.063**

The contract cost, delay duration, expected duration and stakeholder issues are significant as shown in Table 4.31. The P values are lesser than 0. 005.Some of the covariates appear to be closed to being significant. Equation-8 is the predictive model produced from the GLM analysis.

Final cost = CC + DD + ED + DO +USC + ODC+CCD+CCI+ UPR + LOTOPPE+ WC+RA+QAC+SI—**Equation (4.9).**

Second GLM analysis was done to produce a robust predictive model.

- **Model-2B**

The GLM is fitted with all the covariates in Model-1(Significant and almost significant) to generate a more robust model. Only the statistically significant covariates were inputted into GLM analysis. Depicted in the **Table-4.32** below is the GLM analysis for the Model**-2B**

Table 4.32 GLM analysis of Model-2B

Coefficients:	Estimate	Std. Error	T value	Pr(>|t|)
(Intercept)	-0.29361	0.10533	-2.787	0.0098
CC	0.63392	0.05727	11.069	2.45E-11
ED	0.36159	0.10447	3.461	0.00187
Stakeholders Issues	0.47055	0.2024	2.325	0.02816

Akaike information Criterion **(AIC)=12.211**

All the covariates appear to be significant as shown on Table 4.32 and utilized for the Equation (4.10) as follows:

Final Cost = Intercept+ CC + ED + SI……. **Equation (4.10)**

4.5.6 Bayesian hierarchical regression model of all covariates using final cost as response variable

- **Model -3B**

This involves using the Bayesian Hierarchical Regression Modelling (BHRM) by inculcating the project random effects to estimate uncertainties. All the covariates (significant and non-significant) and project random effects are fitted into this analysis to produce a predictive model. All the covariates and project random effects are inculcated into the BHRM analysis. Only 15 covariates functioned effectively in the BHRM analysis. Below is **Table 4.33** showing the BHRM analysis of Model-3B

Table 4.33 BHRM analysis of Model-3B

Estimates:	Mean	SD	10%	50%	90%
(Intercept)	-0.8	0.5	-1.5	-0.8	-0.1
CC	0.6	0.1	0.5	0.6	0.7
ED	0.4	0.2	0.2	0.4	0.7
Designer.Omission	0.4	0.4	-0.1	0.4	1
Unforseen_site_construction	0.3	0.4	-0.2	0.3	0.9
Owner Driven Changes	0	0.5	-0.5	0	0.6
Contractor_Caused.delays	0.1	0.3	-0.3	0.1	0.5
Construction Coordination Issues	0.1	0.4	-0.4	0.1	0.6
Unclear Project Requirements	0.4	0.6	-0.4	0.4	1.1
Lack of thoroughness of Preconstruction • Planning & Estimating	0.2	0.4	-0.3	0.2	0.7
Weather Condtion	0.3	0.6	-0.4	0.3	1.1
Resources Availability	0.3	0.7	-0.5	0.3	1.1
Quality Assurance Control	0.1	0.5	-0.4	0.1	0.7
StakeholdersIssues.1	0.6	0.3	0.2	0.6	1
b[(Intercept) ProjectID:1]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:2]	0.2	0.2	0	0.1	0.5
b[(Intercept) ProjectID:3]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:4]	-0.1	0.2	-0.4	-0.1	0.1

b[(Intercept) ProjectID:5]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:6]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:7]	-0.1	0.2	-0.4	-0.1	0
b[(Intercept) ProjectID:9]	0	0.1	-0.1	0	0.2
b[(Intercept) ProjectID:10]	0.1	0.1	-0.1	0	0.3
b[(Intercept) ProjectID:11]	0	0.1	-0.2	0	0.1
b[(Intercept) ProjectID:12]	0.1	0.2	0	0.1	0.4
b[(Intercept) ProjectID:13]	0	0.1	-0.1	0	0.2
b[(Intercept) ProjectID:14]	0	0.1	-0.2	0	0.1
b[(Intercept) ProjectID:15]	0	0.1	-0.2	0	0.1
b[(Intercept) ProjectID:16]	-0.1	0.2	-0.3	-0.1	0.1
b[(Intercept) ProjectID:17]	0	0.1	-0.2	0	0.2
b[(Intercept) ProjectID:18]	0	0.1	-0.2	0	0.1
b[(Intercept) ProjectID:19]	0	0.1	-0.2	0	0.2
b[(Intercept) ProjectID:20]	0.1	0.2	0	0.1	0.4
b[(Intercept) ProjectID:21]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:22]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:23]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:24]	0	0.2	-0.1	0	0.2
b[(Intercept) ProjectID:25]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:26]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:27]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:28]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:29]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:30]	0	0.2	-0.2	0	0.2
b[(Intercept) ProjectID:31]	0	0.2	-0.3	0	0.2
sigma	0.3	0.1	0.2	0.3	0.4
Sigma[ProjectID:(Intercept),(Intercept)]	0	0	0	0	0.1

Equation- below was generated from BHRM analysis of Model-3B

Final Cost=CC+ED+DO+USC+ ODC+CCD+CCI+UPR+LOTOPPE+WC+RA+QAC+SI

Caterpillar plot depicted in **Fig 4.32** shows the confidence intervals of the **covariates**

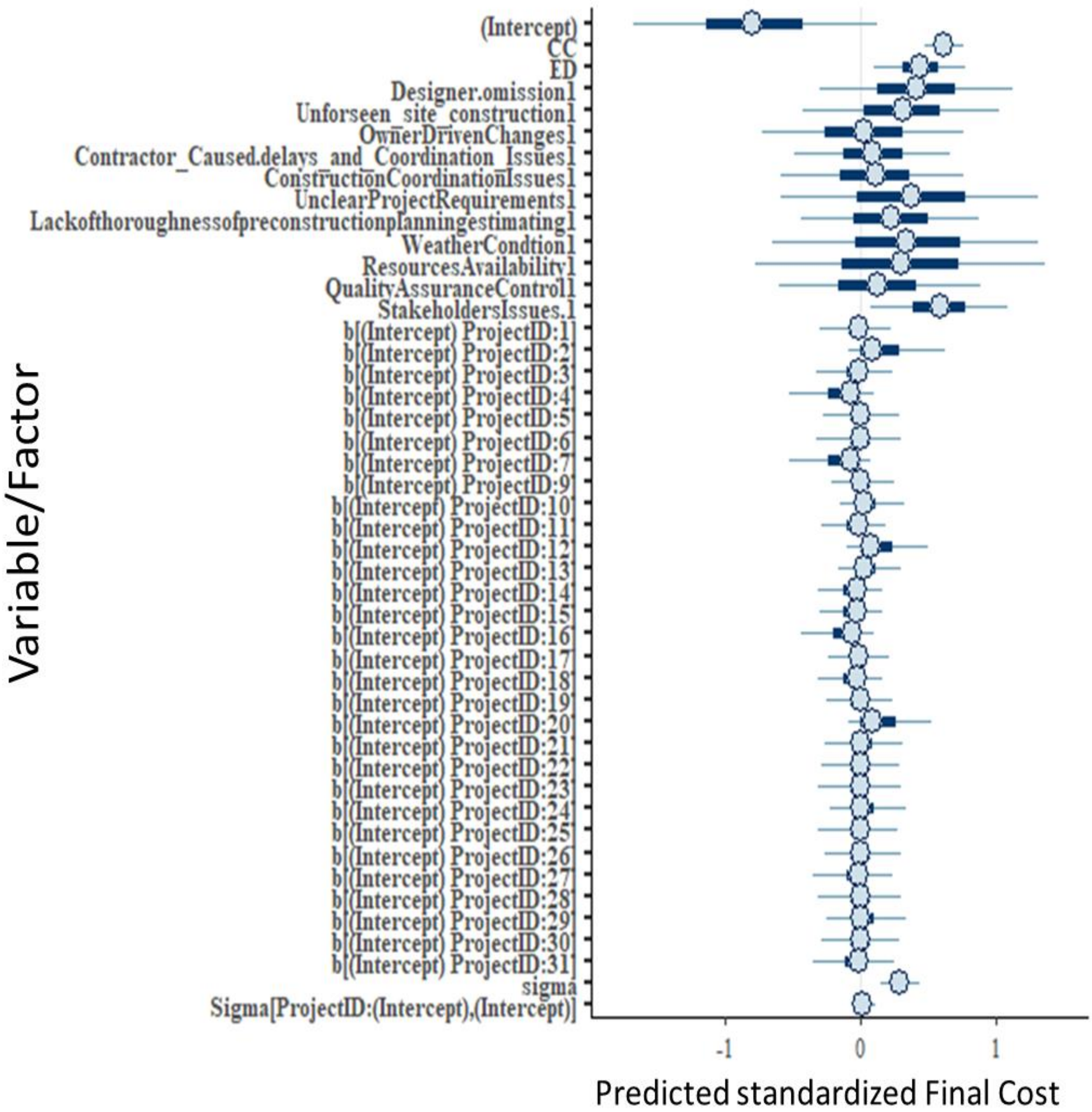


Fig 4.*32* Caterpillar Plot of Model-3B

According to **Fig-4.32** the contract cost, expected duration and stakeholder issues are significant while the intercept is significant at both 80% and 95% confidence intervals. While the project level random effects appear to be insignificant.

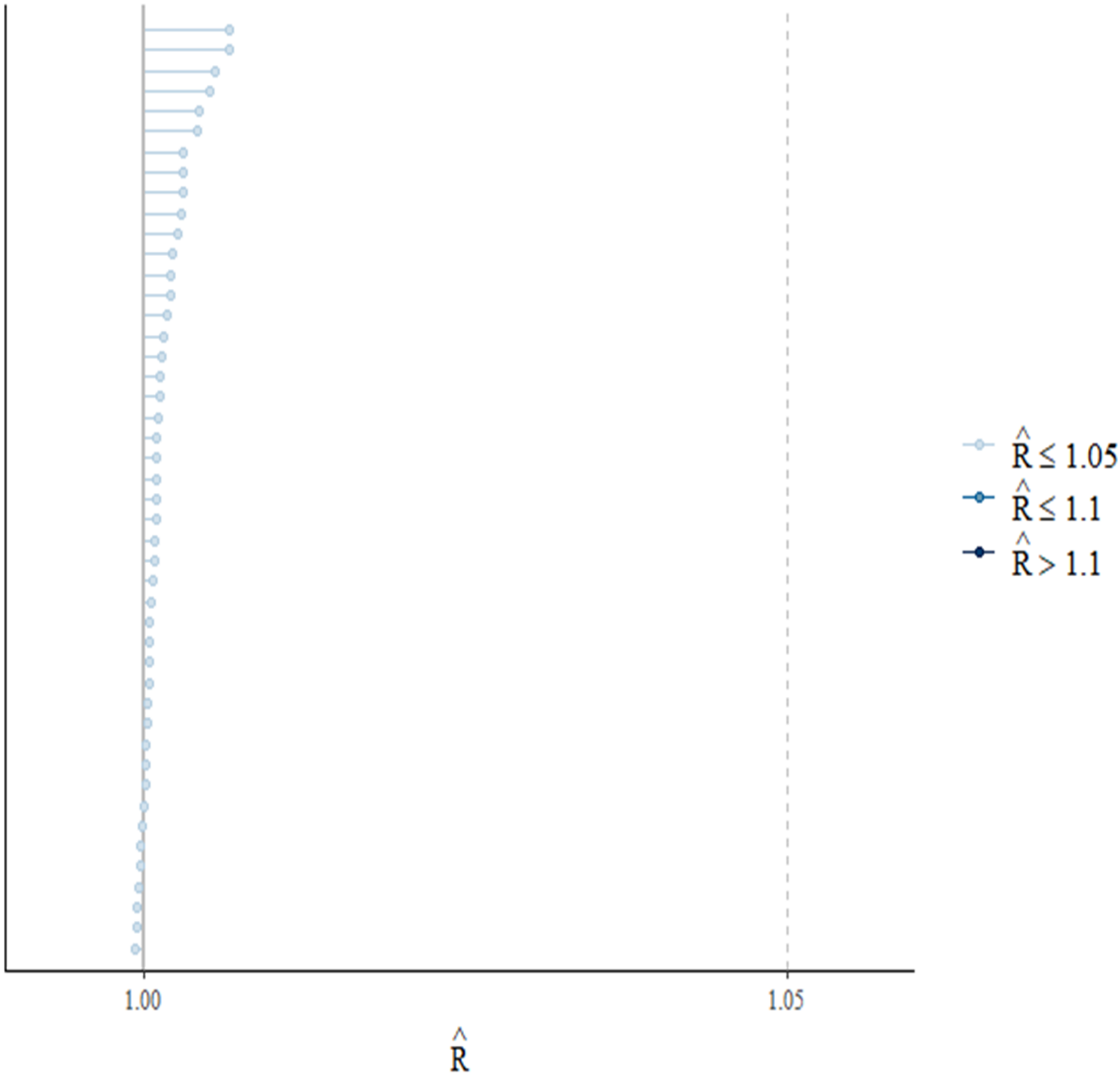


Fig 4.33 Rhat plot for Model 3B

Rhat is > 1 as shown on the Fig 4.33 above. The above plots indicate the MCMC chains did not perform so well for some parameters requiring further investigation. The significant covariates from the model-3B were used to formulate a robust BHRM Model-4B.

- **Model-4B**

The significant covariates excluding the project random effects were fitted into the BHRM analysis to generate a predictive model. Below is **Table 4.34** showing the BHRM analysis of the Model-4B. The intercept, contract cost, expected duration and stakeholder issues are all significant at 80% confidence interval. The significant covariates were used to generate predictive model. Below is equation 10 for Model-4B

FC =Intercept + CC + ED + Stakeholder Issues…………………. **Equation (4.11**).

As shown on the caterpillar plot in Fig-4.33 the intercept, contract cost, expected duration and stakeholder issues are all significant at both 80% & 95% confidence intervals. The Rhat is > 1 as shown in the Fig 4.34. The plots indicate the MCMC chains did not perform so well for some parameters requiring further investigation.

Table 4.34 BHRM analysis of Model-4B

Estimates:		Mean	SD	10%	50%	90%
(Intercept)		-0.3	0.1	-0.4	-0.3	-0.2
CC		0.6	0.1	0.6	0.6	0.7
ED		0.4	0.1	0.2	0.4	0.5
Stakeholders		0.5	0.2	0.2	0.5	0.7
b[(Intercept)	ProjectID:1]	-0.1	0.1	-0.2	0	0.1
b[(Intercept)	ProjectID:2]	0.2	0.2	0	0.1	0.6
b[(Intercept)	ProjectID:3]	-0.1	0.1	-0.3	0	0.1
b[(Intercept)	ProjectID:4]	-0.1	0.2	-0.4	-0.1	0
b[(Intercept)	ProjectID:5]	0	0.1	-0.2	0	0.1
b[(Intercept)	ProjectID:6]	0	0.1	-0.1	0	0.2
b[(Intercept)	ProjectID:7]	-0.2	0.2	-0.4	-0.1	0
b[(Intercept)	ProjectID:9]	0	0.1	-0.1	0	0.2
b[(Intercept)	ProjectID:10]	0.1	0.1	-0.1	0	0.2
b[(Intercept)	ProjectID:11]	0	0.1	-0.2	0	0.1
b[(Intercept)	ProjectID:12]	0.2	0.2	0	0.1	0.4
b[(Intercept)	ProjectID:13]	0.1	0.1	-0.1	0	0.2
b[(Intercept)	ProjectID:14]	-0.1	0.1	-0.2	0	0.1
b[(Intercept)	ProjectID:15]	0	0.1	-0.2	0	0.1
b[(Intercept)	ProjectID:16]	-0.1	0.2	-0.3	-0.1	0
b[(Intercept)	ProjectID:17]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:18]	0	0.1	-0.2	0	0.1
b[(Intercept)	ProjectID:19]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:20]	0.2	0.2	0	0.1	0.5
b[(Intercept)	ProjectID:21]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:22]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:23]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:24]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:25]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:26]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:27]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:28]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:29]	0.1	0.1	-0.1	0.1	0.3
b[(Intercept)	ProjectID:30]	0	0.1	-0.1	0	0.1
b[(Intercept)	ProjectID:31]	0	0.1	-0.1	0	0.1
sigma		0.2	0.1	0.1	0.2	0.3
Sigma[Project	ID:(Intercept),(Intercept)	0	0	0	0	0.1

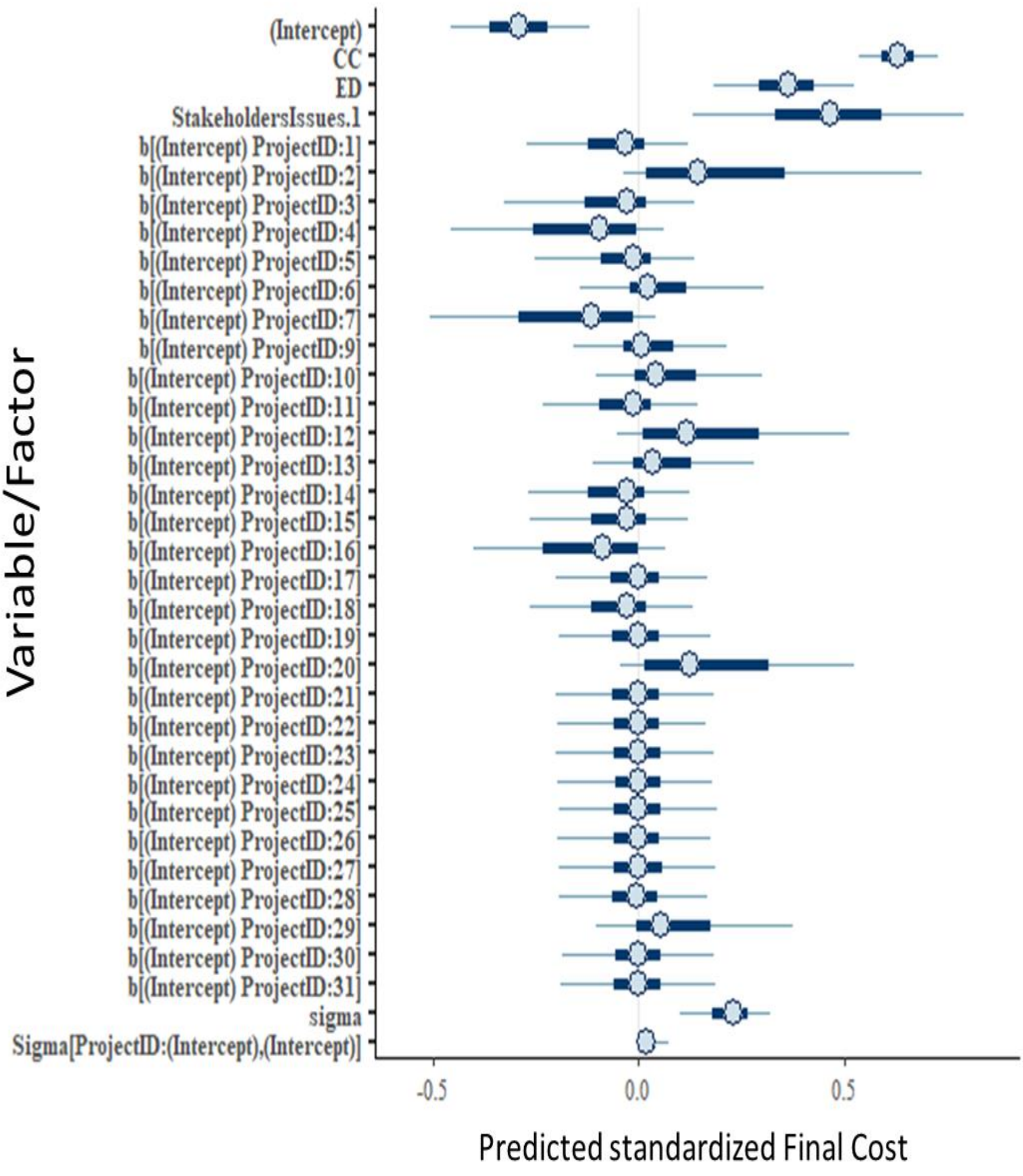


FIG 4.34 CATERPILLAR PLOT OF MODEL-4B

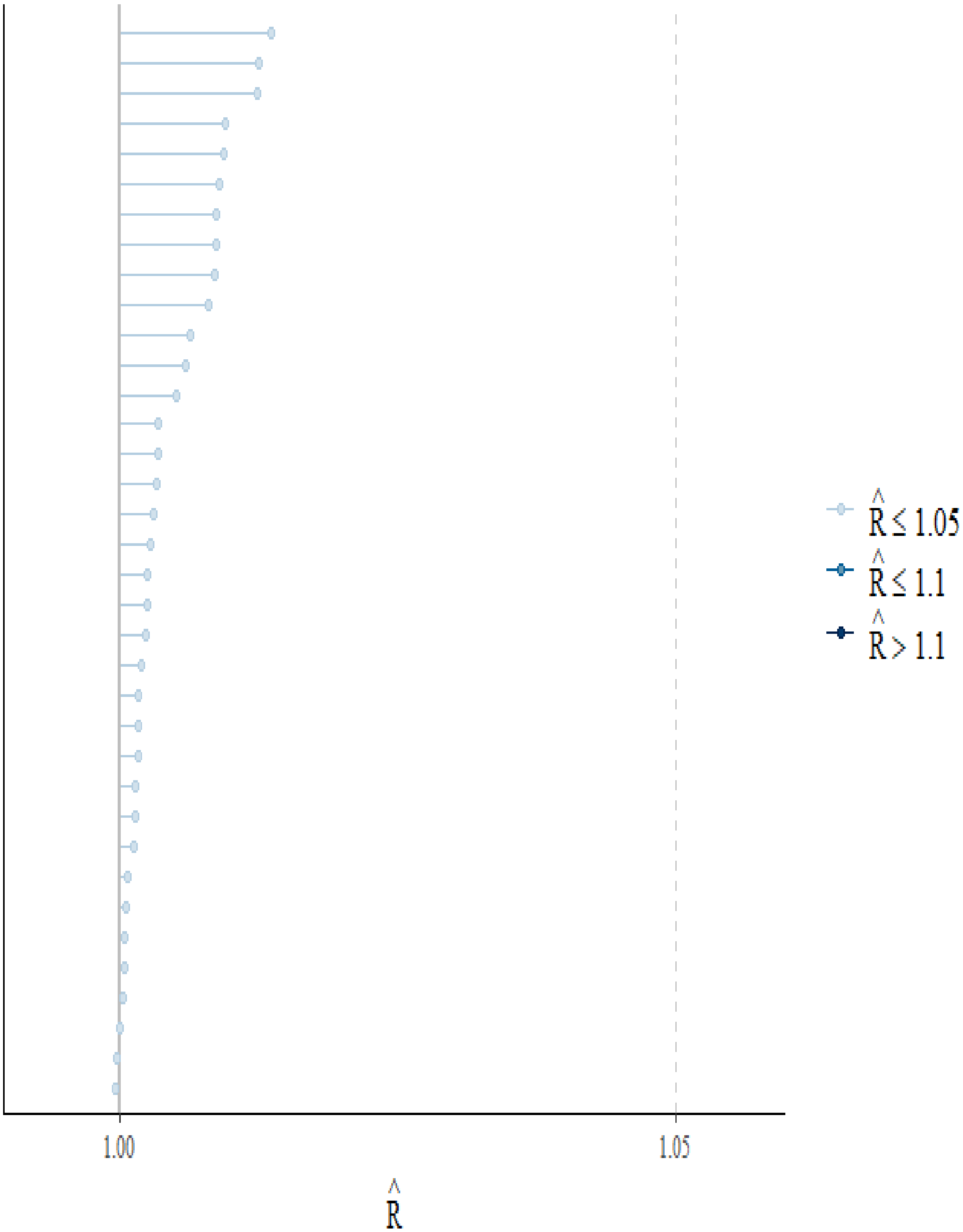


FIG 4.35 RHAT PLOT OF MODEL-4B

- **Model-5B**

All the covariates (significant and non-significant) are fitted into the BHRM analysis to produce Model-5B. Only 15 covariates functioned from the BHRM analysis which are shown on the **Table 4.35**.

Table 4.35 BHRM analysis of Model-5B

Estimates:	Mean	SD	10%	50%	90%
(Intercept)	-0.8	0.6	-1.5	-0.8	-0.1
CC	0.6	0.1	0.5	0.6	0.7
ED	0.4	0.2	0.2	0.5	0.7
Designer.omission	0.4	0.4	-0.1	0.4	1
Unforseen_site_construction	0.3	0.4	-0.2	0.3	0.9
Owner Driven Changes	0	0.5	-0.5	0	0.6
Contractor_Caused.delays	0.1	0.3	-0.3	0.1	0.5
Construction Coordination Issues	0.1	0.4	-0.4	0.1	0.7
Unclear Project Requirements	0.4	0.6	-0.4	0.4	1.1
Lack of thoroughness of preconstruction planning estimating	0.2	0.4	-0.3	0.2	0.7
Weather Condtion	0.3	0.6	-0.4	0.3	1.1
Resources Availability	0.3	0.7	-0.5	0.3	1.1
Quality Assurance Control	0.1	0.4	-0.4	0.1	0.7
Stakeholder Issues	0.6	0.3	0.2	0.6	1
sigma	0.4	0.1	0.3	0.3	0.4

The intercept, contract cost, expected duration and stakeholder issues are significant at 80% confidence interval. While the other covariates appear to be insignificant. Fig 4.36 shows the caterpillar plot of Model-5B

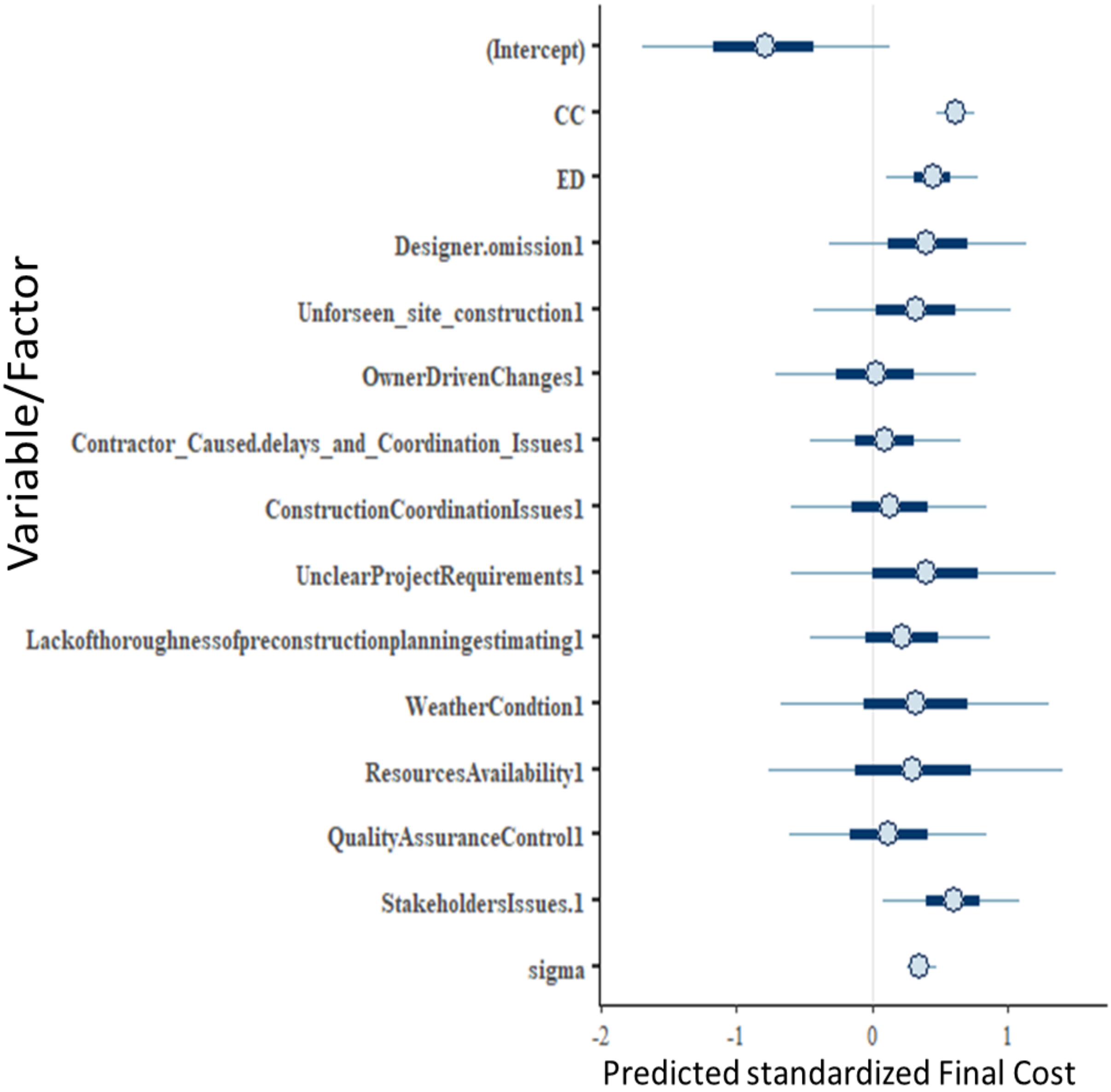


Fig 4.36 Caterpillar plot of Model-5B

The intercept appears to be significant at 80% confidence interval while the CC, ED & SI are significant at both 80% & 95% confidence levels as shown in Fig-4.36. Some of the covariates appear to be significant at 95% confidence interval. There is need to run another test to generate a robust predictive model.

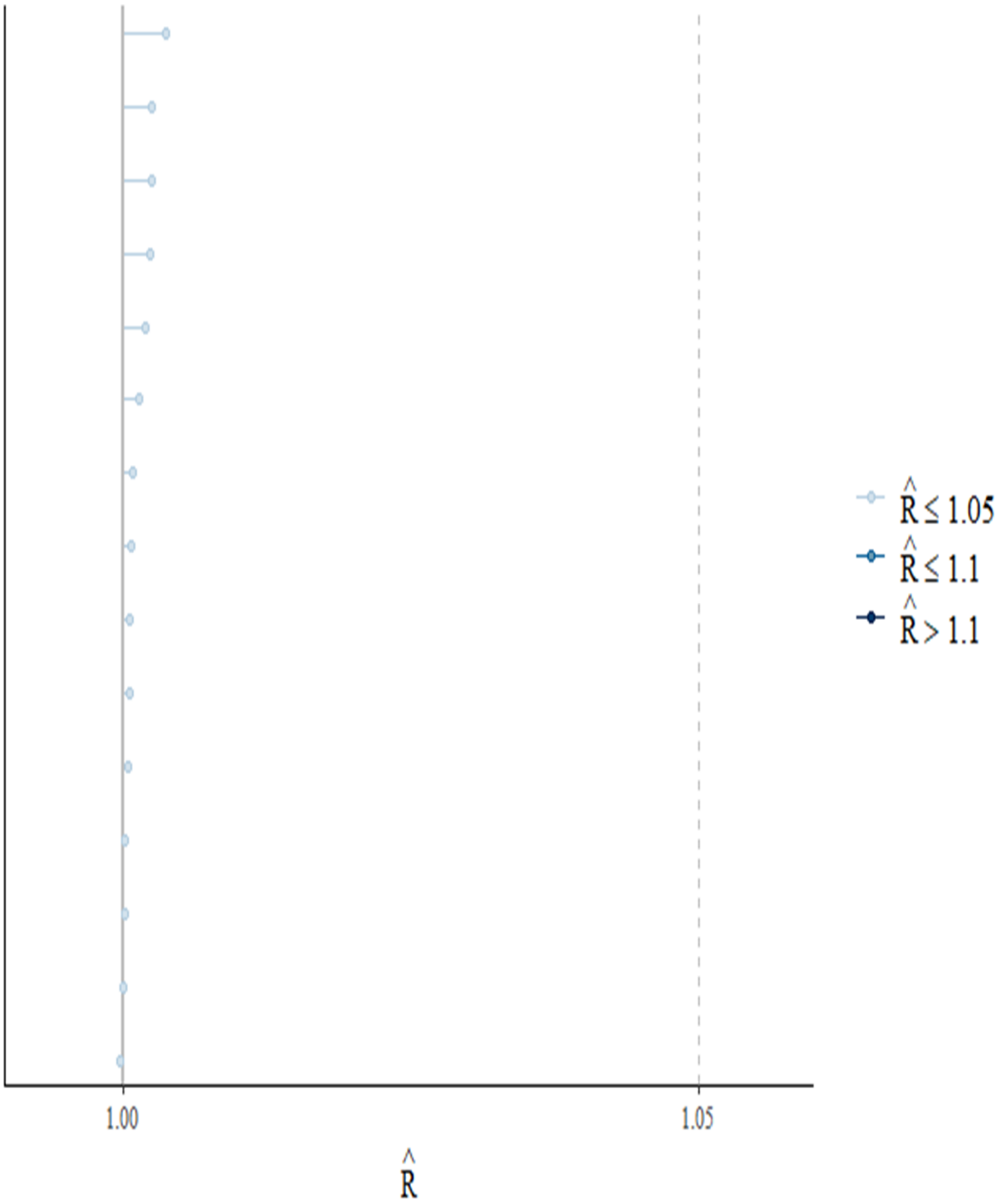


Fig 4.37 Rhat plot of Model-5B

The Rhat is > 1 as shown on the Fig 4.37 above. The plots indicate the MCMC chains did not perform so well for some parameters requiring further investigation. Below is the predictive model generated from this analysis

Final cost= Intercept +CC + ED +DO+USC+ODC+CCD+CCI+UPR+LOTOPPE+WC+RA+QAC+SI **Equation (4.12).**

Model-6B

The significant covariates from the model 5 BHRM analysis were fitted into the Model-6B BHRM analysis. Below is the Table 4.36 of the Model-6B BHRM analysis.

Table 4.36 BHRM analysis of Model-6B

Estimate	Mean	SD	10%	50%	90%
Intercept	-0.3	0.1	-0.4	-0.3	-0.2
CC	0.6	0.1	0.6	0.6	0.7
ED	0.4	0.1	0.2	0.4	0.5
SI	0.5	0.2	0.2	0.5	0.7

The intercept, CC, ED & SI are all significant at 80% confidence level, respectively. This was utilized to create a predictive model. Below is the predictive model equation generated.

FC =Intercept+ CC + ED + SI………. **Equation (4.13).**

The caterpillar plot shown below in Fig 4.38 is used to illustrate the confidence level of the covariates.

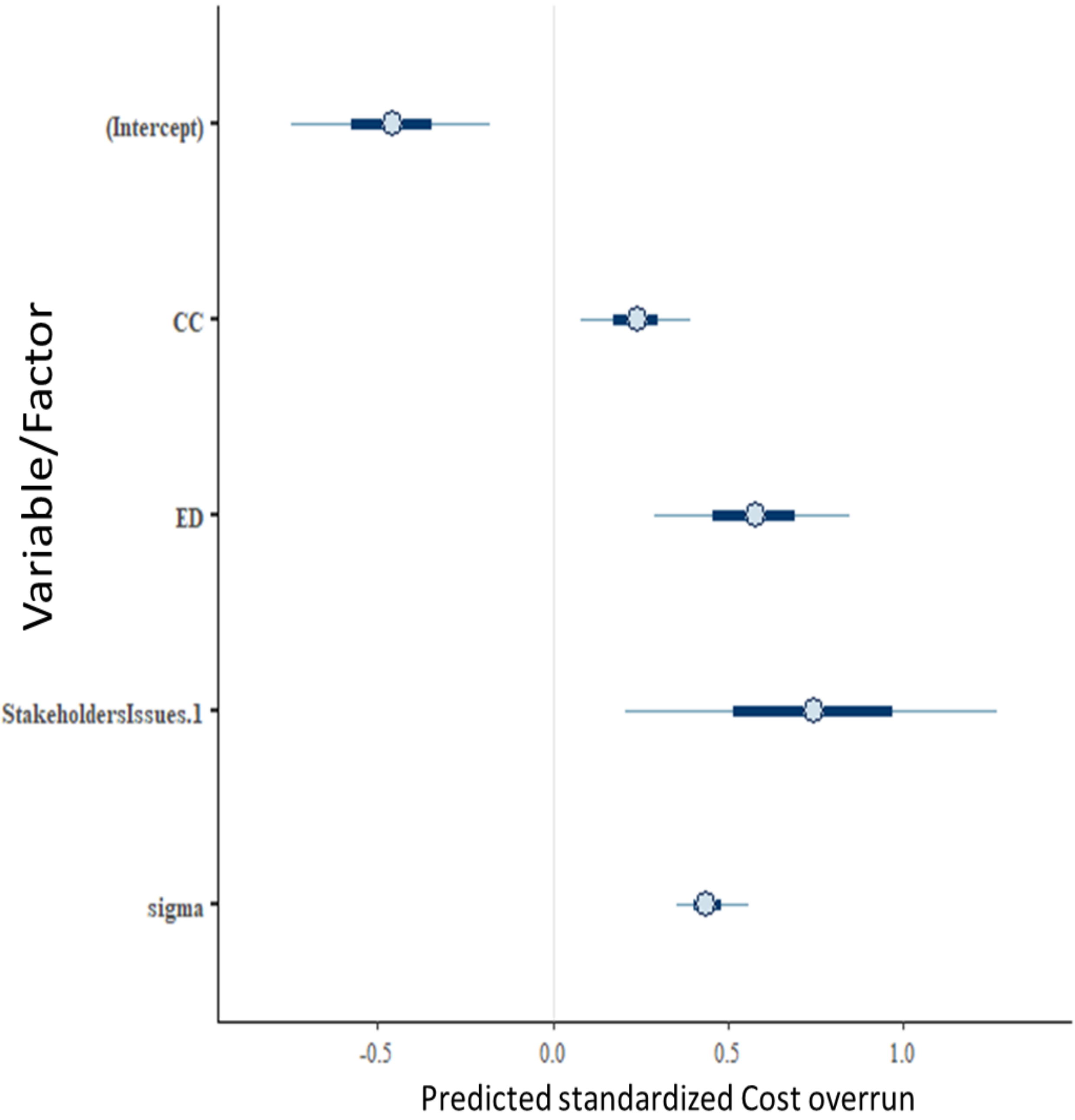


Fig 4.38 Caterpillar plot of Model-6b

The intercept, CC, ED, and SI issues are significant at 80% and 95% confidence level as shown in Fig 4.38. The robustness of the predictive model is tested using Rhat-plot.

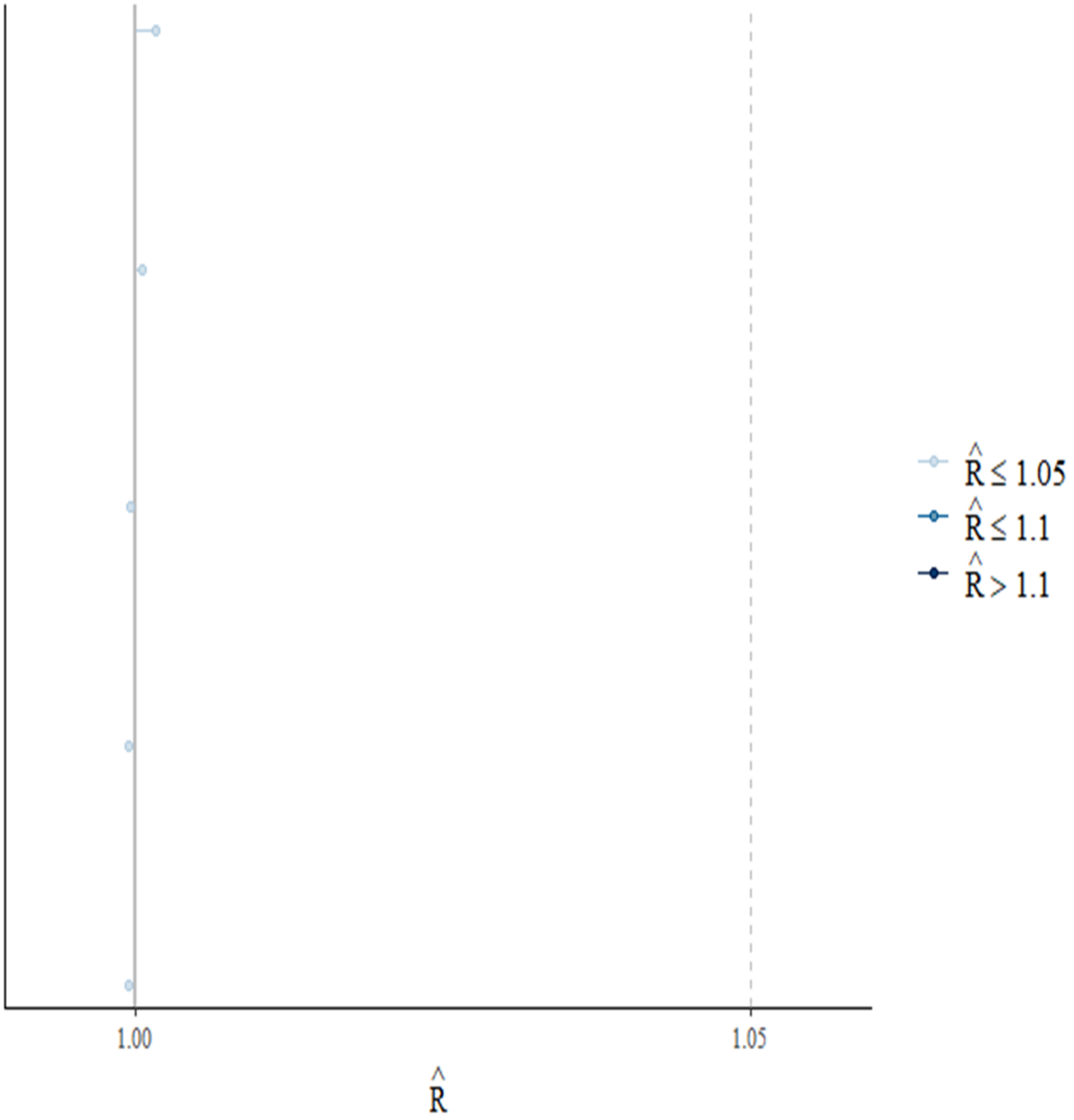


Fig 4.39 Rhat Plot of Model-6B

The Rhat =1 shown on Fig 4.39. The above plots indicate the MCMC chains did performed well with majority of the parameters. This shows a good predictive model.

4.5.7 Models predictive diagnostics

The models produced were compared with the observed response variables. Below is Table-4.37 showing the observed predictive capability of the models using cost overrun as response variable.

Table 4.37 Predictive capability of cost overrun as response variable

Observed Cost overrun	Model1A	Model2A	Model3A	Model4A	Model5A	Model6A
-0.60843721	-0.434645	-0.334995	-0.50786998	-0.3892978	-0.4850925	-0.33650969
1.96905837	1.0458722	0.9543034	1.19642948	1.1971884	0.9802336	0.9662014
-0.48299531	-0.429594	-0.164094	-0.3425295	-0.2257168	-0.2874262	-0.14975429
-0.09582894	0.7563265	0.5986808	0.51012633	0.43606235	0.6527146	0.60562261
-0.18616776	-0.301594	-0.014448	-0.23086944	-0.0514429	-0.2191405	-0.00257802
0.04613206	0.0461321	-0.176214	0.06707073	-0.1346533	0.0643675	-0.17323762
-0.3126421	0.4408725	0.5025329	0.2905141	0.28978065	0.4828061	0.51932974
0.12614645	0.0445166	0.015725	0.03763959	0.02739651	0.034469	0.02573744
0.3945818	0.0799055	0.05919	0.12121343	0.12147035	0.0744991	0.06980818
-0.13712668	0.0265004	-0.006403	-0.01740159	-0.0331126	0.01409	0.00330143
0.80497815	0.0342216	0.0030807	0.18724677	0.19638174	0.0228239	0.01291687
0.40748734	0.1172247	0.1050258	0.15510477	0.15760238	0.1167126	0.11628278
0.02290208	0.2748663	0.2986426	0.23945187	0.23355084	0.2950285	0.3125979
0.0564565	0.2787269	0.3033842	0.24170426	0.24344514	0.2993954	0.31740562

-0.52687416	0.089557	0.0710441	-0.05410231	-0.0798482	0.0854164	0.08182748
0.06936205	0.1217288	0.1105577	0.10286824	0.0983331	0.1218074	0.12189179
-0.27134436	-0.003098	-0.042755	-0.06946936	-0.0899671	-0.0193897	-0.03355773
-0.07259896	-0.006958	-0.047497	-0.03832668	-0.0565913	-0.0237566	-0.03836545
1.02179132	0.1712733	0.1714087	0.35796649	0.38047604	0.1778495	0.18359082
-0.61198763	-0.670353	-0.562386	-0.67935882	-0.5652494	-0.6463799	-0.56501906
-0.61199707	-0.680586	-0.562485	-0.58869138	-0.5676768	-0.5677647	-0.56511965
-0.61159907	-0.611599	-0.587017	-0.62655823	-0.5878489	-0.6110726	-0.58976622
-0.61172991	-0.635923	-0.58763	-0.7360534	-0.5891484	-0.716013	-0.59038721
-0.61086459	-0.552499	-0.587274	-0.57803883	-0.5911845	-0.5437797	-0.59002663
-0.6114642	-0.66983	-0.586907	-0.63670303	-0.5900756	-0.6384603	-0.58965404
-0.6115268	-0.587333	-0.587672	-0.48320066	-0.5881298	-0.4395855	-0.59042968
-0.61178339	-0.611783	-0.58665	-0.59152392	-0.5876143	-0.5802642	-0.58939362
-0.46750865	-0.491702	-0.918947	-0.61478314	-0.8317328	-0.6279189	-0.91284919
-0.61153454	-0.611535	-0.61204	-0.60720803	-0.6100896	-0.5959561	-0.61490958
-0.6120502	-0.587857	-0.587329	-0.48179574	-0.5895965	-0.4655196	-0.59008272

Below is Table 4.38 the model predictive capability of final cost as response variable

Table 4.38 Model capability of final cost as response variable

No	Observed Final Cost	Model1B	Model2B	Model3B	Model4B	Model5B	Model6B
1	-0.78308136	-0.67394732	-0.61131446	-0.72809398	-0.64411604	-0.70189083	-0.60817153
2	2.45216986	1.87235048	1.81483365	1.92106375	1.94730614	1.83968942	1.82085279
3	0.66894777	0.70246283	0.86923639	0.73110472	0.8356008	0.73367892	0.87151681
4	0.42578112	0.96098522	0.86198819	0.83217575	0.76008964	0.90558986	0.86667579
5	0.13398114	0.06150344	0.24183241	0.10078967	0.23031156	0.1255714	0.2427219
6	0.46793	0.46793	0.32830113	0.45582486	0.34393544	0.46930881	0.3330142
7	0.6008611	1.07413104	1.11283494	1.01922294	0.99483003	1.1000723	1.11468451
9	-0.1221544	-0.17342673	-0.19150463	-0.17563072	-0.17823761	-0.17860621	-0.19147779
10	0.13560225	-0.06203765	-0.07504574	-0.04461906	-0.03053285	-0.06443849	-0.07485615
11	-0.33289883	-0.23013391	-0.25079279	-0.25053101	-0.25962188	-0.23672796	-0.2508488
12	0.27826002	-0.20583083	-0.22538358	-0.13808321	-0.10427651	-0.21181864	-0.22540408
13	0.23773224	0.05542721	0.04776546	0.07520125	0.08461866	0.05595657	0.04812666
14	0.3933589	0.55161496	0.56653687	0.53807021	0.53766349	0.56452188	0.56762303
15	0.42416001	0.5637665	0.57924148	0.55267637	0.55237715	0.57697654	0.58034539

16	-0.41881771	-0.0316588	-0.04328422	-0.0933261	-0.12556612	-0.03330183	-0.04305025
17	0.03671448	0.069604	0.0625875	0.06299247	0.06353459	0.07048701	0.06296941
18	-0.49176771	-0.32329569	-0.34819477	-0.35513693	-0.3706992	-0.33221369	-0.34838689
19	-0.37666883	-0.33544723	-0.36089938	-0.34772176	-0.35808218	-0.34466835	-0.36110925
20	0.75972998	0.22554872	0.22562994	0.3103955	0.35194163	0.23032182	0.2262397
21	-0.78899841	-0.82565474	-0.75781492	-0.83437322	-0.76166766	-0.80998524	-0.75464533
22	-0.78920785	-0.83225775	-0.75808074	-0.79631492	-0.76214276	-0.80594085	-0.75491153
23	-0.78786363	-0.78786363	-0.77239419	-0.79018493	-0.77495032	-0.77719901	-0.76921927
24	-0.78920217	-0.80438965	-0.7740352	-0.87884709	-0.7769536	-0.88097394	-0.77086257
25	-0.78792919	-0.75127286	-0.77308235	-0.77170252	-0.77695728	-0.73604203	-0.76990839
26	-0.78755197	-0.82420831	-0.77209775	-0.82732785	-0.77495549	-0.80887685	-0.76892241
27	-0.78916052	-0.77397304	-0.77414742	-0.70340537	-0.77696845	-0.69953315	-0.77097495
28	-0.78722558	-0.78722558	-0.77140958	-0.78796732	-0.7768097	-0.7959812	-0.76823328
29	-0.35559438	-0.37078187	-0.63911388	-0.45519235	-0.58546049	-0.46236981	-0.6386842
30	-0.78773394	-0.78773394	-0.78802044	-0.79262691	-0.79016269	-0.80197072	-0.78484165
31	-0.78843102	-0.77324354	-0.77323057	-0.70182511	-0.77625683	-0.68144039	-0.77005682

4.5.8 Model selection

The AIC and Rhat plot were used to select the best predictive models from the GLM and BHRM analysis. Below is Table-4.39 which shows the summary of all the predictive models produced by Generalized Linear Models (GLM) and Bayesian Hierarchical Regression Models (BHRM) respectively. The highlighted green sections are the best fit models according to the AIC and Rhat plots. This research work is focused on producing a predictive model which take cognizance of inherent uncertainties in the project. BHRM with the Rhat Plot equal to one or closer were used to validate the model with a practical project cost information in the next Chapter-5. Model-6A &6B meets this criterion.

Table 4.39 Selected predictive models

Inference	Response variable	Model	Specification	Link
Frequentist	Cost Overrun	1.1+CC*0.2+DD*0.3+ED*0.7+DO*0.5+USC*0.3+ODC*0.2+CCD*0.3+CCI*0.2+ RPP*3.5+UPR*0.5+LOTOPPE*0.4+WC*0.5+RA*-1.4+QAC*0.4+SI*1.1	Model-1A	Identity
Frequentist	Cost Overrun	-0.46748+CC*0.23659+ED*0.57573+SI*0.74920	Model-2A	Identity
Bayesian	Cost Overrun	1.2+CC*0.2+ED*0.7+DO*0.6+USC*0.4+ODC*0+CCD*0.1+CCI*0.1+UPR*0.5+LOTOPPE*0.3+WC*0.5+RA*0.4+QAC*0.2+SI*0.9	Model-3A	Identity
Bayesian	Cost Overrun	-0.5+CC*0.2+ED*0.6+SI*0.7	Model-4A	Identity
Bayesian	Cost Overrun	1.1+CC*0.2+ED*0.7+DO*0.6+USC*0.4+ODC*0+CCD*0.1+UPR*0.5+ LOTOPPE*0.3+WC*0.4+RA*0.4 +QAC*0.2+SI*0.9	Model-5A	Identity
Bayesian	Cost Overrun	-0.5+CC*0.2+ED*0.6+SI*0.7	Model-6A	Identity
Frequentist	Final cost	-0.7+CC*0.6+DD*0.2+ED*0.5+DO*0.3+USC*0.2+ODC*0.1+CCD*0.2+CCI*0.1+UPR*0.3+LOTOPPE*0.3 +WC*0.3+RA*-0.9+QAC*0.2+SI*0.7	Model-1B	Identity
Frequentist	Final cost	0.29361+0.63392*CC+ED*0.36159+SI*0.47055	Model-2B	Identity
Bayesian	Final cost	-0.8+CC*0.6+ED*0.4+DO*0.4+USC*0.3+ODC*0+CCD*0.1+CCI*0.1+UPR*0.4+LOTOPPE*0.2+WC*0.3+ RA*0.3+QAC*0.1+SI*0.6	Model-3B	Identity
Bayesian	Final cost	-0.3+CC*0.6+ED*0.4+SI*0.5	Model-4B	Identity
Bayesian	Final cost	-0.8+CC*0.6+ED*0.4+DO*0.4+USC*0.3+ODC*0+CCD*0.1+CCI*0.1+UPR*0.4+LOTOPPE*0.2+WA*0.3 +RA*0.3+QAC*0.1+SI*0.6	Model-5B	Identity
Bayesian	Final cost	-0.3+CC*0.6+ED*0.4+SI*0.5	Model-6B	Identity

4.3.6 Scope of infrastructure project uncertainty identification.

Table 4.40 Showing the scope of infrastructure project uncertainty identification

Values	Frequency	Percent
Flexible and iterative	15	23.1
In-house standardized proces	26	40
Generic formal process	8	12.3
Informal process	10	15.4
Not too sure	6	9.2
Total	65	100

Note: This is a typical multi-response table. Respondents chose more than one answer.

According to the Tabulated findings of the respondents on **Table-4.40**, it is revealed that In-house standardized process scope is mostly utilized in infrastructure project uncertainties during initiation stage. Out of 50 respondents surveyed, 40% utilizes In-house standardized process scope, 23.1% utilizes flexible/iterative process, Generic formal/Informal process method 12.3%/15.2% while 9.2 % of the respondents were not sure of the method utilized in their various organizations.

4.6 Uncertainty identification during project initiation stage

Table 4.41 Showing focus of infrastructure project uncertainty identification

Value	Frequency	%
Known Unknown Uncertainties	39	33.33
Unknown Unknown Uncertainties	15	12.84
Opportunity management	31	26.49
Threat Management	28	23.93
Other	4	3.42

Note: This is a typical multi-response table. Respondents chose more than one answer.

According to the tabulated findings of the respondents on **Table-4.41**,33.33%ofthe respondents focuses on Known/Unknown uncertainties, 12.84 focuses on unknown/unknown, 23.93% focuses on threat management, and 26.49% focuses on opportunity management, while 3.39% of the respondents focuses on other aspect, respectively. 3.42% expatiated more on their focus of uncertainty identification during initiation stage. The focus of their uncertainty identification varies and depends on scale, complexity, and business sector.

4.6.1 Level of documentation of identified infrastructure project uncertainties during initiation stage.

Table-4.42 Showing Level of identified infrastructure project uncertainties documentation

Value	Fequency	%
Analysis documented and used throughout the project duration	45	59.2
Documentation reported and used for the purpose of initial estimate	34	44.7
Documented informally	6	7.9
Other	6	7.9

Note: This is a typical multi-response table. Respondents chose more than one answer.

According to the tabulated findings of the respondents on **Table-4.42**,59.2% of the respondent's document and analyse identified infrastructure project uncertainties throughout the project duration, 36.8% document and report identified infrastructure project uncertainty for the purpose of initial estimate,44.7%documentidentifiedinfrastructureproject uncertainties informally while 7.9% utilizes other means of documentation of infrastructure project uncertainties.

4.6.2 Techniques utilized in identifying infrastructure project uncertainties

Table 4.43 Techniques utilized in identifying infrastructure project uncertainties

Value	Fequency	%
Expert Knowledge	47	62.7
Facilitated workshop	42	56
Multicriteria Decision Analysis	20	26
Brainstorming	25	33.3
Other	4	5.3

Note: This is a typical multi-response table. Respondents chose more than one answer.

According to the Tabulated findings of the respondents on **Table-4.43**, 33.3% utilizes expert knowledge in identifying infrastructure project uncertainties,29.8% utilizes facilitated workshop in identifying infrastructure project uncertainties, 13.2% utilizes multicriteria decision analysis in identifying uncertainties, 20% utilizes brainstorming in identifying uncertainties while 4% utilizes some other techniques. Some of the respondents expatiated by inculcating all the techniques in their respective organization.

4.6.3 Dedicated uncertainty management training

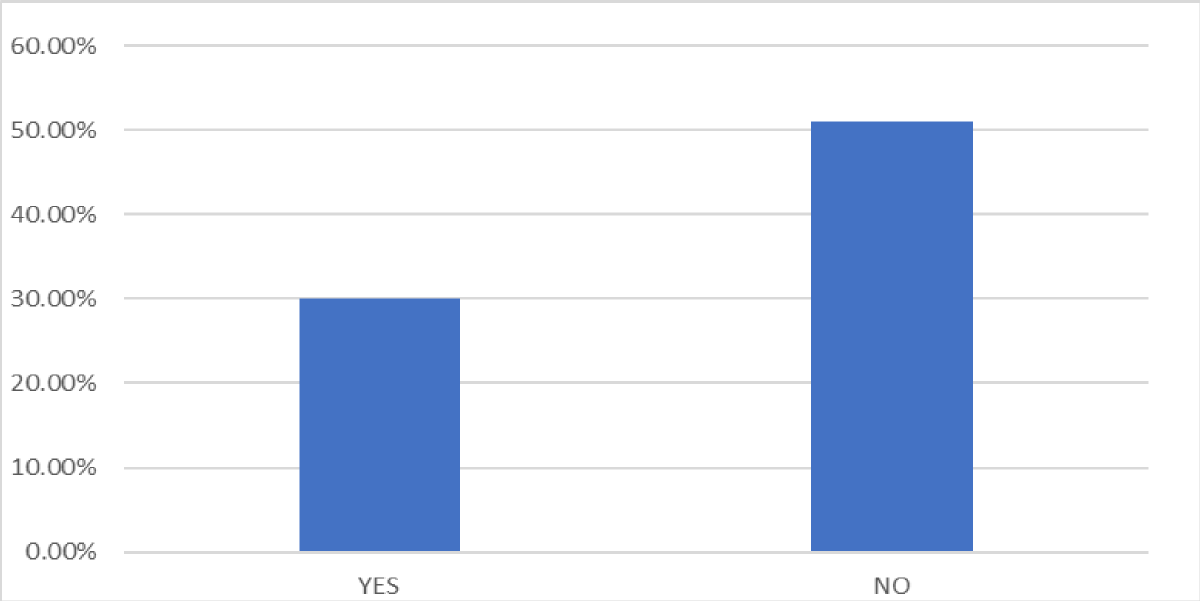


FIG-4.40 PERCENTAGE OF RESPONDENTS INVOLVED IN DEDICATED UNCERTAINTY MANAGEMENT TRAINING in their respect organization.

According to the findings in Fig-**4.40**, 66% of the respondents do not have a dedicated uncertainty management training in their respective organization while 34% have.

4.41 Uncertainty Management Team

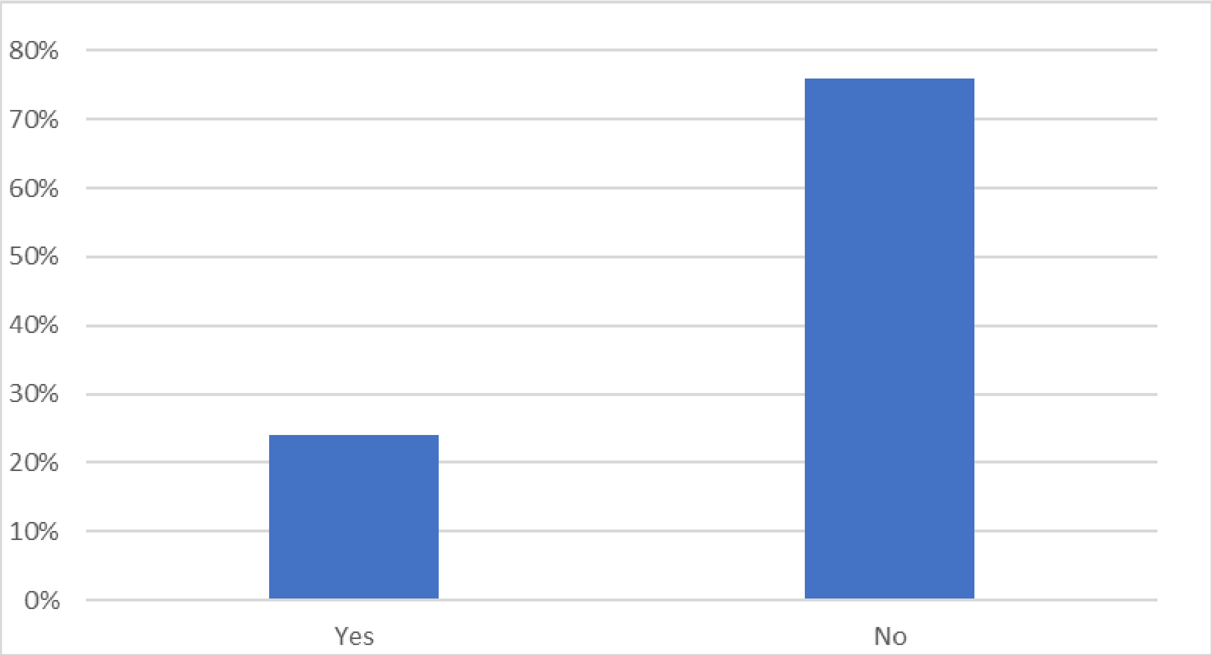


Fig-4.41 Percentage of dedicated uncertainty management team in respective organization.

According to the findings in Fig **4.41**, 34% of the respondents have dedicated uncertainty management team in their respective organization while 66% don't have. These findings **(Fig-4.40 & 4.41)** show that infrastructure project institution does not get seriously involved in uncertainty management.

4.6.5 Duration of infrastructure project uncertainty identification

Table 4.44 Showing durations in which infrastructure project uncertainties are identified

Value	Frequency	Percent
<6 month	**22**	**28.9**
>12 month	**20**	**26.3**
6-12 month	**20**	**26.3**
None of the above	14	18.4

According to the tabulated findings of the respondents on **Table-4.44,** 28.9% of the respondents identifies uncertainties for less than 6 months project in duration, 26.3% identifies uncertainties for project greater than 12 months in duration, 26.3% identifies uncertainties for project of 6-12months in duration while 18.4% do not have a specific duration criterion for infrastructure project uncertainty identification. The Findings show that close 28.9% don't identify infrastructure project uncertainties for project <12months in duration.

Table-4.45 Correlation between the dedicated uncertainty management team, uncertainty training undertaken by respondents and durations of uncertainty identified

			Is uncertainty management carried out in your organization on infrastructure projects with following durations?	Is there a dedicated uncertainty management team in your organization?
pearman's rh	Is uncertainty management carried out in your organization on infrastructure projects with following durations?	Correlation Coefficient	1	.246*
	Is there a dedicated uncertainty management team in your organization?	Sig. (2-tailed)	.	0.001
		N	76	76
		Correlation Coefficient	.246*	1
		Sig. (2-tailed)	0.001	.
		N	76	76
	* Correlation is significant at the 0.05 level (2-tailed).			

The Spearman's rho correlation coefficient of the dedicated uncertainty management team, and project durations of identified uncertainty in an infrastructure project firm is 0.246. This indicates a positive correlation between the two variables. The correlation is moderate, but the Sig(2-Tailed) value is 0.001(<0.05), indicating a statistical significance. The findings show that uncertainty management team in an infrastructure project firm has impact on the project durations of identified uncertainty. Alternatively, inadequate uncertainty management team in infrastructure project firms prevents adequate uncertainty identification regardless of project durations.

4.7 Focus of risk identification process

Table-4.46 Percentage and Frequency of the focus of infrastructure project risk identification process.

Value	Frequency	Percent
Threat	18	23.7
Opportunities	9	11.8
Unknown	26	34.2
All of the above	34	44.7

Note: This is a typical multi-response table. Respondents chose more than one answer.

According to the Tabulated findings of the respondents on **Table-4.46, 23.7%** focuses on threat during risk identification process,11.8% focuses on opportunity,18.4% focuses on Unknowns and 63.3% focuses on all techniques. The findings show that approximately 37.18% of the respondents just focus on Unknowns.

4.7.1 Scope of risk identification process

Table 4.47 Showing the Frequency and Percentage of the scope of risk identification process

Value	Frequency	Percent
Flexible and iterative	22	28.9
In-house standardized process	35	46.1
Generic formal process	28	36.8
Other	1	1.7

Note: This is a typical multi-response table. Respondents chose more than one answer.

According to the tabulated findings of the respondents on **Table-4.47**, it is revealed standardized formal process scope is mostly utilized in infrastructure project uncertainties during initiation stage. 50.8% utilizes in-house standardized formal process scope during the risk identification process scope, 15.3% utilizes generic informal process scope, 32.2% utilizes flexible and iterative process scopes while 1.7% utilizes other identification process scope.

4.7.2 Technique utilized in Risk identification process

Table 4.48 Showing the Frequency and Percentage of the technique of risk identification process

Value	Frequency	Percent
Expert knowledge	36	48
Analytical technique	41	54.7
Facilitated workshop	40	53.3
Meeting	28	37.3
Other	3	4

According to the tabulated findings of the respondents on **Table-4.48,**48% utilizes expert judgement in identifying infrastructure project risk,54.7% utilizes analytic technique,53.3% utilizes facilitated technique, 37.3%utilizesmeetingtechniquewhile 4% utilizes other technique for their risk identification process.

4.7.3 Dedicated risk management team

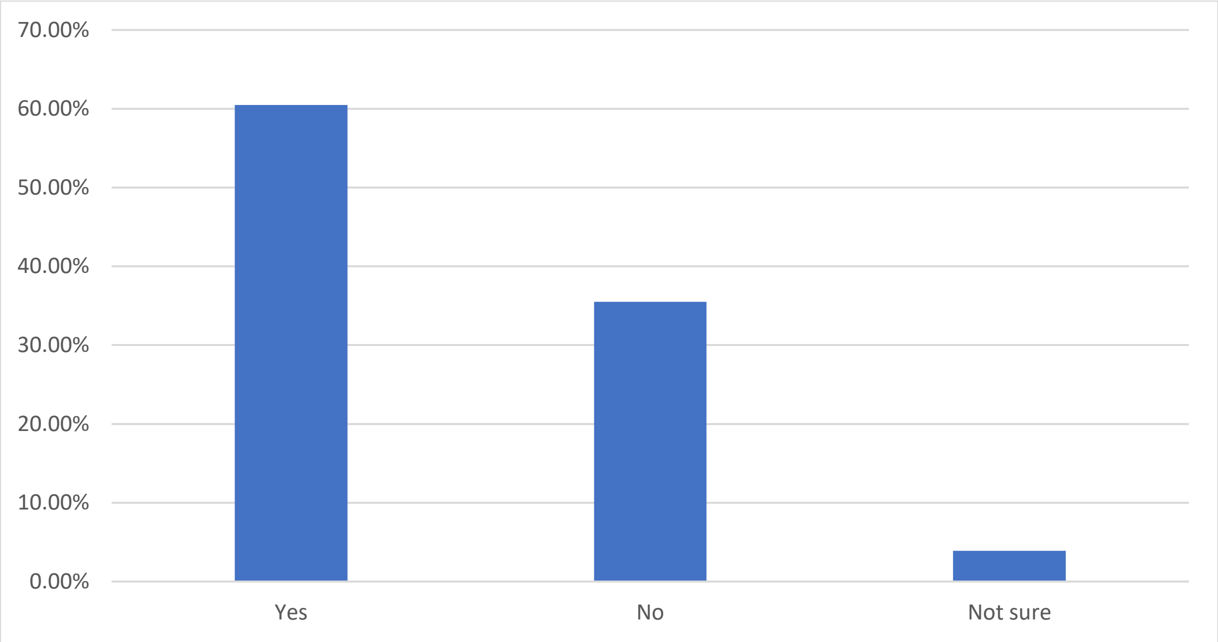


Fig 4.42 Showing the graph of frequency and percentage of dedicated risk management team in respondent’s organization.

According to **Fig-4.42** 62% of respondents confirms that their organization has dedicated risk management team,32% confirms no risk management team in their organization while 6% is not sure about it.

4.8 Major sources of cost estimation

Table 4.49 Showing the frequency and percentage of cost estimation sources

Value	Frequency	Percent
In-house Cost data base	45	60
Quotation from subcontractor or suppliers	52	69.3
Cost indices	34	45.3

According to Table-4.49, it was revealed that the major sources of infrastructure project cost estimation is In-House Cost Data base. 38% of the respondent's source that cost information from In-house Cost Data base, 35.6% respondents source their cost information from Quotation from Suppliers and subcontractors while 27.9% source their cost information from cost indices and schedule of rates.

4.8.1 Cost estimation technique

Table 4.50 Showing the frequency and percentage of cost estimation techniques utilized by respondents.

Value	Frequency	Percent
Historical data assessment	42	55.3
Professional experience	42	55.3
Analytical technique	30	39.5
Benchmarking	23	30.3
Expert knowledge	24	31.6
Other	2	2.6

According to the Tabulated findings of the respondents on **Table 4.50,** 24% of the respondents utilizes historical data assessment, 20.7% utilizes professional experience, 18% utilizes analytical technique, 13% utilizes benchmarking, 22% utilizes expert knowledge while 2% utilizes other techniques.

4.8.2 Association between sources of infrastructure project cost estimation and techniques

Table 4.5125 Pearson Chi-square test

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.272[a]	1	0.039		
Continuity Correction[b]	2.897	1	0.089		
Likelihood Ratio	3.920	1	0.048		
Fisher's Exact Test				0.065	0.048
Linear-by-Linear Association	4.207	1	0.040		
N of Valid Cases	66				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.17.

b. Computed only for a 2x2 table

According to the Chi-square test shown on **Table-4.51**, the P-Value is less than 0.05 which shows statistical significance. This shows an association between the sources of infrastructure project cost estimation and the technique, respectively. Alternatively, the sources of infrastructure project cost estimation have an impact on the techniques used in cost estimation.

4.9 Chapter summary

This chapter has introduced the importance of system thinking approach in infrastructure cost estimation and the uncertainty factors impacting on the process. Also, it has introduced the project cost estimating model and described its components and use. The project level random effects were statistically analysed. The predictive diagnostics of these models were tested as well.

The data collection and analysis have revealed and clarified the existing process and its flaws. The cost estimating process, like the rest of the project, is a system with relationships, connections, and inputs. This is where the entire cost estimating system is operational and integrated. The estimating process involves numerous forces and interactions, all of which have a financial impact. A holistic approach, rather than relying solely on historical cost data, will be a significant step forward. The system thinking scale score and need for cognition score of the project control/management professionals showed positive correlation. A project control/management professional with a higher system thinking scale score may be able to think holistically while performing cost estimation. The next chapter puts the model to the test with a variety of projects, examining how well it achieves its goals. This chapter has been able to satisfy the research 4th objective by analysing cost information in producing predictive models and determining the influential uncertainty factors that impact on the cost estimation at the initiation stage.

Chapter-5.0 Model building and validation

5.1 Introduction

This chapter explains how the mixed-method findings generated by the survey and case-study cost information data were utilized for infrastructure project cost estimating model. Firstly, the model involves uncertainty factors identification using system thinking while the second phase includes how generalised linear model and Bayesian hierarchical regression model were used for cost overrun and final cost prediction. Knowing the impacts of uncertainty factors on early cost estimate will enable project control and management professionals make informed decisions on the production of robust contingency budget. The results of the models are explained extensively in the chapter-6 of this research work.

5.2 Model building

The most challenging process of cost estimation by project control and management professionals is the determination or prediction of the initial cost of infrastructure project by relying on available information prior to execution (Odusami and Onukwube, 2008). It is generally viewed as an approximation of the final cost used to deliver a project. According Madi, Mohammed and Enshassi (2007), cost estimate is a judgement, opinion, forecast or prediction-based process. This process is carried out by experienced project control and management professionals with the assistance of software tools. Inherently, the reductionist approach utilized by this professional is a recipe for bias or error in achieving initial cost estimate required to deliver infrastructure project. There is need for robust and holistic approach in producing the required cost estimate to deliver the project during the initiation stage. This model utilizes the uncertainty factors to improve the initial cost estimate. System thinking approach provides the holistic technique required to produce a robust initial cost estimate by taking cognizance of all factors that impact on it. This model formulation is a synthesis of the findings deduced from previous chapters.

5.2.1 Model framework process

I. Understand the Infrastructure project scope

In other to produce a robust initial project cost estimate required to deliver an infrastructure project there is the need to adequately understand the scope. The project boundaries need to be ascertained and well understood amongst the project control and management professionals prior to embarking on its execution. According to the PMBOK (2012), project scope includes the features and functions that characterize a product, service. Also, the work performed to deliver a product, service or result with the specified features and functions. As the project progresses from the initiation stage, the project scope becomes clearer gradually with more available information. This model deals with the project scope at the initiation stage where information about the project is a bit vague to the project control and management professionals. It is desirable to understand both internal and external factors that impact on the project scope to capture the dynamics. The interplay between these factors may generate uncertainties which may impact adversely on the project. It is advisable for key stakeholders to identify and manage these uncertainty factors prior to actual execution of the project. Project control and management professionals involved in the understanding of the scope should have considerable amount of system thinking scale and need-for-cognition score. This will ensure holistic thinking of the project to identify adequate potential uncertainty factors. Understanding the dynamics of the internal and external factors that impact on the project scope will serve as inputs in producing a robust rich picture of the project and identifying uncertainty factors.

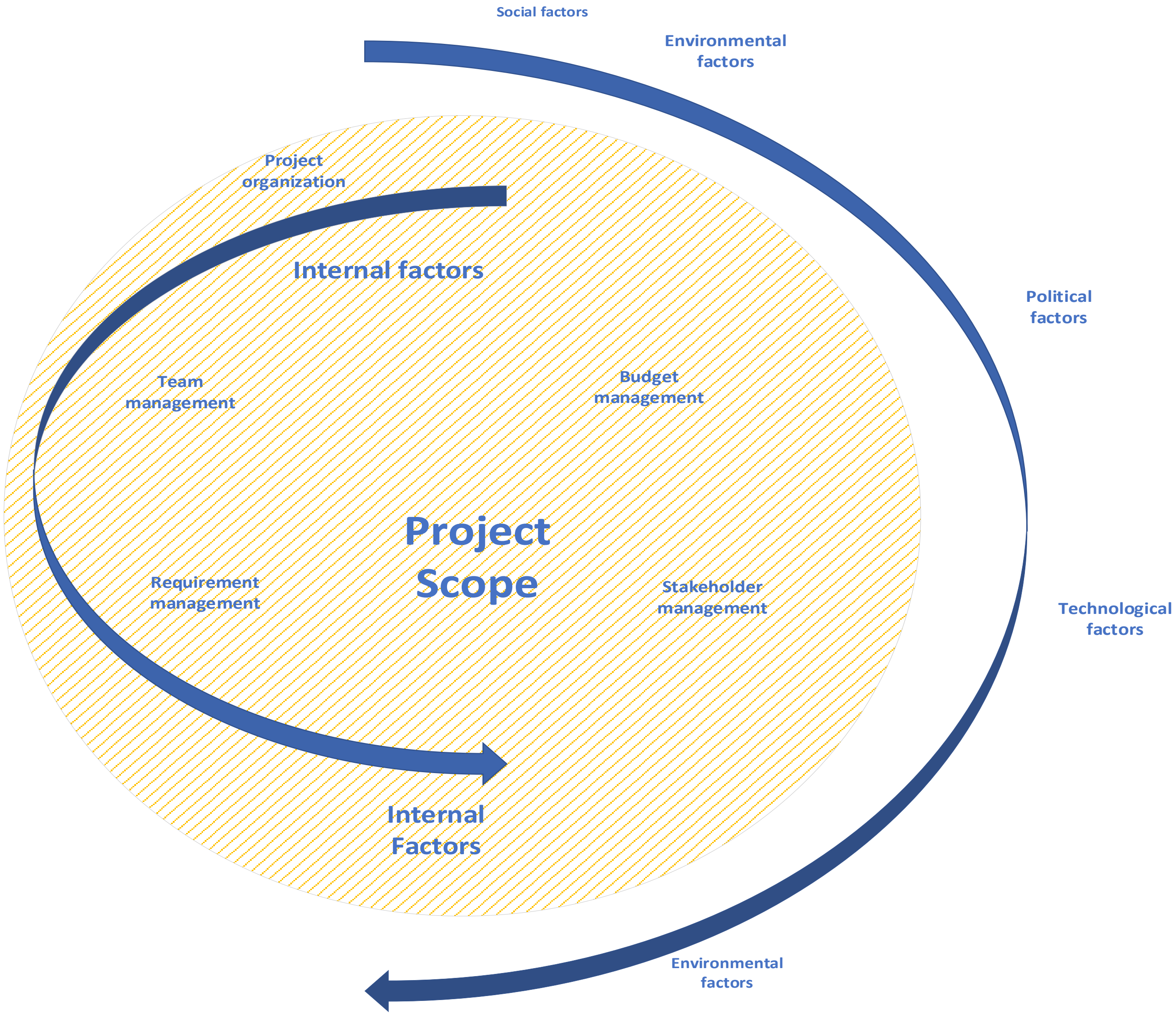


Fig 5.1 Schematic illustration of factors impacting on infrastructure project.

All the potential uncertainty factors that may impact on infrastructure project during initiation stage are identified from the literature review of related projects sourced from journals, articles, online publications, and magazines etc. The most influential uncertainty factors are then derived through factor analysis using SPSS software. Alternatively, these uncertainty factors can be identified from lesson learned, RAID (Risk, Assumption, Issues and Dependency) Log & history files of past similar infrastructure projects.

II. Infrastructure project rich picture

To gain general appreciation and insight of the infrastructure project activities, a rich picture will be utilized. Project control and management professionals involved in creating rich picture should have a good awareness of system thinking methodological approach. System thinking scale and need for cognition of >60 score will be appropriate for professionals involved in the production of rich picture. Fig 5.2 depicts the flow-chart of rich picture production.

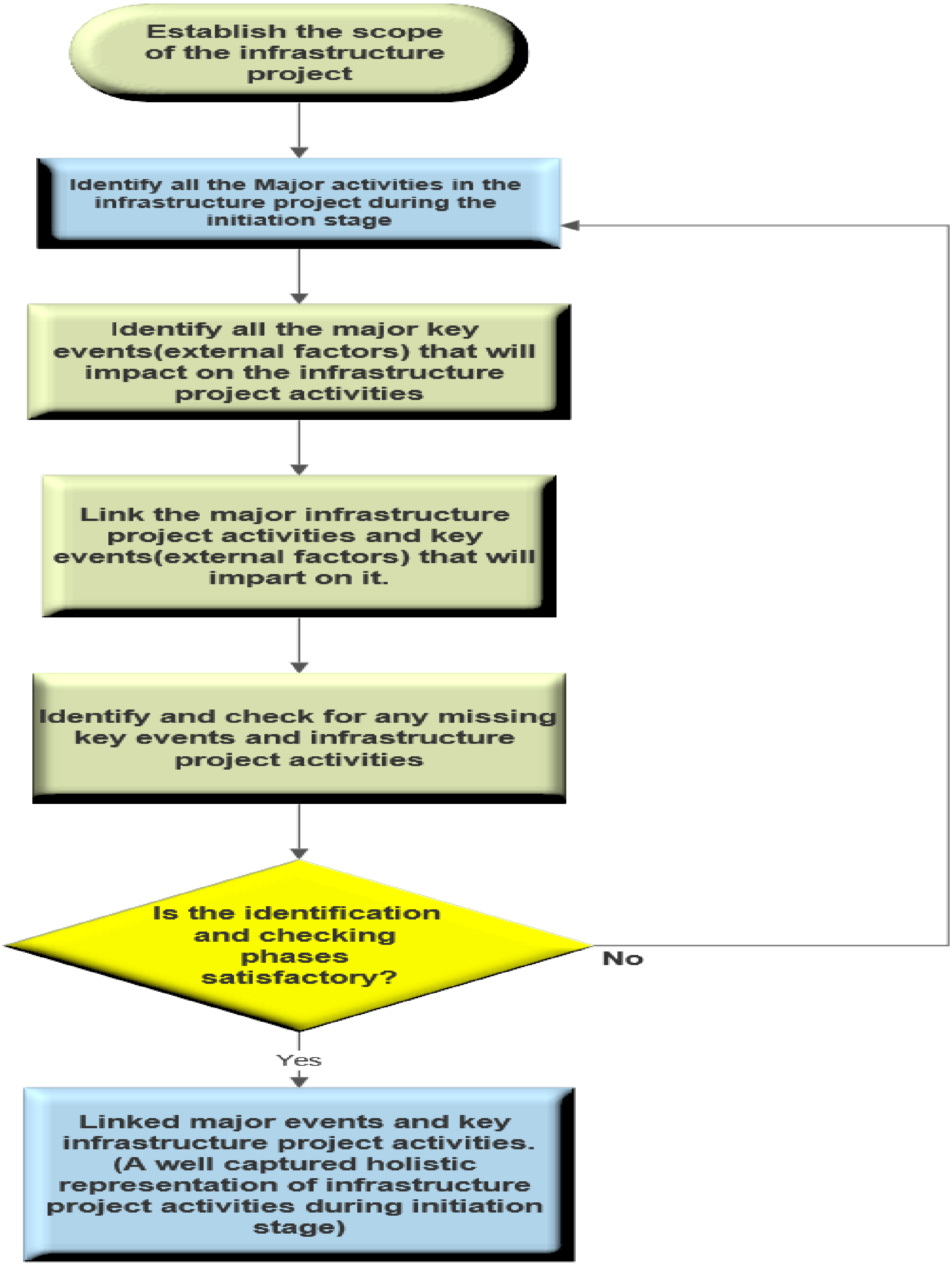


Fig 5.2 Flow-chart of Rich Picture

III. Relationship establishment (Concept mapping).

The interrelationship amongst infrastructure project activities and major events (external factors) are established in this section. This serves an input into the Causal Dag described below.

IV. Causal (Diagrammatic Acyclic Graph (DAG) Diagram

This is utilized to represent the interrelationship/interconnectedness amongst the major infrastructure project activities and major events that impact on the early estimate during project initiation by taking cognizance of uncertainty factors.

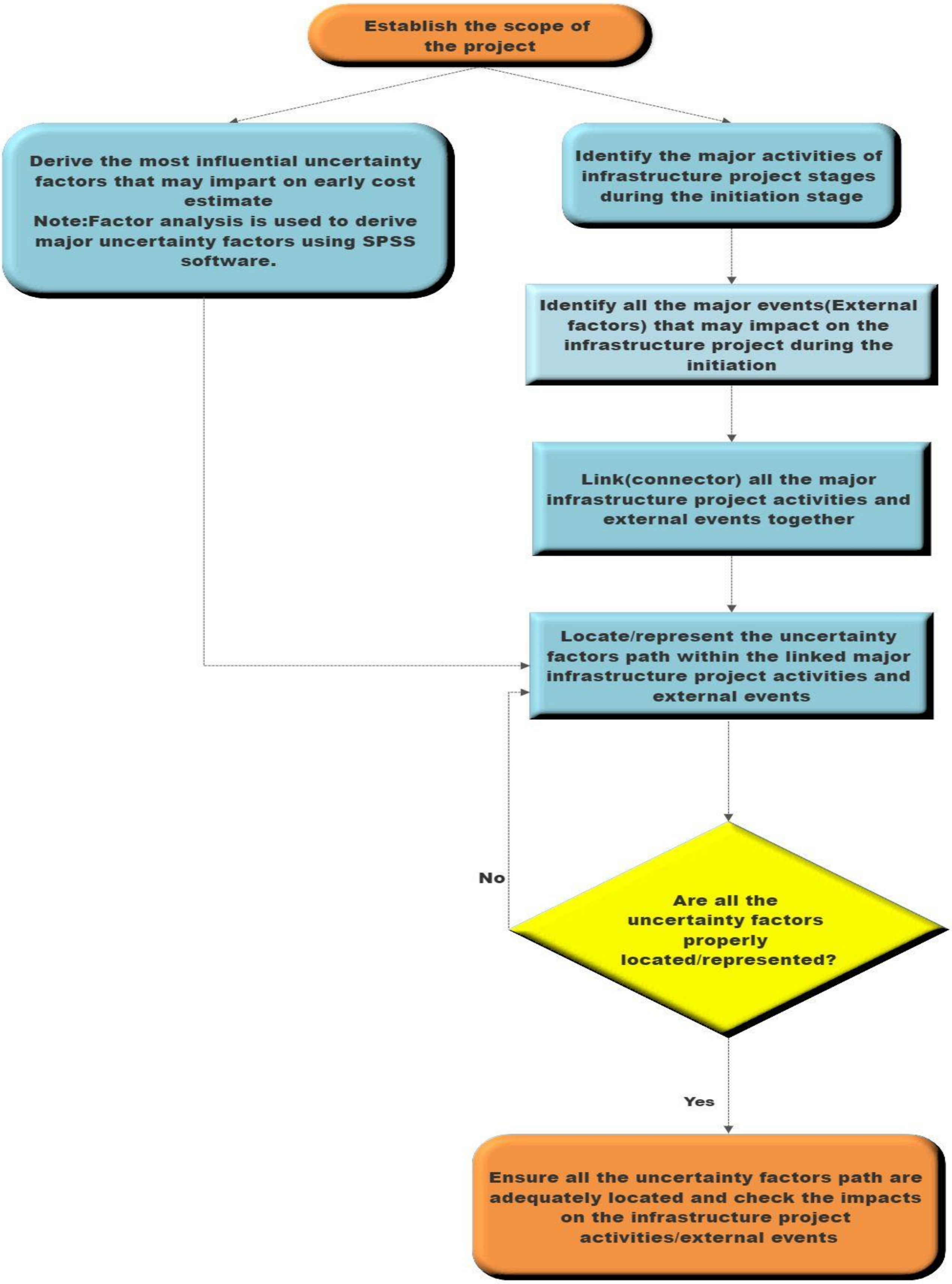
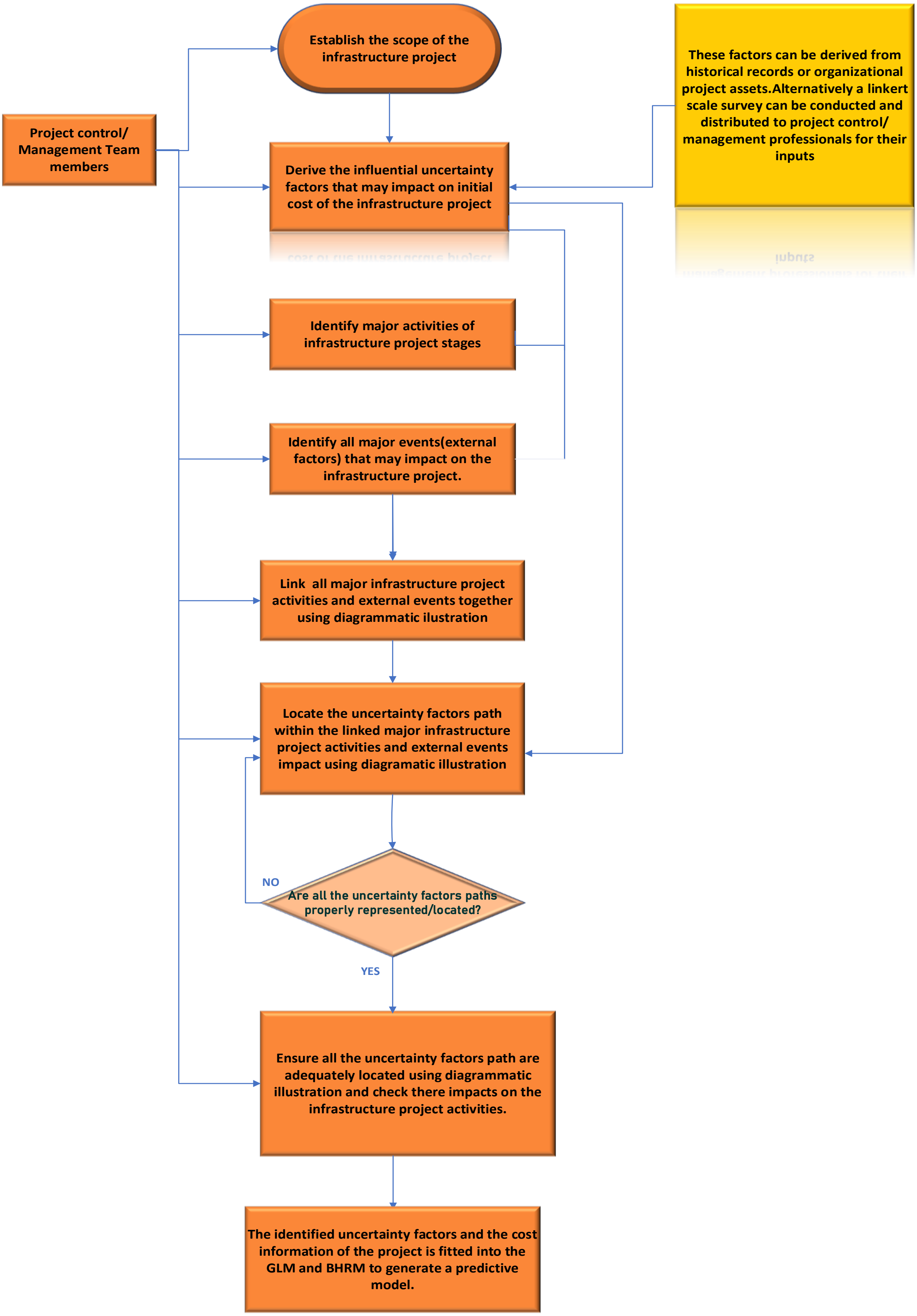


Fig 5.3 Flow-chart of causal DAG

V. Integrating uncertainty factors and cost information for the cost predictive model.

Infrastructure project uncertainty factors identified during initiation stage using system thinking approach and cost information derived from case-study firms are fitted into Generalized linear model (GLM) and Bayesian Hierarchical regression model (BHRM) to produce a predictive model. Generalized linear models (GLM) provide a unified approach to many of the most common statistical procedures used in applied statistics (Lindsey, 1997). This is a frequentist method applied in statistics unlike the Bayesian hierarchical regression model that estimates parameters based on posterior distributions of the parameters given the data which is obtained by combining the data likelihood with some expert knowledge, otherwise known as prior distribution (Dimaggio, 2015). The core advantage of the application of this model in this research is the provision of confidence intervals to communicate the inherent uncertainty in the output (predicted estimate). The project level random effects are adequately taking into cognizance in this model.


Establish the scope of the infrastructure project
Project control/ Management Team members
These factors can be derived from historical records or organizational project assets.Alternatively a linkert scale survey can be conducted and distributed to project control/ management professionals for their inputs
Derive the influential uncertainty factors that may impact on initial cost of the infrastructure project
Identify major activities of infrastructure project stages
Identify all major events(external factors) that may impact on the infrastructure project.
Link all major infrastructure project activities and external events together using diagrammatic ilustration
Locate the uncertainty factors path within the linked major infrastructure project activities and external events impact using diagramatic illustration
NO
Are all the uncertainty factors paths properly represented/located?
YES
Ensure all the uncertainty factors path are adequately located using diagrammatic illustration and check there impacts on the infrastructure project activities.
The identified uncertainty factors and the cost information of the project is fitted into the GLM and BHRM to generate a predictive model.

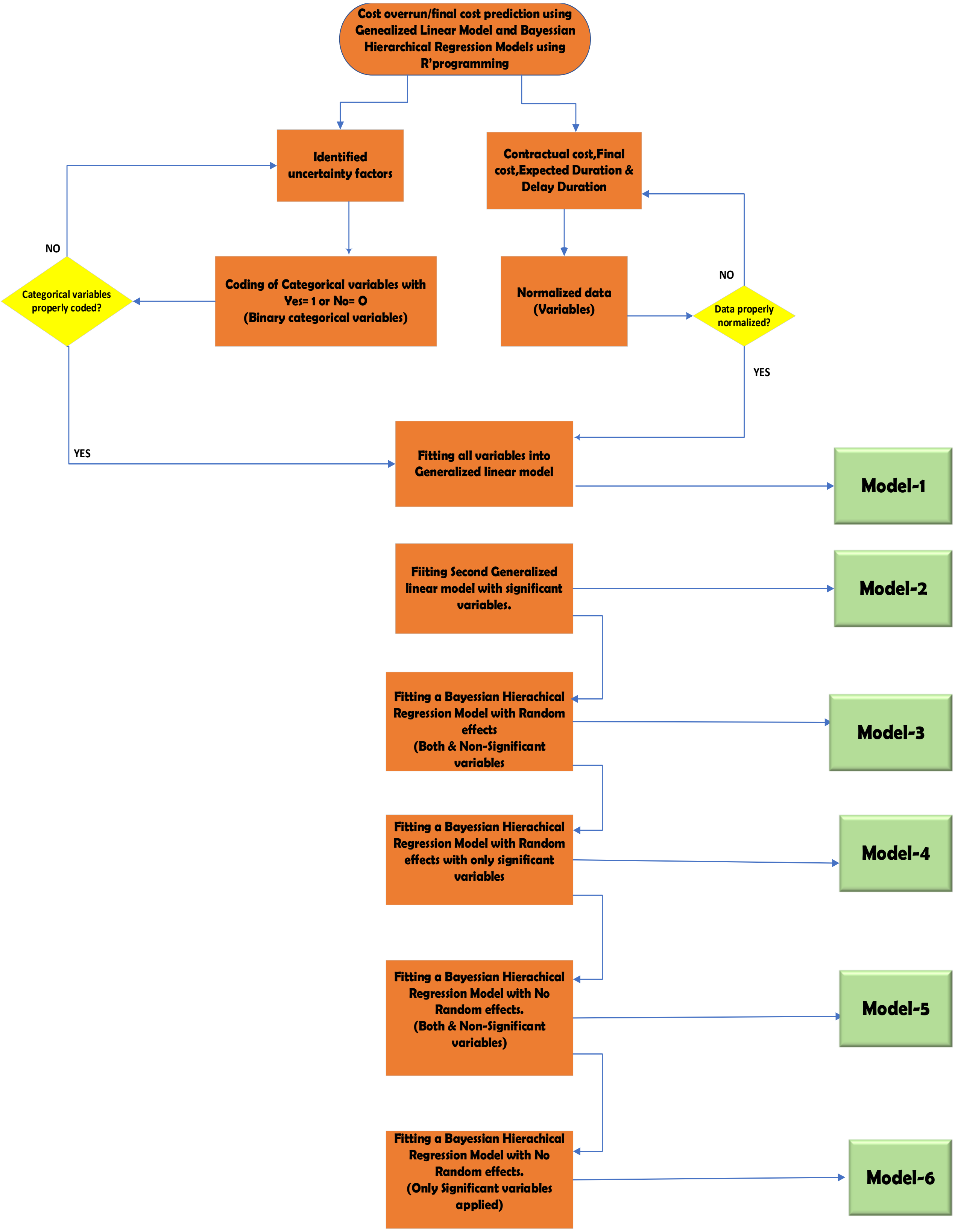


Fig-5.4 Predictive model framework process

5.2.2 Model validation

This validation process is to assess the credibility of the infrastructure project cost estimating model described in the section 5.1 of this research work. Additionally, validation process enables the evaluation of the completeness, practicality, and feasibility of the formulated model framework. It was achieved by evaluating the risk register (Initiation stage) and project scope of the case study firm. The explanation of this scope was made possible by having online conference call with the project control and management professionals of the case study firms. During the workshop, a quick survey was done to determine the system thinking scale score and need for cognition of the project team as explained in Chapter-3. Table 5.1 below is the background of the project control and management professionals of the case-study firms.

Table 5.1 Professional background of the case-study firm staffs (Project control and management professional)

No	Profession	Qualification	Certification	Years of Experience in Infrastructure project management industry
1	Project manager	Degree	Chartered	22
2	Planning Engineer	Master	Chartered	8
3	Cost Controller	Degree	Chartered	12
4	Qunatity Surveyor	Degree	Chartered	13
5	Risk Engineer	Master	Nil	16

5.2.3 Case-study description

The validation of the cost-estimating model was done using 6 case-study projects (Railway infrastructure) in the UK. Four of the projects are handled by the same infrastructure project management firm located in the UK with 18,000 staff population. It is a transformational, long-term railway development programme worth several billion pounds that will increase connectivity in the UK. It will foster regional economic development and bring substantial advantages to communities and travellers along this important train route. The 2 other project is carried out by a different case study firm which operations are located in the south part of England. The projects are described below as follows:

A1-Infrastructure project description: The infrastructure project involves railway track construction within the Midland axis of England (UK). It is one of the most capital-intensive projects embarked by the UK government. Due to the Non-Disclosure Agreement signed, the project will remain anonymous for confidential reasons. The scope involves constructing a 3KM railway track on an existing utility facilities R.O. W(P Way).it will be achieved by removing existing sewers/pipes on the proposed railway track Pway. The project is made of stages which is the removal of existing utility facilities along the Pway and building of railway track. The contract value for this project is £53M and still at the bidding stage. The duration of the project is 18months.

Fig5.5 Pictorial view of Pwaypriorto railway track construction (Railway Technology, 2014)

A2- Infrastructure project description: This project involves constructing an overhead line Electrification for the railway track in the Northwest region of England (UK). It is a 3.5KM OLE (Overhead Line Equipment) electrification railway project of contract value of £26M and to be completed within 30 months.

Fig 5.6 Pictorial View of OLE ELECTRIFICATION project in the Northwest England (Lawson, 2019)

B-1 Infrastructure project: This project involves the construction of bridges for the railway along the Northwest region of England (UK). The contract value for this project is £39M in value which spans for 3. 5years.The pictorial view is represented in Fig-5.7.

B-2 Infrastructure project: This project involves the construction of rail stations for railway along the Northwest region of England (UK). The contract value for this project is £65M in value which spans for 6 years. The pictorial view is represented in Fig-5.8.

Fig 5.7 Pictorial *v*iew of bridge project in the Northwest England

Fig 5.8 Pictorial View of rail station project in the Northwest England (Railway, 2014)

C-1 This project involves the revamping and construction of railway station/platforms in the Northwest region of the UK. The contract value for this project is £33M in value which spans for 3.5years. The pictorial view is shown in Fig-5.9.

Fig-5.9 Showing the construction rail-station/platform in South of England (Railway, 2014)

C-2 This project involves the revamping and construction of tunnels/earthworks in the Northwest region of the UK. The contract value for this project is £23M in value which spans for 2.2 years. The pictorial view is shown in Fig-5.10.

Fig 5.10 Showing the construction of tunnels/earthworks in South of England (Railway,2014)

5.2.4 Cost estimation validation using case-Study-A,B &C

The first step in the cost-estimation model is the adequate description and understanding of the infrastructure project scope. Below is the process to be followed:

A- **Understanding of Infrastructure project scope:** this process is quite essential to enable the adequate understanding of the scope of the diversion/rail project robustly. The scope of the infrastructure project was grasped through shared documents (statement of work, schematic diagrams) and conference call (Via Zoom) with the project control/management professionals (Table 5.1). The project is a tender project for water utility project and railway track construction. The subcontractor intends to divert an existing water utility facility and replace it with a new pump station from a proposed Pway (Permanent Right-of-Way). Robust understanding of the scope of work will serve as an input for the next stages of this model. The diagram of the proposed work is illustrated on the Appendices section (5.1).

B- **Identification of uncertainty factors**

The uncertainty factors that may impact on the infrastructure project are identified by the project control and management professionals during the initiation stage. In this validation process, these factors are derived from the literature review and a survey (using Bristol online) is carried out to determine the impact ratings. These factors are also validated by the project control/management professionals of the case-study firms. These uncertainty factors are shown in section-3A of the appendix part. It is expected for the infrastructure project control and management professionals to have 60% system thinking scale score and need-for-cognition, respectively. This is to ensure that project control and management professionals are capable of holistic thinking approach in the identification and rating of the uncertainty factors.

C- Infrastructure project Rich picture

To view the infrastructure project holistically, a rich picture is produced to capture all activities and events (external factors) that may impact on the project during the initiation stage (Strategic definition and Preparation/Brief). Understanding of the infrastructure project scope is a key factor in producing a rich picture diagram. Below is the diagrammatic illustration of the infrastructure project rich picture

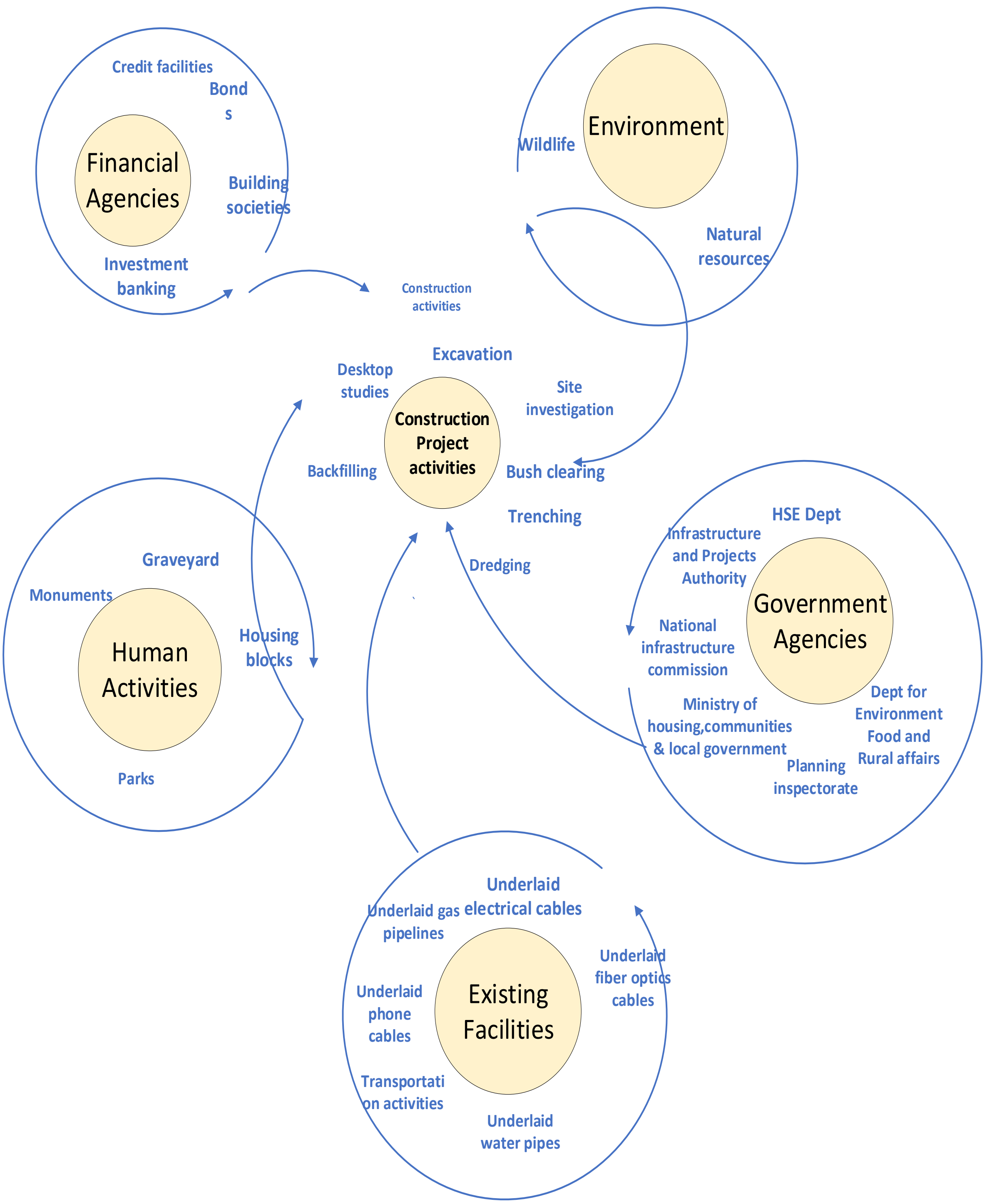


Fig 5.11 Diagrammatic illustration of the Rich picture of diversion/Railway Track construction in the *midland's* region of England.

As depicted in Fig 5.11 diagram, the infrastructure project activities are Trenching, bush clearing, dredging, backfilling, site investigation, excavation desktop studies. While the

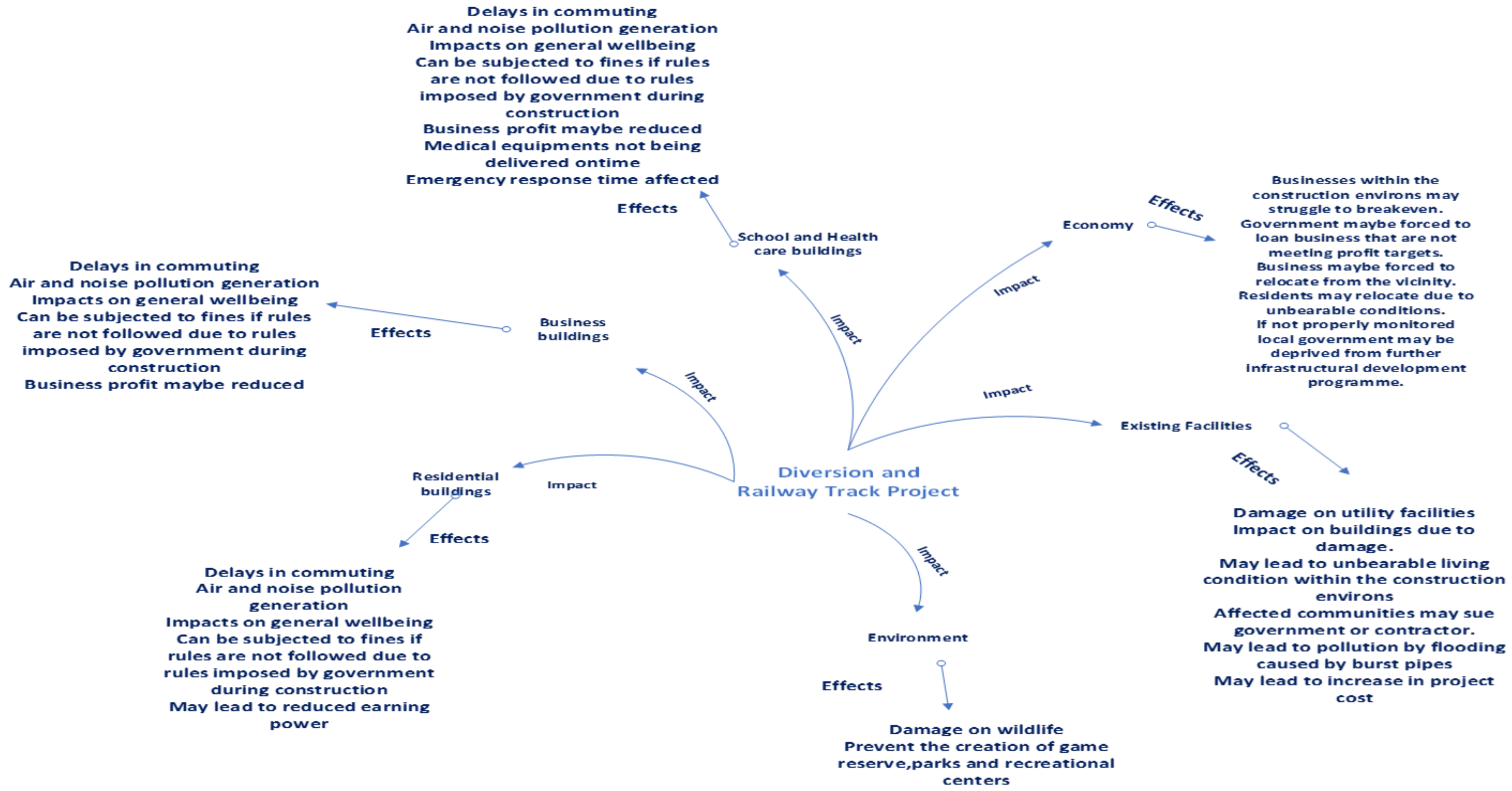


Fig 5.12 Diagrammatic illustration of holistic impact of Diversion/Railway track construction project.

External events are human activities, financial agencies, existing facilities, environment, and government agencies.

D- Relationship establishment using Concept mapping

The concept mapping utilized for this model enables the establishment of relationship amongst core activities within the infrastructure project (Diversion/Railway Track). It assists in showing the interrelationships amongst the major infrastructure project activities during the initiation stage(Strategic definition and Preparation/Brief). Any uncertainty factors impacting the infrastructure project activities will have an overall impact on the initiation stage.

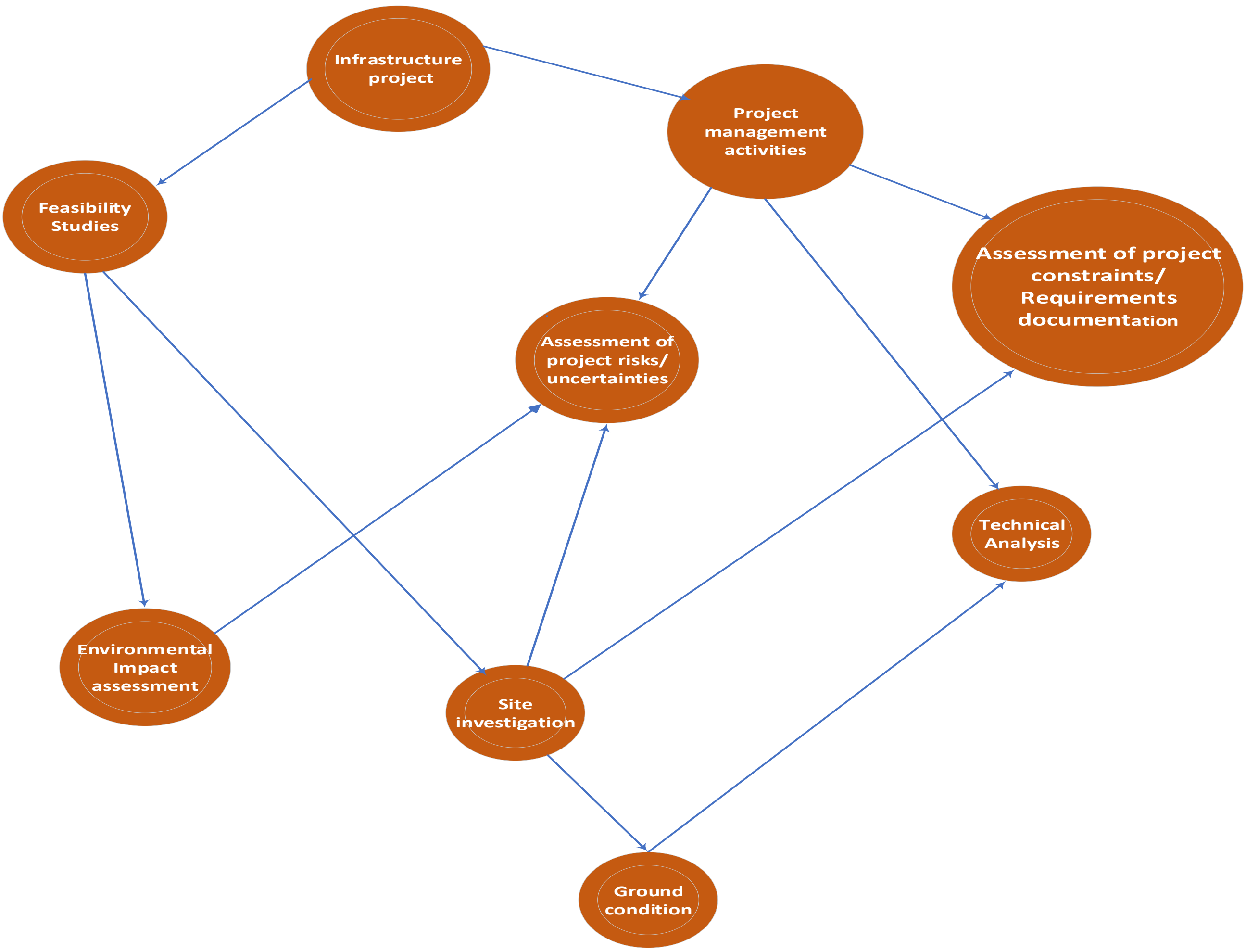


FIG-5.13 CONCEPT MAPPING OF INFRASTRUCTURE PROJECT AT INITIATION STAGE

E- Causal DAG establishment

This is used to establish relationships between the major activities and the events (external factors). The interaction of the major infrastructure project activities with the external events that may impact on the initiation stage are depicted here as well.

Uncertainty factors that may impact on these major activities are identified/traced along the Causal Dag path of the infrastructure project activities. Fig 5.14 shows the diagrammatic illustration of the Causal Dag path of the diversion/railway construction project. The case study firm project control/management professionals explained all the initial activities carried out before developing the initial estimate prior to the definite estimate. The activities are described below as follows:

The project management activities of the case study projects are headed by the project manager which the involvement is the monitoring of day-to-day activities of the project. Prior to actual planning of the project, a feasibility study is carried out to take cognizance of all relevant factors (economic, technical, political & legal) that may impact on the project (Investopedia, 2020). Prior to actual site investigation(feasibility study) of the construction site a desk top study is carried out. Desktop study is mainly research work done rather than physical investigation. The aim of it is to provide initial understanding of site situation, risks/uncertainties, inform the scope and methodology of prospective investigations (DesignBuildings, 2020b). Environmental Impact assessment is part of the feasibility study mandated by the Government prior to further site investigation (Ground condition). Permits from the Government is required prior to actual site investigation(ground condition).The ground condition are carried out to determine the existing site ground condition, highlighting any findings that will affect the construction of the infrastructure and the health/safety of everyone involved (AiSolutionsLtd, 2020). The construction options for the project were determined from the site report gathered during the site investigation. This information was properly analysed by the technical team and project engineer to optimize the project cost.

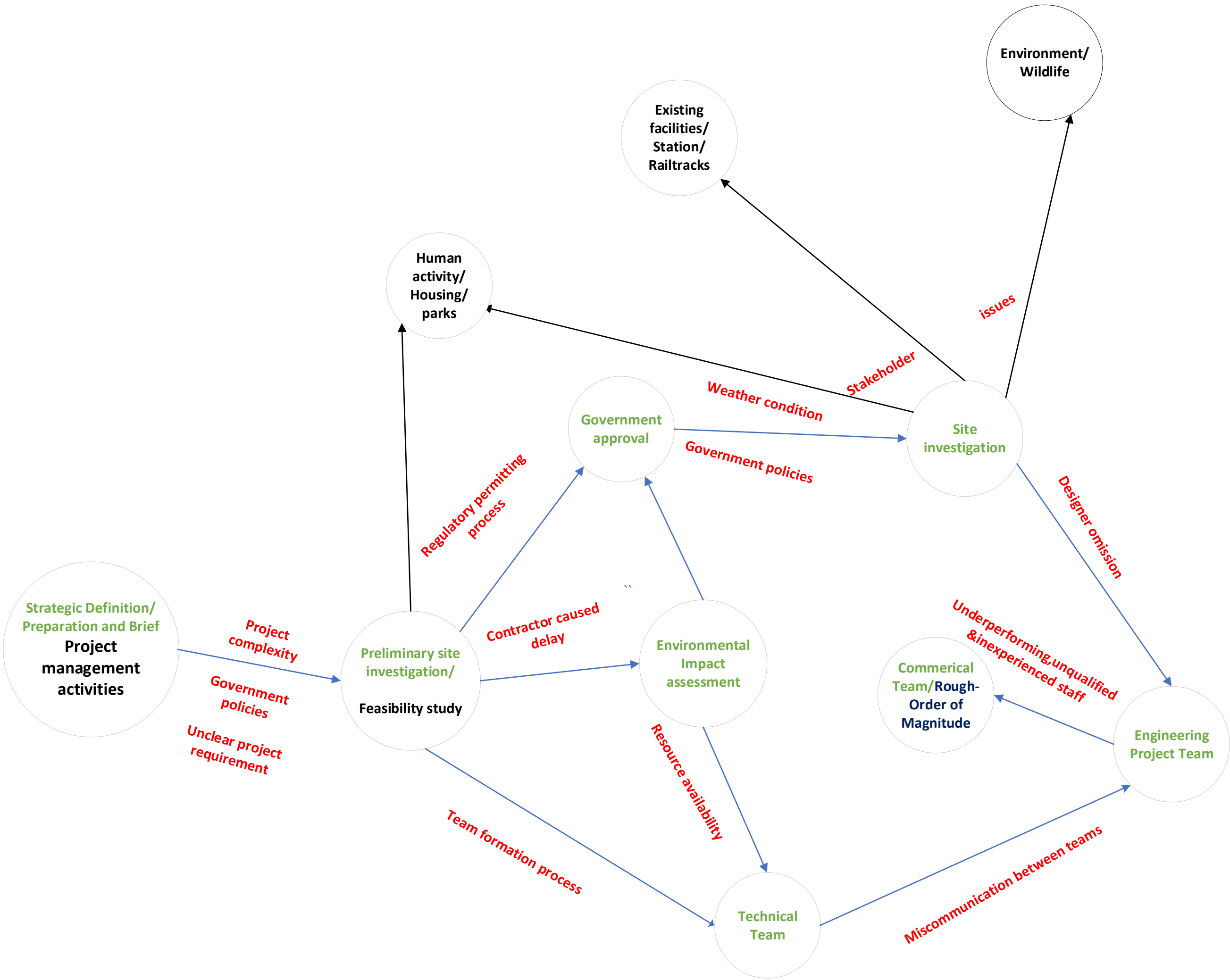


Fig 5.14 Showing the diagrammatic illustration of the Causal DAG path of the Diversion/Railway track construction project.

The Fig 5.14 shows the causal Dag path with a green node while the external factors impacts are denoted with black nodes. According to **Fig 5.14** depicted, the ground condition is a major driver due to the impact it has on the external factors such as human activities, existing facilities and environment which may potentially impact on the initial project cost estimate. All the uncertainty factors identified along the causal Dag will be estimated.

F- Uncertainty factors estimation

The identified uncertainty factors in the Railway track construction project which are project complexity, government policies, unclear project requirement, regulatory permitting process government policies, weather condition, contractor caused delay, resource availability, Stakeholder issues, miscommunication between teams, designer omission & Underperforming/unqualified/inexperienced staff as indicated in Fig-5.1. These factors are fitted into the Generalized Liner Model and Bayesian Hierarchical Regression Model produced in Chapter-4 **(Table-4.39).** Using the best fit models that take cognizance of inherent uncertainties in the project, below models highlighted in Table 4.39 were utilized for the validation.

A-$COR = -0.462 + 0.238 * CC + 0.572 * ED + 0.740 * SHI$ **------**Equation 5.1

B-$FC = -0.291 + 0.635 * CC + 0.361 * ED + 0.468 * SHI$)-------Equation 5.2

These model parameters were standardized using the Z-score as explained in chapter 3.6.5. Using the same procedures of the standardization the project contractual cost (CC) and Expected duration were standardized to fit it into the predictive models. The validation of these predictive model with a real project is done using the posterior estimates of the model parameters with the cost overrun (COR) and final cost (FC) response variable, respectively. Table 5.2 & Table 5.3 showing the posterior distribution

Table 5.2 Posterior estimates of the model parameters with the cost overrun (COR) as the response variable

Variable/factor	Mean	SD	Quantiles		
			10%	50%	90%
Intercept	-0.4624	0.1734	-0.6835	-0.4589	-0.2425
Contract cost (CC)	0.2379	0.095	0.115	0.2399	0.3562
Expected duration (ED)	0.5717	0.1722	0.348	0.5785	0.7857
Stakeholder issues (SHI)	0.7404	0.332	0.3192	0.7439	1.1547

Table 5.3 Posterior estimates of the model parameters with the Final cost (FC) as the response variable

Variable/factor	Mean	SD	Quantiles		
			10%	50%	90%
Intercept	-0.2912	0.11	-0.4288	-0.2931	-0.1532
Contract cost (CC)	0.6352	0.0587	0.5606	0.6348	0.7097
Expected duration (ED)	0.3606	0.1115	0.2188	0.3615	0.4969
Stakeholder issues (SHI)	0.4682	0.2151	0.1998	0.4739	0.7301

Using the predictive distributions in **Table-5.2 & 5.3**, cost overrun (COR) and Final cost (FC) were predicted across different values of contract costs (CC) and expected duration (ED) if the stakeholder issues exist, that is, $SHI = 1$. The results are presented in **Table-5.4 & 5.5.** These values were analysed using 80% confidence interval to yield the lowest, medium & highest ranges of cost overrun and final cost, respectively.

Table 5.4 Predicted Cost overrun A-1, A-2, B-1,B-2,C-1 &-C-2

Project	Contract Cost £(M)	Expected duration (ED)(Yrs)	Stakeholder issue	Cost overrun estimated Mean £(M)	Cost overrun Lower boundary	Cost overrun Upper boundary
A1	53 000,000	1.5	1	88,000,000	55.78,000,000	263.33,000,000
A2	26,000,000	2.5	1	140,000,000	37.72,000,000	243.29,000,000
B1	39,000,000	3.5	1	200,000,000	73.65,000,001	325.46,000,000
B2	65,000,000	6	1	347.68,000,000	162.87,000,000	528.96,000,000
C1	33,000,000	3.5	1	199,000,000	73.1,000,000	323.69,000,000
C2	23000000	2.2	1	123,000,000	27,000,000	219,000,000

Table 5.5 Predicted final cost A-1, A-2, B-1,B-2,C-1 &-C-2

Project	Contract Cost £(M)	Expected duration (ED)(Yrs)	Stakeholder issue	Final cost estimated Mean £(M)	Final cost Lower boundary	Final cost Upper boundary
A1	53 000,000	1.5	1	162,000,000	58,000,000	263.33,000,000
A2	26,000,000	2.5	1	200,000,000	74,000,000	326,000,000
B1	39,000,000	3.5	1	286,000,000	130,000,000	440,000,000
B2	65,000,000	6	1	387.75,000,000	259.47,000,000	619.79,000,000
C1	33,000,000	3.5	1	280.24,000,000	124.56,000,000	433.5,000,000
C2	23000000	2.2	1	179.11,000,000	60.38,000,000	296.65,000,000

The predicted cost overrun, and final cost were able to show the mean, the lower and upper boundary for the values(£-M) using BHRM parameter estimations. This is very essentials for the key stakeholders to make valuable decision at the strategic phase of the project prior to actual commitment of scarce resources.

5.3 Chapter summary

The interviewees' (Case-study firm project team) input affirmed that the created framework may be used as a platform and standard for project control/management professionals to employ to improve uncertainty identification and cost estimation integrity at the initiation stage of an infrastructure project. It was observed that the predicted cost overrun and final were within ±10 of the estimated cost by the firm project control and management team. The aspects identified in the framework are vital and significant to improve the performance of cost prediction, according to the respondents. They recognise the significance of incorporating the new dimension (system thinking) in the identification of uncertainties and estimating infrastructure project cost during the initiation stage. This chapter has been able to satisfy the fifth objective of the research work by producing project cost estimating framework that is utilized to make decision in determining the contingency estimate.

Chapter 6 Research findings and Discussion

6.1 Introduction

This chapter's purpose is to discuss the findings of this study and add to existing literature in the understanding of how risk/uncertainty management is implemented in the cost estimation of construction project. The findings from the case-study investigation, qualitative data and quantitative data analysis were discussed in this chapter, respectively. The discussion also goes over the thesis's objectives followed by an explanation on the relevance of the formulated framework. Additionally, it emphasises the idea that typical risk management techniques are unsuitable for addressing the uncertainties associated with construction projects (Kerzner, 2018). The need for new methods of managing construction risk and uncertainty has arisen as a result of this deficiency (Asadabadi and Zwikael, 2021). Development of a holistic understanding in the identification of uncertainty factors that impact on early cost estimate and how it can be utilized to improve the reliability was discussed as well.

6.2 Factors impacting early cost estimate of infrastructure project

Cost estimate made at the pre-tender stage of project development could impact whether a project is pursued. So, for pre-tender decision making, the accuracy of early-stage estimates is a crucial piece of information (Wang et al., 2022). Improving the reliability of infrastructure project early cost estimate will prevent loss of scarce resources. There are no two identical projects when it comes to infrastructure project regardless of similarities, the price will always differ. According to Flybjerg et al. (2013), many factors influence project costs, including underestimating the length and cost of delays, setting low contingency estimate, underestimating, or ignoring the exchange rates between currencies and geological risks etc. Most of these factors are not properly accounted for during the early stage of the project due to either incompetence on the part of the project control/management professionals or a dearth of cogent information. A realistic overview of all the variables at the early stage of a project would prevent a tremendous number of unwanted issues during the project lifecycle. As stipulated by Flyvbjerg et al. (2013), cost overruns are mainly caused by a lack of realism in early cost estimation. There is a need for infrastructure project control and management professionals to create realistic early cost estimation certainty to mitigate the impact of cost overrun during the project lifecycle. The human mind appears to have a basic drive to create certainty. Ironically, despite progress in this sector, there appears to be a lot of evidence that the ability to manage uncertainty efficiently and effectively in many circumstances is significantly deficient (Gingerenzer, 2002). The new paradigm shift in managing variables during the early stage of an infrastructure project is to explicitly account for uncertainties to prevent uninformed decision while producing the initial cost estimate. Some literature has been able to identify the uncertainty factors that impact on the early cost estimate which were quite different after undergoing statistical analysis as shown in Chapter-4 (Table-4.7). In this research work twenty-two uncertainty factors were derived from the literature (Chapter-2.4.1) but were reduced to seven factors after undergoing factor analysis (Chapter-4: Table-4.7). These factors need to be closely monitored and analysed during the early stage of project development to improve the informed decision in producing the initial cost estimate. Project related factors appear to be the top-most factor that impact on the early cost estimate. There are many projects related factors that impact on early cost estimate of infrastructure project. Project complexity is one of the projects related factor that impact on early cost estimate of infrastructure project. Project complexity is a feature of projects made up of numerous interdependent components that interact with one another and their environment (organisations, governments, laws, among others) through feedback loops to produce adaptation and non-linear emergent behaviours that can only be explained by principles and patterns. These components can learn (people, stakeholders, among others) or not (products, documents, among others) over time (de Rezende and Blackwell, 2020). Also, It suggests that the person is unfamiliar with the task at hand

(Bolzan de Rezende et al., 2022). This is corroborated by the interview (Semi-structured interview) given by both Commercial manager-A, Earned Value and Scope baseline manager-C, Interviewee D, E, J, k, M,N & P that understanding project terrain and environment at the early stage of the project is quite crucial to be able to ascertain properly the scope of work. Whitty (2009) stipulates that a complicated project system is seen as a system made up of numerous components that necessitates an additional level of management capacity and experience. These components (variables) are interrelated with one another thus requiring a holistic overview or understanding of the project before embarking on the cost estimate. An adequate understanding of the terrain of the project is quite necessary in producing a robust initial cost estimate that will take a complete understanding of the interrelated variables. If there is no adequate understanding of the site or environmental terrain, may lead to other uncertainties such as scope gap, unforeseen site condition and unclear project requirement etc. The type of terrain and other environmental challenges have an impact on the project's scale and, as a result, its cost. The accuracy of early cost estimate is also influenced by the consultant (contractor) involved in the project. Having much needed experience in the project will give an added advantage of the all the respective modalities in the construction process. To be more efficient, a consultant must visualise in detail the required resources, to account for any uncertainties in the estimate process. Consultants' expertise with the construction process demonstrates that, to create trustworthy cost estimates they must have significant and broad knowledge of the construction process. This proactive step will prevent unnecessary delays and lapses thus preventing additional cost to the project.

Legal issues within the construction project can be a very task daunting task thus generating unnecessary delays and incurring overhead cost. The most common type of legal issue is issuance of permit to work by the government. Permit to Work (PTW) systems are formal procedures that are used to govern high-risk activities (DesigningBuildings, 2020a). Prior to issuing the PTW government representatives must very convinced that contractors are competent enough to carry out the construction process within the designated locality. Incompetent contractors can delay these procedures completely and can lead to increase in the cost estimate. According to Badawy et al. (2022) the degree of experience in estimating is determined by one's comprehension of the cost-determinants. Differential perception, sensitivity, and attitude toward ambiguity are other attributes that strongly influence project control and management professional decision (Skitmore and Picken, 1994).It has become more apparent that project control and management professionals should have proper attitude toward uncertainty in order to deal with incomplete/inadequate information. The more experience a project control and management specialist has, the more precise their estimations will be (Millar et al., 2016).

A lack of thoroughness in preconstruction planning and estimation may lead to the PTW being delayed. Systematic itemization of the construction procedures are the criteria required for the PTW issuance. If it is not done properly by the client/consultant of the project, government representative may refuse to grant the PTW. This issue will lead to increase in the cost estimate of the project due to unprecedented delays.

According to Hyvari (2006) organization design is directly linked to project management effectiveness. Ineffective organizational structure will disseminate a lot of uncertainty factors that may impact on the early cost estimate of a project. According to the interviewee (Commercial Manager-B), appropriate organization strategy (methodology) for a project is quite essential, no two projects are identical. An Ineffective methodology will bring many uncertainty factors that may impact on the initial cost estimate.

External factors such as the influence of socio-economic conditions are rapidly affecting local and national construction sectors, resulting in significant and unanticipated volatility and unpredictability in the construction market. The cost estimate for the project shows the most likely cost at the time of estimation. When an estimate is generated or revised, the unit pricing must represent the cost at the time of creation or modification. Market trends and how they affect resource costs for a project should be taken into consideration by experts in project control and management. Inflation affects both labour and materials, and it also has an impact on the client's budget (Millar et al., 2016). It is quite essential for the project control and management professionals to be cognisant of the uncertain market conditions during the early stages before undergoing infrastructure project cost estimation. Weather condition are a crucial factor that impact upon the infrastructure project cost estimate during the early stages. This factor leads to a delay in carrying out the project effectively. It is also regarded as unforeseen events which can be severe depending on the impact. Understanding the environs and planning adequately to include the impact on the early cost estimate will improve its accuracy.

Technical factors are also a crucial factor that needs to be taken into consideration while performing the early cost estimation of an infrastructure project. Technical complexity in a project may lead to project complexity if not properly managed. This may be due to overlapping, interdependencies in construction stages, project organization, site layout and the unpredictability of work and site construction. All these variables hinder performance on site (Akintoye, 1999). Being cognisant of all these variables during the early cost estimation will improve the accuracy and minimize the impact of cost overruns. All the factors explained above are interrelated with one another and need a holistic overview in analysing the embedded factors impacting them prior to the early cost estimation.

6.3 Early-stage Uncertainty management

Variability and ambiguity are two aspects of project uncertainty (Chapman et al., 2006). According to Olsson (2007), variability is a situation in which measurable element can take on a range of possible values. Ambiguity can be referred to as an absence of knowledge about functional variables (San Cristóbal et al., 2018). Ambiguity and variability are pervasive throughout the project lifecycle, although they are particularly evident in the first stages. (Atkinson et al., 2006a). Uncertainty, unknowable events, or the inability to predict outcomes of actions due to the interaction of too many variables are the causes of inadequate knowledge (Kvalnes, 2016). Project control and management professionals are faced with limited information at the early stage of infrastructure project delivery. This is corroborated by the Interviewees (A, B, C, D, &F) during the semi-structured interview (Appendix-Section: I) that cost estimators work with limited information and have to rely solely on historical data and expert knowledge(intuition) to produced estimates. This type of approach in estimating infrastructure project cost may lead to moribund estimate. It is used at the strategic level in determining the project progression. Having knowledge of variables that impact on the infrastructure project prior to execution will assist greatly in producing a robust cost estimate. This research work has been able to demonstrate that uncertainty management is not adequately carried out by the project control/management professionals of the infrastructure project. According to **Table-4.41(Chapter-4**),8.91% of the participants organization (infrastructure project delivery firm) focuses on the identification of unknown unknown(uncertainties) during the project initiation stage. Most project management activities are focused on decreasing uncertainty from the earliest stage through the latter stages, explaining what needs to be done and ensuring that it is completed Agnar Johansen et al. (2014) and (Ramgopal, 2003). One of the crucial activities at the initiation stage is to mitigate the impact of unknown/unknown uncertainty while delivering a new infrastructure project. If the project control/management professionals of the infrastructure delivery firm are not concentrating enough on mitigating the impact of the latter, there is tendency of witnessing cost overrun during the project lifecycle. According to **Table 4.40 & 4.41 (Chapter-4)** 66% of the participants organizations do not have an uncertainty management team and no specific training for the latter. Agnar Johansen et al. (2014) suggest that the project control and management professionals should have appropriate training and follow-up on uncertainties. This will ensure that key stakeholders are typically aware and capable enough to manage uncertainties in projects. Irrespective of the duration of the project, uncertainty management should be carried out to identify potential variables that may impact one of the cost estimates. According to **Table 4.44 (Chapter-4),** 32% of the participants organization carry out uncertainty identification for a project less than 6 months. Also, 68% of the participants organization do not carry uncertainty identification during the initiation stage of the project delivery. This indicate that project duration plays an important role whether an infrastructure project delivery firm will identify uncertainty factors during the initiation stage. More attention is focused on the project with longer duration to identify uncertainty factors. Most of the complex project carried out today are subdivided into manageable entity. If proper uncertainty identification is not done for project with shorter duration which is an integral part of a bigger picture, this may impact on the strategic objective of the overall project, respectively. Techniques utilized by the project control/management professionals are found to be ineffective enough and this impact on the project uncertainty identification. Findings reveal that human experts make specific errors on a regular basis, but that these maybe corrected by a mix of training, incentive systems and mathematical changes (Hubbard, 2009a). According to **Table 4.43 (Chapter-4),** 33.3% of the participant's organization utilizes expert knowledge in identifying uncertainty factors during initiation stage while 13.2% of the participants utilizes multicriteria decision analysis. According to Hubbard (2009a), experience is a non-random, scientific collection of events that occur throughout the course of our lives. Also, it is a memory-based procedure and is thus quite selective about what is remembered. Utilizing expert knowledge solely makes the uncertainty identification process prone to logical errors. According to Hubbard (2009a), experts appear to be quite inconsistent in their application of experience, regardless of how much is gathered. Tradition holds that experience is (at least initially) a psychical phenomenon that is permeated with "subjectivity." What experience implies about itself is a genuinely objective world that interacts with the actions and suffering of men and changes as a result of their reactions (Kvalnes, 2016). This reinforces that experience and expert opinions are limited in the identification of uncertainty factors that impact on early cost estimate. It will be highly appropriate to have project delivery with holism capabilities. if reliable and holistic techniques are employed in uncertainty factors identification during the project initiation stage.

6.4 System thinking scale prediction

System thinking scale prediction of project control/management professionals is quite essential to enable holistic analysis of infrastructure project during the early stage. The determinant of the system thinking scale capabilities of project control and management professional has not been established. There is a dearth of cogent information while carrying out early cost estimate of infrastructure project. A need to have a holistic understanding of the variables that impact on the early cost estimate becomes pertinent to mitigate the impact of cost overrun. The need for project control and management professionals to develop a cognitive approach to infrastructure project cost estimation has become inevitable. This research work has been able to determine the system thinking scale and need for cognition of the project control and management professionals of infrastructure project delivery firms. These scales were displayed in Table-4.16 (Chapter-4), also showing the years of experience of the participants**.** The need for cognition relationship with the system thinking scale was analysed using correlation plot. These were displayed in Table-4.17-4.19, respectively. The years of experience of the project control and management professional is insignificant with the system thinking scale and need for cognition as shown in Table-4.18 & 4.19. According to Hubbard (2009a), the ability to engage in and enjoy effortful cognitive activity is not completely dependent on experience. The findings of the need for cognition and system thinking scale shows that the project control and management professionals have different scores as shown in Table-4.15 & 4.16. Hubbard (2009a), stipulates that individuals with a strong need for cognition seek out and reflect on knowledge to make sense of stimuli and events, whereas those with a low need for cognition rely on other sources to make sense of the world, such as heuristics. According to the correlation Table 4.18, there is a positive correlation between need for cognition and system thinking scale score. This implies that the higher the need for cognition, the higher the system thinking scale score, respectively. A predictive regression model was developed to predict the system thinking scale scores of the participants and it could predict less than 50% of the scores as shown in Table-4.23. It is expected that participants with high scores will have a holistic view while estimating the infrastructure project cost during the initiation stage. Also, it will enable the investigation of inter-relationships, viewpoints, and boundaries of an infrastructure project during the early stage thus improving the cost estimating process. It can be deduced from the findings that ability to engage in holism in infrastructure project is independent of experience rather than need for cognition capability. These findings can be used to improve theory of tolerance of ambiguity (TOA) to enable project control and management professionals possess the capacity to manage uncertainties in a project. According to Gray (2017), one of the key traits of effective project managers has been recognised as TOA. Given that project managers carry out their duties in an environment with significant amounts of ambiguity and uncertainty, the significance of this ability is understandable. According to study, people are more likely to use their creativity and make wiser judgments when they perceive uncertainty as an opportunity rather than a danger (Gray,2017). The project control and management team will be able to see beyond the linear method and identify the uncertainties and risk that may have an impact on the early cost estimate by having a holistic understanding of the infrastructure project at the outset.

6.5 Cost predictive model framework overview

Cost modelling can be described as a symbolic representation of a system that expresses the content of that system in terms of the factors that influence its costs (Ferry et al., 1999). According to Okmen and Oztas (2010), the symbolic representation must also be manipulable. The models generated in this research work is in the form of regression models for predicting cost overrun and final cost of an infrastructure project by being aware of the uncertainty factors identified using system thinking. This model framework is quite nascent and peculiar due to the utilized approaches. Uncertainties are prevalent at the early stage of the project and most project control and management professionals have a shortage of information to produce a reliable cost estimate. Utilizing system thinking ensured problems were understood and solutions defined outside-in to first find the boundaries of the problem and then identify leverage points, providing a framework to understand the situation and is driven by the context (Cole, 2019). The holistic context used for the uncertainty factors identification were rich picture, concept mapping and Causal DAG, respectively.

The predictive model process was divided into stages, the first stage involves uncertainty factors identification using a system thinking approach while the second stage involves the analysis of the identify uncertainty factors using Generalized Linear Model (GLM) and Bayesian Hierarchical Regression Model (BHRM). These models were used to observe the impact of the project level random effects on the covariates. The inclusion of the project-level random effects term p_i in the model helps to account for uncertainties in parameters estimation due to unobserved effects such as ‘’weather conditions’’, thus, minimising bias. The quantification of the uncertainty factors was mainly done using the BHRM.12 predictive models and their fitness for purpose was carried out to ensure robustness of the predictive models. Model predictive diagnostic shows efficient and effective capabilities.

The first predictive model utilized cost overrun as a response variable while the second model utilized final cost as a response variable. The ranges of the lower (10% confidence interval), upper bounds (80% confidence interval) and the mean were derived. The best fit value(mean) was chosen. These two models will assist the project control and management professionals to estimate the contingency estimate during the early stage of the project and thus improving it. The challenges with cost contingency estimation is that it’s a forecast of future costs ,and the future is unclear (Erfan et al., 2020). A project’s cost contingency estimate account for known unknowns’’ and ‘’unknown unknowns’’ eventualities. The core advantages of these predictive models are the accountability of uncertainties (Known/unknowns) and project level random effects (Unknown/unknowns). The impacts of these variables on the covariates were statistically analysed. Stakeholder issues happen to be the most statistically significant amongst the covariates. However other covariates such as designer’s omission, unclear project requirement, owner driven change, contractor caused delay, Construction caused delay, lack of thoroughness of preconstruction /planning estimate, weather condition, resources availability &quality assurance control were not statistically significant completely. Project control and management professional should be aware of these uncertainty factors while implementing the predictive models. Statistical insignificance does not correlate to irrelevance during infrastructure project cost estimation. Also, the uncertainty factors are categorised under the most influential factors that impact on the initial cost estimate derived using the factors analysis in Chapter-4.3.4. This shows that the statistically insignificant uncertainty factors for these predictive models should be closely monitored after the initiation stage of the project.

These predictive models have another advantage of determining the contingency estimate at the early stage of the infrastructure project. This is achieved by deriving the percentage difference between the contractual cost and the final cost/cost overrun. Alternatively, by taking cognizance of the mean, lower and upper boundary of the parameter estimations. It will give key stakeholders an informed decision on the initial cost of the project. Cost estimate biases are mitigated at the project inception. The traditional contingency estimate is filled with biases due to expert judgement of the project control and management professionals. Contingency cost estimates have traditionally been deterministic, based on the most likely value. Contingencies are frequently computed as a percentage increase on the base estimate, which is generally based on intuition, experience, and historical data (Curto et al., 2022). The percentage addition method is based on a subjective approach that takes into account project variables including the type of work, project phase, and scope specification level. This is achieved after most of the information has been known and collated (Lorance and Wendling, 2001). The core advantage of these novel predictive models is the holistic analysis of the infrastructure project at the early stage thus making the uncertainty factors identification process more robust with fewer biases. This in turn improves the reliability of the conceptual estimate utilized during the project initiation stage. It can be deduced that the cost overrun, and final cost estimate are independent of the length of the project delay once uncertainty factors were considered during the early cost estimation process. Contract cost expected duration and stakeholder issues impact on early project cost estimate. Another valuable aspect of this predictive model is the generation of mean, lower and boundary of posterior estimations which gives the key stakeholder robust informed decision prior to the commitment of resources. In a broader context, these predictive models have improved upon on ‘’the function-based cost model for early cost advice’’ produced by (Arab, 2011). The assumption of linearity of the response variable and the covariates were adequately dealt with the use of BHRM and GLM. These models use a more flexible approach which allows for the nonlinearity of the expected value to the set of covariates. This model can be used to improve the contingency estimate model produced by Curto et al., (2022), which involves allocating contingency estimate at the planning stage using Monte-Carlo Simulation. Risks and uncertainties associated with work packages are identified and inculcated into the analysis. This differs from the methodology used for this research which takes cognizance of posterior distribution, project level random effect and quantification of uncertainties as well at the early stage using MARKOV-CHAIN MONTE-CARLO ANALYSIS(MCMC). The MCMC is more efficient in generating posterior sample rather intractable computation with the use of MCS(Monte-Carlo). This improves the generated mean, lower and upper boundary estimate that can be used to allocate contingency estimate in the project lifecycle.

These findings can be utilized in improving the Should Cost Model used in the UK project works procurement lifecycle. Should cost model(SCM),forecasts the costs that a service, project, or programme "should" incur over the course of its existence(GCF, 2021).The activities of the SCM includes the price tags associated with other market variables like risk and profit. It gives insight into overall costs, including how risk and uncertainty affect price and timeline. Establishing the potential cost overrun and final cost will assist the effective production of should cost model (SCM). This will facilitate effective implementation of the output definition and feasibility stage of the network GRIP framework. In broader context of cost estimation process, if utilized properly these predictive models can be used to improve the rough order of magnitude.

6.6 Chapter summary

On each given infrastructure project, a large amount of project and cost data is often created. If this is done in a meaningful and retrievable manner for several projects over time, a large database of information will be created which will be useful in producing an effective uncertainty factors identification during the early stage.

The main outcomes of the research were described in this chapter, as well as the development of a framework for including a nascent approach to improve early cost estimation. The produced framework has the potential to reduce and minimize the impact of uncertainty factors which later generate risk in the later life of the project. It could also help with minimizing the impact of cost overrun during the infrastructure project execution stage.

Chapter 7 Conclusion

This final chapter summarises the project's findings in terms of its key goals. It examines the difficulties encountered during the study's execution and identifies areas in which more research is needed. The production and validation of a cost predictive models were covered in earlier chapters.

The main goal was to develop and build a cost estimation model to predict infrastructure project costs in the United Kingdom at the early stages of the project life cycle, by identifying uncertainties using system thinking approaches. The findings of the research have provided the foundation for understanding of the key uncertainty factors that impact on early cost estimate and project level random effects. The main research contribution to knowledge and future recommendations are presented in this section.

7.1 Findings summary

The current cost estimation practises used to estimate the infrastructure project cost in the early stages of the project life cycle are not comprehensive. Cost estimators typically base their estimates of cost contingency on subjective judgement, such as a 5–10% reduction from the cost projected by taking into account prior, comparable projects (Islam et al., 2021). Prediction of cost estimate for decision making is of prime importance to project stakeholders at the early stage which is always fraught with dearth of cogent information (Mahmoodzadeh et al., 2022). This is the primary issue addressed in this study. The accuracy of early cost estimates, according to most academics, is low due to the limited knowledge about the project information at the strategic definition stage and preparation/briefing stage (RIBA) (Liu and Zhu, 2007).

Project control and management professionals overlooked, however, how extensive the information accessibility during the briefing stage is in terms of client needs and requirements. The importance of early cost estimates stems from the fact that they have a significant impact on the client's decision to initiate the project. This research work has been able to utilize a system thinking approach in the identification of uncertainty factors that may impact on the early cost estimate. Based on the semi-structured interviews result conducted, the project control/management professionals agreed that system thinking approaches will be ideal in examining the interrelationship, interconnectedness, and interdependencies of all the variables during the early stage. System thinking scale score and need for cognition of the project control/management team of infrastructure project were determined. Scores varies individually and were relatively high. A system thinking scale score predictor of the project control/management professionals was produced using a need for cognition scale and experience level as a covariate. It was discovered that there was a correlation between the need for cognition and the system thinking scale score. There was no significance between need for cognition/level of experience and system thinking scale score/level of experience. This is an indicator of the system thinking capabilities of the project control/management professionals involved in the management of infrastructure project. It is expected that the higher the system thinking scale score the more the holistic analytical capabilities of the project control/management professionals. The ability of project control/management team to see things holistically (as a whole), considering the many different sorts of relationships that exist between the various pieces of an infrastructure project(system) will enable informed decision while preparing cost estimate during the early stage. Understanding and identification of uncertainty factors at the early stage is quite crucial in producing a robust cost estimate that will mitigate the impact of cost overrun during the project lifecycle. A cost predictive models that take cognisant of uncertainty factors were produced using frequentist and Bayesian approaches. The best fit models were chosen based AIC/RHAT plot and on uncertainty quantification, respectively. The impacts of the project level random effects on the model were investigated to ascertain the robustness of the predictive models. Key uncertainty factors that may impact on the early cost estimate was derived from the project studied and project level random effects were insignificant.

This research work has been able to delve into both soft and hard system approaches to infrastructure project management focusing more on cost estimation process at the early stage.

7.2 Meeting-up the research objectives

The findings above revealed that the research objectives were met well. Below is the description of the objectives achieved by this research work.

- **First objective: To review the traditional infrastructure project cost estimation and identify/explore major uncertainty factors that impact on infrastructure project early cost estimate.**

  The research began with the literature review of traditional infrastructure project cost estimation to identify and investigate the uncertainty factors that impact the early cost estimate.

  The goal of studying the traditional cost estimation and techniques of a project is to develop a theoretical grasp of its functions, ideas, principles, individuals engaged, and procedures utilised in infrastructure projects in general. These objectives were achieved in Chapter-2.

- **Second objective: To review the literature of the system thinking holistic approach for enhancing infrastructure project cost estimate reliability.**

  This section focuses on studying the main ideas and principles of system thinking techniques, missions, as well as the approaches utilised, and the wider application with a focus on infrastructure project cost estimation. The understanding of the underlying variables and interactions amongst them will assist in unravelling the core uncertainties that may impact on early cost estimate. This literature review was achieved also in chapter-2 and assisted in formulating questionnaires for the research work.

- **Third objective: To develop a robust cost predictive model that forecast Cost overrun/final cost of an infrastructure project by being cognisant of uncertainty factors.**

  This objective focused on producing cost predictive model, as well as the approaches utilised, the cost & uncertainty factors involved, and the benefits. A non-conventional approach was utilized in identifying the uncertainty factors which serves as an input into both Generalized Linear Model/Bayesian Hierarchical Regression Model coupled with other cost factors such as expected duration, contractual cost etc. This was used to produce predictive models that predict the cost overrun/final cost of an infrastructure project. It was achieved in Chapter-5.

- **Fourth objective: To determine the system thinking scale scores of project control and management professionals involved in the delivery of infrastructure project.**

  This objective focused on producing the system thinking scale scores of project control and management professionals involved in the delivery of infrastructure project. The capacity to identify and analyse patterns, relationships, and interdependencies in a group of project activities is required in project management (most especially at the early stage). To deepen the understanding of the mechanisms (cost estimation process) that support improvement attempts, some degree of systems thinking is needed to be acquired by the project control and management professionals. The system thinking scale scores is achieved in Chapter-5.

- **Fifth objective: To validate the infrastructure cost model using predictive Diagnostics and project case studies.**

This objective focused on validating the cost predictive models using predictive diagnostics and case-study cost data. The predictive diagnostic was carried out using R'stan (R'programming software) while the case-study utilised cost data from an active project and a project which was at the bidding stage. The predictive diagnostic was closed to the observed data while case-study projects were deemed effective by the project control/management professionals. This was achieved in Chapter-4 & 5, respectively.

7.3 Contribution to knowledge

There is very little critical debate on system thinking towards cost estimation in the current literature on cost estimating systems and system thinking, therefore the research constitutes an original contribution to knowledge. The extent to which the research activity contributes to knowledge determines the research endeavour's evaluation This study's contribution to knowledge is thought to be as follows:

- Identification of uncertainty factors that impacts on cost estimate using system thinking approaches during the early stage of the project lifecycle. The uncertainty that comes with executing an infrastructure project emanates from a variety of sources and sometimes involves many people. These variables at the early stage tend to impact on the project in the long run. Many impacts on the ability to comprehend these influences on project early cost estimates, including techniques, project cost data, the purpose of preparing cost estimates, project characteristics, and project stage etc

  As a result, a holistic view of the project cost estimate is generated by examining individual sub-forces from several qualitative and quantitative perspectives. This research work has been able to apply system thinking approaches as a conceptual framework to develop holistic contingent viewpoints and practices by combining various ideas, tools, and methodologies in the identification of uncertainty factors during the early stage to improve the cost estimation process.

- Soft system analysis of project control and management professionals involved in infrastructure project was carried out in this research work. System thinking scale Score and Need for cognition score were utilised for the analysis. The study paves the way for evaluating both subjective and objective elements rather than only objective variables during the project cost estimation process. It considers the holistic view capabilities of the of individuals and groups involved in the cost estimation process. The influence of the project control and management professional years of experience on both the system thinking scale and need for cognition scale scores were investigated and appears to be insignificant. It has been discovered that the need for cognition scale score has influence on the system thinking scale score. Project control and management professionals with a higher need for cognition scores will possess a high system thinking scale scores thus improving their holistic view capabilities during the cost estimation process. This research work has been able to derive both the soft and hard information of infrastructure project early cost estimate.
- Developing a cost predictive model that estimate cost overrun and final cost at the early stage of project lifecycle. Project level random effects were analysed and appears to be insignificant to this model. Investigation and analysis revealed key uncertainty factors and cost data(drivers) are significant to the models. Some of the uncertainty factors appear to be insignificant in these models but should be monitored throughout the project Lifecyle.
- This research work paves the way for both subjective and objective variables to be used in estimating and evaluating infrastructure project costs, rather than only objective variables. Determination of system thinking scale score and need for cognition score of

project control and management professionals will ensure the cost estimation team has an appreciable amount of holistic view capabilities.

- This study's methodology and research methodologies can be used to guide researchers who want to conduct similar studies or the same study on different projects.

7.4. Contribution to theory

- Regardless of expertise, engaging in holistic project delivery for infrastructure is not dependent on the years of experience of the project control and management professionals.
- It can deduce that the infrastructure project and management professional's system thinking scale score is directly linked to their demand for need cognition scale score.
- It can be deduced that the cost overrun, and final cost estimate are independent of the length of the project delay once uncertainty factors were considered during the early cost estimation process of a new project.
- The project level random effects are insignificant to the cost overrun and final cost estimate at the project early stage during the cost estimation process.

7.5 Limitation of the research

The findings of this study are valid in and of themselves, but they do have limitations, which include the following.

- Cost data used for the model building was from the UK only. A wider representation of collated data would have been more appropriate for the model building.

7.6 Future research recommendation

Building on the findings from this study, a few areas that could benefit from more investigation have been identified, including the following:

- Creating a predictive cost estimating model with expansive cost data to investigate and adequately ascertain the project level random effects with multiple covariates. It would be useful to understand the unforeseeable occurrences that may impact the early cost estimates.
- Exploring the use of cognitive complexity (attributional complexity, need for cognition) of the project control and management professionals to predict system thinking scale scores. It would be useful to investigate the ability of the project control/management professionals to engage in holism during the early cost estimation process.
- Exploring the impact years of experience of project control and management professionals on system thinking scale score and cognitive complexity. It would be useful to investigate the impact of experience in engaging in holism during the early cost estimation process.
- Using the model concept to design a comprehensive predictive cost model for other types of infrastructure projects in different nations.(Curto et al., 2022).

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Appendices

Section-I: Semi-structured Interview

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: STRUCTURE AND EARTH WORKS (CIVIL WORKS)

YEARS OF EXPERIENCE: 17YRSIZE OF PROJECT INVOLVED: £1,000,POSITION OF PARTICIPANTS: COMMERCIAL MANAGER/QUANTITY SURVEYOR

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

   Ans: I would say yes. It would be and we go through numbers of factors as we put in through a and meet for delivery work. We have certain stages which we go through where normally a project cannot pass almost stage gate we call it. It is a milestone for delivery so there are certain products where we couldn't actually go further until satisfy those products.

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: Yes we do.

3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: We can do probably as a team. We almost brainstorming as you go through and in this company we do risk readiness reviews as from both safety, delivery and cost impact. Mostly safety is the main driver, can we do this project successfully safely and how much is it going to be. What potentially those risk and the cost impact on the project.

4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?

   Ans:N/A

5. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans: Definitely Yes

6. Does your organization consider holistic view for short term infrastructure project?

   Ans:Yes

7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

   Ans: Definitely yes

8. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?

   Ans:Yes

9. What are the main factors that impact a robust infrastructure project cost estimation process?

   Ans: Ermm, that's very difficult one to think of. I think is just whoever is chairing the estimating process is certain knowledge. I think the earlier in the project stage there is a greater degree of percentage uplift or deduction so you have primers where you say it's a fault where we think is a million pound but we potentially add an extra 80% on because we just don't know how much it will cost. The process which we have is in stages so if we start in stage one you have very limited information we will just say 60% on then we go to next stage which is a bit more defined we actually know where we going now. We know particularly where we going to deliver now particularly in 4yrs times is better information we had previously we have somebody looking at maybe doing feasibility work which is almost optioneering so building up the story as you go along and reducing the risk as you go down. As you start doing intrusive works so start doing ground investigation to determine what the ground conditions are, to determine maybe location of services, and determine whether you interface with local authorities or third-party organization your access regime start becoming more defined. You almost removing potential area of risk until you actually come to do tender works. Your actual tender works and contracting organization to come do works for you. It depends on the contract you working with and maybe you have collaborative contract types, I think as you go through you build particular knowledge base of a particular job. We also potentially use cost information so if you keeping on doing particular kind of job you are actually building a foot bridge. If you building 20 of those a year nationally through different organization and how much this is costing, are you putting ram sum, are you doing circular stairwells going up to the bridge, is the bridge in between a cutting so is it just the bridge itself there is no staircases required for it so the factors start building for it. You can say meter squared this is how much it is costing or each millimetre squared is costing or that one is very expensive well is actually this bridge is going to be going up it 10m high bridge and it is ramped which is a requirement for disable access also increasing the cost of the overall project. You are building up someone's land you have to pay for that as well. Estimate is subjective at the beginning of the project.

10. Is risk management enough to mitigate impact of cost overrun in infrastructure project?

    Ans: Ermm, I think you can only work on information which is known at that particular time. As you go each stage of development of that project you will hopefully start mitigating some of the risk which you might not consider really consider at the early stage. There is a nature reserve near the project you're going to work you going to have to know the access to the site. The only way to the project site is the nature reserve that's going to cost much on the project. We will have to source alternative which wouldn't impact on the project. So it is development as you start to understand the project. So the risk management is an ongoing exercise. So a lot might come along during the project during execution.

11. Do you think unidentified risk emanates from infrastructure project uncertainties?

    Ans.Yes

12. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?

    Ans.I would say partially until that event has passed. We say we've done as much we can to get to where we actually need to be. Until deliver that part of the project or install an element you can't. You can't rule out until it is in the ground but it's there.

13. Does your organization consider holistic view of infrastructure project prior to cost estimation during project initiation stage?

    Ans.I would probably say not to be really be honest. It is things which emerges as we go through. It is a slow burn process as we go through the diff stages from project initiation, design, development, implementation, and closeout.

14. Does your organization have a standardized or internally devised infrastructure project cost estimating method?

    Ans.I would say no. There are rates like schedule rates type of scenario, we trying to put in what a certain amount of job cost. We try to factor in external factors as well. So there is not a standard so we can develop our own.

15. Does your organization do an infrastructure project cost estimation for a short d

Ans:No

16. Do you think infrastructure project uncertainties impact on cost estimating methods?

    Ans:Yes

17. What factors do you consider in carrying out robust infrastructure project uncertainties in your reputable organization?

    Ans: Majority of work which I deliver is coming from remit we then take the design and implementation so it is very basic pre-design so we can use unit cost information. So the structure we are replacing is 50msquare from a plan view so what's is the cost of the plan for a meter is going to be $1000 and it is limited of that we can look at as it develops so early does is very basic.

18. Do you think is pertinent to inculcate infrastructure project uncertainty management approach in your organization before project is being initiated?

    Ans: I think the generally the industry is moving towards that way so I think is something which cause cost certainty. If we say a job is half million it did got to be that. It is when we start considering other factors. So construction (railways) is moving towards holistic approach. Looking at things hold

19. Does your organization involve key stakeholders in determining the infrastructure cost estimating method or solely rely on the project management team?

    Ans: So we use our project management team initially but we still source our key stakeholders in partaking in the estimating process. We also try I bring expert (engr) and try to source their opinion. We have facilitators who are risk analyst with good grasp of safety>Like having Environmental Engr for a particular project so as the project environs.

20. Do you think a robust infrastructure project cost estimation mitigates the impact of cost overruns in projects?

Ans.I think it will be beneficial to the project. Anything that helps u get to finished product is beneficial.

21. Do you think systemic approach will improve infrastructure project cost estimation?

    Ans: I think it would certainly would do improve on it.

22. Do you think the conventional non- system approach of infrastructure project cost estimation method is adequate to mitigate cost overruns impact?

    Ans: I think the level which we do it until you actually get a job designed. I think what we do now it works. We do bench marking with other project to compare issues.

23. Do you think soft system approach can supplement the conventional infrastructure project estimation method?

    Ans: Yes

24. Has your organization utilized system thinking approach in identifying infrastructure project uncertainties or risks?

    Ans: : I have heard about it but not utilized for estimating process in our organization.

25. Does your organization take cognizant of infrastructure project uncertainties in cost estimation process?

    Ans. Yes I do. It is trying to get a step back. It is involving other members of client organization

N.B Standard, legislation and circumstances changes. Pretty much to predict. Materials cost might change thus circumstances outside your control. If you try to mitigate everything it will be difficult to get job kicked-off. Construction industry escalate cost.

How do you calculate the unknown and unknown. We do benchmark or use unit cost/use knowledge base idea. I think every project is individual. The project is much bespoke. We start developing the contingency at the design stage to get a robust risk analysis.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: Railway Infrastructure Enhancement project

YEARS OF EXPERIENCE: 13years of Experience

SIZE OF PROJECT INVOLVED:>10**POSITION OF PARTICIPANTS:** Commercial Manager

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

   Ans: Yes .Infrastructure project uncertainties are identified during initiation stage using personalized process known as stage gate process. It takes the project from feasibility then option selection. Feasibility-Initiation stage (Concept formulation). Undertaken a few desktops base analysis so the project is being done achieve it purpose. There are 8 stages. Each stage undertakes an estimate and risk analysis. Each stage has some extent of uncertainties. Uncertainties start from initiation stage. As the project progresses, the scope expands and budget refined etc. Uncertainties manifest as assumption and risk.

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: Schemes are designed and implemented, go through design stage. Undertake budget estimate, assumption and refined. Benchmarking projects. Understanding how project will work and cost based on the information collated from benchmarking. Understand what the work is and understanding the cost estimate of the project. How the work is going to be delivered. Uncertainty remaining used to create contingency value. So project budget is made after all these process are done. The project goes through governance where management makes decision on project. Is easy to know the estimate cost of the work but the methodology is not known. The methodology of the project needs to be understood because that might spring out a lot of uncertainties.

3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: Carried out concurrently because Uncertainties generates risk.

4. Does your organization indulge in infrastructure project uncertainty management during initiation stage? **Yes.** dedicated risk team in the organization

   Ans: Yes

5. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans: Yes

6. Does your organization consider holistic view for short term infrastructure project?

   Ans: Yes. Adding more railway network. It has a standard lifecycle.

7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

   ANS: YES…I THINK IT WILL IMPROVE THE MANAGEMENT OF INFRASTRUCTURE PROJECT.IF IT IS EMBEDED IN AN APPROACH WITHIN THE ORGANIZATION

8. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?

   Ans: Yes…It can create an uncontrolled level of cost overrun. Review risk exercise, where all assumption are recorded. Risks registers update and reviewed. It can reduce the magnitude and impact of risk occurring on infrastructure project. Mitigation plan is put to prevent cost overrun which in turn reduce the target score.

Yet. It can create level or magnitude of cost overruns. We tend to have risk review exercise. We then put mitigation plan which prevent risk and uncertainty happening which will reduce the target score. There will be some cost, time overruns. There will be issues, risk happening but it will reduce the impact of cost of overrun to some certain level.

9. What are the main factors that impact a robust infrastructure project cost estimation process?
10. Is risk management enough to mitigate impact of cost overrun in infrastructure project? I think if it is done properly then is enough because it drives the focus. A presentation of risk management was done and one of the slides was statement from different organization about what is project management to them. One of the statement was from BP executive if I remember correctly what he was saying that the high quality action plans get driven from or outputted from risk review those are the things they focus on almost 95% working daily as a project manager because are those actions he has to focus on and close/address in order to eliminate the uncertainties that drives the risks. Those are the hurdles he sees in delivering the project as long as his focused in managing only those actions those all the other aspect will automatically drive itself in terms of project delivery. I will say if it is done properly it will mitigate to some certain level. I wouldn’t say it is 100% efficient because at the early stage there are other things that would have to be done in a certain so as to reduce the uncertainties.
11. Do you think unidentified risk emanates from infrastructure project uncertainties?

Ans.**Yes**

12. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns? It may reduce the impact of cost overrun.
13. Does your organization consider holistic view of infrastructure project prior to cost estimation during project initiation stage?

    Ans. The part of organization may do that. The part of the organization doesn't go that far for estimation process. So not too sure about it.
14. Does your organization have a standardized or internally devised infrastructure project cost estimating method?

    Ans: Yes. I don't know if you remember, I mentioned estimating uncertainty. It goes into the estimate when we do risk review to get our contingency, the estimator also undertakes an exercise where they give us their estimate and then they will risk review the estimate that would itself drive an exposure called estimating uncertainties to cover the unknown and unknown in connection with the actual estimate.
15. Does your organization do an infrastructure project cost estimation for a short d
16. Do you think infrastructure project uncertainties impact on cost estimating methods? Yes, they do
17. What factors do you consider in carrying out robust infrastructure project uncertainties identification in your reputable organization? Ans:

    Ans: Environmental, commercial, engineering, construction methodology uncertainties.
18. Do you think is pertinent to inculcate infrastructure project uncertainty management approach in your organization before project is being initiated?

    Ans: Yes, I do
19. Does your organization involve key stakeholders in determining the infrastructure cost estimating method or solely rely on the project management team?

Ans: We consider key stakeholders when we do things like value management workshop so as to understand how the project impact on them.

20. Do you think a robust infrastructure project cost estimation mitigates the impact of cost overruns in projects?

    Ans: Yes

21. Do you think systemic approach will improve infrastructure project cost estimation?

    Ans: Yes

22. Do you think the conventional non- system approach of infrastructure project cost estimation method is adequate to mitigate cost overruns impact?

    Ans. No I don’t think so.

23. Do you think soft system approach can supplement the conventional infrastructure project estimation method?

    Ans: Yes

24. Has your organization utilized system thinking approach in identifying infrastructure project uncertainties or risks?

    Ans: If we have, I haven’t seen or known it.

25. Does your organization take cognizant of infrastructure project uncertainties in cost estimation process?

    Ans: Yes

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: HIGHWAY ROAD WORKS (REGIONAL INVESTMENT PROGRAMME-BYPASS & ROAD WIDENING SCHEMES)

YEARS OF EXPERIENCE: 34YRS

SIZE OF PROJECT INVOLVED: £2 00M

POSITION OF PARTICIPANTS: HEAD OF PROJECT

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

   Ans: Erm, what we do, highways England project department is quite a young in the industry. What we try to instil is risk management and, in my experience, Project managers are always keen to deliver project on time, budget but I will question whether they take risk management seriously enough, whether is part of their day-to-day thinking, that's something we try to drive in Highways England. So we investing in risk system called exert team and all of our project have risk management plan. All our project has risk management plan and should define all the roles involved in the project. It should also define what happens and when. We've had the exert team for 6month and what I want the project management to do is data quality system (Data Completeness). We tell the people to do risk management. We check the risk register, stage gate but are they on the weekly/monthly basis identifying the risk and assigning owners/managing them as well and am not convinced they are doing it. What am pushing for is data completeness/quality out of the system so that we can look at all our project and say how many risks are open/new risk created this month are they doing their actions on time. So that we can test whether project manager are paying attention to it or leaving it too late or leave it active risk management on ongoing basis. I believe if you do it on an ongoing basis you take ownership of your actions and manage them out you will be more successful. The challenge is at the early stage of the project we talk about unknown/unknown, and it is not always easy to identify all the risks. That's one of the challenges and why is the reason we need 3point estimate to know what range we are working with. Too often we focus on one number rather than being on a range and what we should be saying we are on a range. If you imagine uncertainty as a cone or hopper furthermore developed is the project the lesser the uncertainty in the project. I don't think the uncertainty management is inadequate is just because the project management focuses too much on one number rather than recognizing boundaries (Upper & Lower). Unknowns/Unknowns uses estimating data base which tells you more about similar projects. Expert opinion is based on history. So they compare with similar project (benchmarking). This is subjective and not précised. It is not perfect.

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: We don't deal with project of that duration. Short term duration project is done once after a very good design and do analysis what you think the risk was. At the end of that design, you will be cracking into construction. I always advocated doing risk management. How much design involved and investigation of the construction period. The risk management tend to be iterative during the design phase and at the end of the phase we now say what's going to happen. Risk management is used as a port of money instead used for the intended purpose. The mind-set is how you get enough money to cover us once things break down. I think that's applicable to many projects.

3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: As I said before it is an ongoing process and that's the culture I want to drive in our programme. We do think of uncertainty absolutely. The approach that we take at the end of stage on a project we do review risk register/workshop which is a representative of the risk that we foresee once we go through estimating department compared to historical project etc. There will be adjustment made on the risk path if you like there is a part of money that says (making some numbers up). There would be some money say 3M and we advise that you include additional 3M for uncertainty because history tells us that we get cost growth. As you get managing through your project what you then need to do is draw down from those part is it something we foresee or is it unknown or something that we didn't foresee isn't in our register, so we draw down from that uncertainty path. I don't' know whether is consistent. In our business that's what we want to drive. Management reserve is determined by history reference, so you've got a risk path of work bottomed-up. Thinks that we can see we concerned about that. You go through probability and mitigating strategies. Once you apply that you go thru monte-carlo analysis thus coming up with a number. History tells me am going to need 5M and need %10. So, the process we take is our estimate is P50 basis

And component of our estimate is bottom-up risk but another component is uncertainty in terms of management reserve we quite a young businesses so we don't have programme risk path but we know we need that. So, we are developing our process to put that in place. When you are working with tight budget what you've got to do is control change. My experience tells me that often the changes that happen to a project isn't critical to the outcome. When you are working with tight budget on a programme a project manager can be empowered to manage a project, but his project is one in a portfolio of projects. If he starts to accept change and draw out is unknown unknown path and actually what he is doing is spending other people's money. Is impacting on other projects. That's why we need to have a control of other project.

4. Does your organization indulge in infrastructure project uncertainty management during initiation stage? Yes

5. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans. Yes. There are always things that crop up from a project that are not foreseen. There are, I did come from a site today. There are Hundreds of uncharted services were discovered which wouldn't have been able to discover. They might have forecasted uncharted services on the project but not on the magnitude discovered by the field workers. We came up with some unexploded bomb along the project right-of-way. We saw unforeseen tank found underneath the earth. This caused about 3months on the project schedule. These unknown/unknown uncertainties wouldn't have been detected easily. I think it wasn't identified early enough in the project phase.

6. Does your organization consider holistic view for short term infrastructure project?

   Ans: No-I don't think we do on a 3-6months project. I think the driver is to get something quickly we work on further restricted budget. There is a risk process done we generally be working on fixed percentage of allowable risk. That will be usually driven by historical estimating data base. Potentially you might have a 5-6% risk budget for that kind of project so you need to operate within that range. I think potentially that brings laziness to project management team because they don't become proactive in managing risks robustly.

7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

   Ans: Ermm. I am not sure how we understand system thinking. I am a big believer in behaviours and influencing behaviour. What we trying to do in Highway England is what is measured gets done.

I am trying to use risk system data base to make sure project team updates risk register. My believe is that If I can say to the programme manager that such a project hasn't raised any risk this month, closed any risk, got X numbers of ageing actions. That tells me that team isn't taking risk management seriously. You need as their line manager to have a word with them. Provide the consequence, basically you say is not acceptable. Make sure risk management is part of their daily routine. That's one aspect of behaviour point of view. Another aspect is HAZOPs of operation. Another aspect is to use HAZOPS, we trying to bring that into project management. Another aspect, one thing that have seen we use HAZOPS. It uses structured process like if we've got flow into a pipe. We've got series of questions, like what happens if we have too much flows or vice versa. The reason I think about is relating to the people operating this operation taking cognizance of behaviour point of view. Sometimes operator don't' understand what's going in the process.

8. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?

   Ans: Yeah.Definately, if you go back to unknown/unknown we often see project overrun is not uncommon. Often the things that cause the overruns were foreseeable, so my question is it that because we don't have enough focus on risk & uncertainty management or we don't put enough resources on project. Is probably the combination of both? If we take the risk and uncertainty management seriously if you invested in the resource. If we have a risk manager on each of the project they will make sure all the identified risks in the project are given owners who manage the risk effectively.

9. What are the main factors that impact a robust infrastructure project cost estimation process?

Ans: Inadequate design (technical),Insufficient investigation(Often driven by time), Learning mistake(Unknown/unknown),interfaces(different path project comes together),Inadequate communication & Inadequate surveys,

10. Is risk management enough to mitigate impact of cost overrun in infrastructure project?

    Ans: Ermm. No I think is the whole project control sweet. Thorough design, cost it, baseline it and build realistic schedule, manage performance against schedule, track productivity against milestone (makes sure project on track) to check what has been done. You have to have a robust plan. That's risk management in real sense as regards with is opinion.

11. Do you think unidentified risk emanates from infrastructure project uncertainties?

    Ans: Ermm. No I think unidentified risk It is either unknown/unknown/Unforeseeable occurrence or extend to inadequate design or surveys. One of the stuffs or can be combination. So one of the things we doing at the moment is to develop a checklist that will be applied to all our project. That should help to counter inexperience in the project execution. No matter how experience you are you will encounter new scenario you've not met before.

    Simply says you've considered multiple events etc. So then if you have done surveys and designs properly that helps you to control controllable and we don't do that. Most project go overruns because they didn't deal with thinks that could have foreseen.

12. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?

    Ans: Yes because if you miss something at some point you will start to get some migum about something and if you can even if you can't fully mitigate but reduces the impact.

13. Does your organization consider holistic view of infrastructure project prior to cost estimation during project initiation stage?
14. Does your organization have a standardized or internally devised infrastructure project cost estimating method?

    Ans**:** Yes we have a standard cost estimating method, we've got specialist estimators that deals with estimation. From experience most infrastructure project operates within that process. The way the estimating team works is someone will produce a scope and give them the risk register then it will be handed to the estimators.

    Does the estimators understand the scope of the project, does the Project manager understand the estimate well enough to understand what's included or removed.

    Human factors and behaviour maybe in our risk approach that's something we don't quantify which may lead to uncertainties as well.
15. Does your organization do an infrastructure project cost estimation for a short d
16. Do you think infrastructure project uncertainties impact on cost estimating methods?

    Ans: Yes I think so as I said we do 3point estimate. Too often we talk about one number rather than range of numbers. We estimate on P50
17. What factors do you consider in carrying out robust infrastructure project uncertainties in your reputable organization?

    Ans: Ermm. What we do is pestle analysis as a framework. We think our strategy as a programme, but I find it limited. I don't think it worked for the project. At the strategic level doesn't work. It doesn't suit people's thinking. I think they should run opportunity workshop. I will prefer to run a session to know what will go wrong. What are the opportunities we can explore, and I think that personally will be beneficial.

18. Do you think is pertinent to inculcate infrastructure project uncertainty management approach in your organization before project is being initiated?

    Ans: Yes absolutely. Before a project is initiated what we do is operating business. A project is rather responding to opportunity or threat.

19. Does your organization involve key stakeholders in determining the infrastructure cost estimating method or solely rely on the project management team?

    Ans: Heavily relies on project management.

20. Do you think a robust infrastructure project cost estimation mitigates the impact of cost overruns in projects?

    Ans: Yes it does. I come back to uncertainty, one of the most successful project was the Olympic project. That was a high profile project with strong team on it. It has good amount of programme risk.

21. Do you think systemic approach will improve infrastructure project cost estimation?

    Ans: I am not sure I can answer that because I don't know much about it. I guess from my perspective there is an opportunity there. Do we do enough at the start to identify enough problems? Let me spend more at start to identify all potential problems. Managing expectation most of our project is constrained by time. I can see enough benefits when thorough investigation is done at the start.

22. Do you think the conventional non- system approach of infrastructure project cost estimation method is adequate to mitigate cost overruns impact?

    Ans. I don't think in Highway England's approach is enough. We take short cut in resolving our problems, which lead it to take longer.

23. Do you think soft system approach can supplement the conventional infrastructure project estimation method?

    Ans.Yes it can.

24. Has your organization utilized system thinking approach in identifying infrastructure project uncertainties or risks?

    Ans: I don't believe we have utilized it. No

25. Does your organization take cognizant of infrastructure project uncertainties in cost estimation process?

    Ans: I think our organization does because we use 3 point estimate. We do take the risk registers which the team has developed. We do use historical records that have been developed to aid estimation. Do we think about cost overrun. Time is money then do you translate that by thinking about what we are delivering.

    N.B

    I think often what you find, going back to the Olympic project there is a desire for an outcome or end project. Looking from the project how much are you willing to invest. The trick is to develop a solution within that project. Recognizing that there is a reason for restricting the budget.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: Defence Infrastructure project

YEARS OF EXPERIENCE: 14years

SIZE OF PROJECT INVOLVED:200M

POSITION OF PARTICIPANTS: Commercial manager

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

    Ans: I am not too sure of questions but break down a little bit. Are we talking about company specifics or customers etc. Individuals are accountable by law to be compliant with the regulations involved in the infrastructure project.

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: Yes, is part of the process is not just about, there is certain criteria that needs to be met. We must make sure the compliance meets the necessary requirements. It saves money and time to do it and it is precaution and criteria for a project.

3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: We identify it together. It is worded in my organization. Risk is what going to happen, and we don’t do independently rather concurrently.

4. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans: Yes for sure.

5. Does your organization indulge in infrastructure project uncertainty management during initiation stage?

   Ans: Well we will do. We don’t’ call it uncertainty management but risk which we manage throughout.

6. Does your organization consider holistic view for short term infrastructure project?

   Ans: Ermm…Yeah good question…There is a whole lot. Yeah, we do but might not go deep into it.

7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

   Ans: Yes because system approach will give an accurate estimation let me put that way. We can get to specific measure that will be accurate.

8. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?

Ans: Of course, because it leads to project in the wrong direction if not done properly. So yes it definitely can.

9. What are the main factors that impact a robust infrastructure project cost estimation process?

   Ans: There are many things is not just the obvious, quality, procurement and time. If you don’t get product at the time we need it thus does impact on business and finance.

10. Is risk management enough to mitigate impact of cost overrun in infrastructure project?

    Ans: Yeah absolutely. If done properly you begin to fail from start of the project.

11. Do you think unidentified risk emanates from infrastructure project uncertainties?

    Ans: Ermm. Y es and no. It depends on the level of expertise expended on the project that will determine whether is done properly or not.

12. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?

    Ans. Yeah. If the project is going awkward you can bring it back to line.

13. Does your organization consider holistic view of infrastructure project prior to cost estimation during project initiation stage?

    Ans: Yeah

14. Does your organization have a standardized or internally devised infrastructure project cost estimating method?

    Ans. For sure without it we just talking for talking sake.

15. Does your organization do an infrastructure project cost estimation for a short d

16. Do you think infrastructure project uncertainties impact on cost estimating methods?

    Ans: Yes definitely

17. What factors do you consider in carrying out robust infrastructure project uncertainties in your reputable organization?

    Ans: From supplier point of view we've got criteria to meet from a basic level. We do selection after the suppliers might meets the necessary requirements.

18. Do you think is pertinent to inculcate infrastructure project uncertainty management approach in your organization before project is being initiated?

    Ans: Yeah. It goes back to we talked earlier. The only question is the level of the details we need. It is good to have the know-how.

19. Does your organization involve key stakeholders in determining the infrastructure cost estimating method or solely rely on the project management team?

    Ans: Yes. There are lot of dependencies. It must involve a lot of team work to make it robust.

20. Do you think a robust infrastructure project cost estimation mitigates the impact of cost overruns in projects?

    Ans: Yeah.

21. Do you think systemic approach will improve infrastructure project cost estimation?

    Ans:

22. Do you think the conventional non- system approach of infrastructure project cost estimation method is adequate to mitigate cost overruns impact?

    Ans. Yeah it is from what we do it works.

23. Do you think soft system approach can supplement the conventional infrastructure project estimation method?

    Ans. Yeah for sure going forward. I use different software tools at work. There is always ways to do things.

24. Has your organization utilized system thinking approach in identifying infrastructure project uncertainties or risks?

    Ans. Yes

25. Does your organization take cognizant of infrastructure project uncertainties in cost estimation process?

    Ans: Yeah.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED:DIRECTRAIL SERVICES

YEARS OF EXPERIENCE:7years of Experience

SIZE OF PROJECT INVOLVED:£200,000

POSITION OF PARTICIPANTS: Head of Project

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

    Ans**:Yes so how we do it we(I am trained in Prince2) can have an initiation where we identify infrastructure projects. We currently going to process arriving at all of our infrastructure projects trying to align all the project with company strategy. The deliverables will be basically aligned to company's strategy.**

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

    Ans:**Yes**

    Do you identify infrastructure project uncertainties and risks independently or concurrently?

Ans: Yes concurrently

3. Does your organization indulge in infrastructure project uncertainty management during initiation stage**?**

   Ans: Yes so, I tell you a story here. We didn't use to however what we start is a stakeholders didn't have a better idea on how to do it. So we do get them more involved at the initiation stage now because support the stakeholders so the project sponsors should be in charge with business case and approve business case so we find a lot of them with using inadequate document for the business case. So, it is most better for them to get involved in the project earlier and it makes the project delivery easier.

4. Do you think infrastructure project uncertainties identification is necessary for project?

   Ans. Ermm. Do I think the identification is necessary. I do from where we are because especially what we spent on project an infrastructure can be big part of our budget so in terms of resource, people and monies ermm where have to identify all our projects really to make sure we are investing in the right projects so as to align with company's strategy so be aware we have wide multiple different type of projects and infrastructure project is one of it. It is necessary to identify all of them so that the company focus is in the right place.

5. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

6. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?

   Ans: Yes it can

7. What are the main factors that impact a robust infrastructure project cost estimation process?

   Ans: Ermm I think the scope of the delivery is the main factor. What we trying to achieve in timescale is a big factor that affect the cost.

8. Is risk management enough to mitigate impact of cost overrun in infrastructure project?

   Ans: I think is enough

9. Do you think unidentified risk emanates from infrastructure project uncertainties?

   Ans: It can do.

10. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?

    Ans: It can mitigate the impact.

11. Does your organization consider holistic view of infrastructure project prior to cost estimation during project initiation stage?

    Ans: As much as we can obviously think change as much as we can catch most of the risks. Anything that can go wrong in the project is identified.

12. Does your organization have a standardized or internally devised infrastructure project cost estimating method?

    Ans No

13. Does your organization do an infrastructure project cost estimation for a short d
14. Do you think infrastructure project uncertainties impact on cost estimating methods?

    Ans: Yes

15. What factors do you consider in carrying out robust infrastructure project uncertainties in your reputable organization?

Ans: Ermm well there is a lot of range. We use requirement, type of the year, weather can affect a lot. Consider Scotland weather affects it a lot. We try to do risk analysis. Environmental factor, Contamination of the land. One of our projects is the railway type and is currently the condition of the railway site are really poor ground condition in terms of contaminated land we've got to prepare of our land if we are digging any soil anything like we've got to consider the land. We need to see what we doing to the environment because we can deposit our waste in the environment just like that.

16. Do you think is pertinent to inculcate infrastructure project uncertainty management approach in your organization before project is being initiated?

    Ans: Yes

17. Does your organization involve key stakeholders in determining the infrastructure cost estimating method or solely rely on the project management team?

    Ans: Ermm probably most, Project Management team

18. Do you think a robust infrastructure project cost estimation mitigates the impact of cost overruns in projects?

    Ans: Ermm…I think it helps control it. I think it helps mitigate it as much as possible it can I have never heard of any project yet that doesn't have some sort creep no matter how hard you drive I think a bit part of it is the more soft project you do you see more into the lessons into the future project and probably get something new that you don't expect.

19. Do you think systemic approach will improve infrastructure project cost estimation?

    Ans: I think it will do.

20. Do you think the conventional non- system approach of infrastructure project cost estimation method is adequate to mitigate cost overruns impact?

Ans: Ermm…it will do when done better. It is a bit of non-answer I think it does what it does but we try and do thinks to get improved upon.

21. Do you think soft system approach can supplement the conventional infrastructure project estimation method?

    Ans: I think it will do.

22. Has your organization utilized system thinking approach in identifying infrastructure project uncertainties or risks?

    Ans: I don't think we have used.

23. Does your organization take cognizant of infrastructure project uncertainties in cost estimation process?

    Ans: Yes we definitely recognised the infrastructure project uncertainties.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: Rail Infrastructure project

YEARS OF EXPERIENCE: 13years

SIZE OF PROJECT INVOLVED:£55B

POSITION OF PARTICIPANTS: Scope baseline and Earned Value Manager

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

   Ans:Yes

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans:Yes, when you look at big programme like HS2 which contains smaller project

3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: There has been group discussion with all the stakeholders involved to identify risks.

4. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans: Yes absolutely.

5. Does your organization indulge in infrastructure project uncertainty management during initiation stage?

   Ans: Yes

6. Does your organization considers holistic view for short term infrastructure project?

   Ans: In term of infrastructure project, I haven't worked on project of that duration so can't comment on that.

7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

   Ans: I think so.

8. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?

   Ans: Yes

9. What are the main factors that impact a robust infrastructure project cost estimation process?

   Ans: There a lots of factors, it depends of the project carried out. Environmental factors(land),Resources etc

10. Is risk management enough to mitigate impact of cost overrun in infrastructure project?

Ans: Yeah

11. Do you think unidentified risk emanates from infrastructure project uncertainties?

    Ans: Yes

12. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?

    Ans: Yes

13. Does your organization consider holistic view of infrastructure project prior to cost estimation during project initiation stage?

    Ans: Yes we do.

14. Does your organization have a standardized or internally devised infrastructure project cost estimating method?

    Ans: We have estimating method which have been developed for this infrastructure project.

15. Does your organization do an infrastructure project cost estimation for a short d

    Ans:No response

16. Do you think infrastructure project uncertainties impact on cost estimating methods?

    Ans: Yeah.

17. What factors do you consider in carrying out robust infrastructure project uncertainties in your reputable organization?

    Ans: No response

18. Do you think is pertinent to inculcate infrastructure project uncertainty management approach in your organization before project is being initiated?

    Ans: Yes

19. Does your organization involve key stakeholders in determining the infrastructure cost estimating method or solely rely on the project management team?

Ans: There are others factors and people involved.

20. Do you think a robust infrastructure project cost estimation mitigates the impact of cost overruns in projects?

    Ans: Yes

21. Do you think systemic approach will improve infrastructure project cost estimation?

    Ans: Yes

22. Do you think the conventional non- system approach of infrastructure project cost estimation method is adequate to mitigate cost overruns impact?

    Ans: Yes

23. Do you think soft system approach can supplement the conventional infrastructure project estimation method?

    Ans: Yes

24. Has your organization utilized system thinking approach in identifying infrastructure project uncertainties or risks?

    Ans: I am not really aware of this approach.

25. Does your organization take cognizant of infrastructure project uncertainties in cost estimation process?

Ans: yes

Section-2-Case-study firm

1- Eastern Tunnel Works(Horgan, 2019)

2- Birmingham station redevelopment project (RailwayTechnology, 2014),(Elkes, 2016) &(McPartland, 2015)

3- Bond street station upgrade(Horgan, 2019)

4- Reading station redevelopment project(BBC, 2014) &(Networkrail, 2018)

5- Tottenham station upgrade (Horgan, 2019)

6- Nottingham Express Transit

7- Paddington station upgrade(Horgan, 2019)

8- Northern Line Expansion

9- Edinburgh Tram Project(Donald, 2018b)

10- White Chapel Station Upgrade(Horgan, 2019)

11- Farringdon Station Upgrade(Horgan, 2019)

12- Edinburgh-Glasgow Rail Improvement programme(Milligan, 2018) &(Barrow, 2016)

13- Off-Track Enabling Works Project

14- Western Tunnel works(Horgan, 2019)

15- London-Cardiff Rail Electrification Project(Barry, 2020),(CalleamConsultingLtd, 2020) &(STEIN, 2020)

16- Thames Tunnel works(Horgan, 2019)

17- Station Tunnel East(Horgan, 2019)

18- Pudding Mill Lane Portal (Horgan, 2019)

19- Eleanor Street and Mile End Shafts(Horgan,2019)

20- System Wide Project(Horgan, 2019)

21- Attleborough Station works(Horgan,2019)

22- Renewal Kenneth Station

23- Great Bentley Station works

24- Great Chesterford Station works

25- Witham Platform Repairs/Refurbishment

26- Roydon Station works

27- Brampton Station Refurbishment Project

28- Hockley Station works

29- Cardiff Resignalling Project (Lynam, 2015)

30- Wymondham Station Works

31- CP-5 Renewals-Needham Market

Section-2A

Asset Management - Project Progress Report

CP 5 Renewals - BR station

1. Report Details

Report week ending:	02/09/15	Programme Number:	N/A	Project Manager:		Project Status	**Green**

2. Programme/Project Summary

The project involves the refurbishment of the station including the following works;

- Platform – Reconstruction of the existing platform including the installation of new combined coper/tactiles, new platform drainage, resurfacing of the station entrance and minor removal of vegetation
- New fencing, resurfacing of the platform entrance and repair of the riser walls

3. Key Updates/Project Status

Following value engineering exercise carried out by AGA project team and the contractor, the need to install the FRP Dura-Composit panels have been removed, the platform is now going to be rebuilt using traditional methods. This will maintain the planned quality of the finished platform, planned programme while reducing the overall cost

Following whole life cost review of the project, additional electrical requirements were added t o the project including installation of a new DNO supply and rewiring of the existing platform lighting

-

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Completion of design and submission for approval	Blue	24/07/15	24/07/15	On target
Commence works to platform	Blue	01/08/15	29/07/15	Ahead of schedule
Planned Platform Closure	Blue	07/08/15	07/08/15	On Target
Planned station re-opening	Blue	16/08/15	16/08/15	On Target
Complete Construction	Blue	30/08/15	30/08/15	On Target
Project Hand-Back	Blue	31/08/15	02/09/15	On Target

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	Working next to an autistic hospice	Blue	We have and will continue to liase with the management of the hospice to ensure our works does not affect the normal operation of the hospice
2	Difficulty in materials and operatives' access due to remoteness of the site	Blue	Arrangement made to temporarily locate the operatives in locally in the village. Negotiations with suppliers (especially tarmac supplier) ongoing
3	Effect of the planned works on the platform back wall	Blue	Following condition survey of the backwall, the effect of the works was minimal. Section of the backwall repointed to improve state and appearance
4	Potential cost rise due to additional works on the station lighting and electrics to bring it up to standard	Blue	the installation of the new DNO supply by UK Power Network completed.

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

Asset Management - Project Progress Report

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
Hammonds	£347k	£550k	-£203k	

7. Time

8. Work to be undertaken in next period

- NONE

9. Detailed Programme:
Start date:02/07/2014

Finished date 09/09/2015

Available

10. Key Decisions:

Key Project Decisions	Date Required

Asset Management - Project Progress Report

CP 5 Renewals - C station

1. Report Details

Report week ending:	05/03/16	Programme Delivery Manager		Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of the station canopy and re furbishment of t he platforms including the following works;

- Platform 1 – Realignment of tactiles, repairs to the platform surface, repairs to the platform boundary wall and extension of the platform drainage
- Platform 2 –Realignment of copers, installation of new viz-tech tactiles and repairs to the platform surface. The works also include replacement of the wooden fence and platform drainage
- Refurbishment of the existing canopy on platform 1
- Decoration of windows above and below the canopy

3. Key Updates/Project Status

The project has progressed with the following carried out this period:

- ✓ Completion of snag items
- ✓ Station Handback
- ✓ Submission of Handback (H&S file)

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Commence works to platform 1	Blue	09/09/15	14/09/15	One week slip due to logistics issues with site set-up
Commence works to platform 2	Blue	09/09/15	14/09/15	One week slip due to logistics issues with site set-up
Commence works to canopy on platform 1	Blue	09/09/15	14/09/15	One week slip due to logistics issues with site set-up
Complete Construction	Blue	22/12/15	15/03/16	Completed
Station Handback	Blue	03/01/16	19/09/16	Handback signed off on **19/03/2016**

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	Work packages improperly sequenced.	Blue	Works completed
2	Budget may be insufficient for intended works	Blue	Works now complete
3	Budget overrun	Blue	Continued review of the workscope and specification to identify any available cost saving at final account

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

6. Budget

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
Clesher Contract Services	£400k	£524,309k	-£124,309k	Blue

Asset Management - Project Progress Report

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
Hammonds	£347k	£550k	-£203k	

7. Time

8. Work to be undertaken in next period

- NONE

9. Detailed Programme:
Start date:02/07/2014

Finished date 09/09/2015

Available

10. Key Decisions:

Key Project Decisions	Date Required

Section-2B

Asset Management - Project Progress Report

CP 5 Renewals- AT station

1. Report Details

Report week ending:	01/11/15	Programme Number:	N/A	Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of the station including the following works;

- Platform 1 – replacement of the copers, installation of new tactiles and resurfacing the entire platform. The works also include the repair of the window reveals and walls to the station building and repairs to the fencing and new platform drainage
- Platform 2 –replacement of the copers, installation of new tactiles and resurfacing the entire platform. The works also include removal of vegetation and minor redecoration of the waiting shelter and new platform drainage

3. Key Updates/Project Status

Following award, the assurance and design process prior to executing the works has been progressing with the following carried out to date;

- ✓ Additional topographical survey carried out
- ✓ Stakeholder engagements including meetings with the Local Authority regarding environmental consents, engagement with the local adoptee with regards to effects and extent of flower dressing on the platforms

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Completion of design and submission for approval	Green	30/07/15	30/06/15	At the current pace we expect to design to be completed a month early
Commence works to platform 1	Green	07/08/15	07/08/15	On target
Commence works to platform 2	Green	14/08/15	14/08/15	On target
Complete Construction	Green	30/09/15	30/09/15	On Target
Handback of the station	Green	01/10/15	15/11/15	On target

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	**Possession availability**	Blue	Possession required activities completed
2	**Variation to cost of works and additional works**	Blue	Contracted quantities are best estimates, re-measure done and completed.
3	**Potential overall Budget overrun**	Blue	Close control of change process. Only Programme level approval for any change

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

6. Budget

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
	£625,539	£650,100K	-£24,461	Green

Asset Management - Project Progress Report

7. Time

Baseline date	Planned On site	Forecast completion	Current slippage (weeks)	RAG Status
07/08/15	07/08/15	30/10/2015	On target	Green

8. Work to be undertaken in next period

- Review and approval of design document F001
- Completion and submission of design documents F002 and F003
- Review and approval F002/3
- Submission of Works Package Plan (WPP)

9. Detailed Programme:
Start date:06/02/2014
Finish date 17/11/2015

Available

10. Key Decisions:

Key Project Decisions	Date Required

Section-2E

Section-2C

Asset Management - Project Progress Report

CP 5 Renewals - C station

1. Report Details

Report week ending:	05/03/16	Programme Delivery Manager		Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of the station canopy and re furbishment of t he platforms including the following works;

- Platform 1 – Realignment of tactiles, repairs to the platform surface, repairs to the platform boundary wall and extension of the platform drainage
- Platform 2 –Realignment of copers, installation of new viz-tech tactiles and repairs to the platform surface. The works also include replacement of the wooden fence and platform drainage
- Refurbishment of the existing canopy on platform 1
- Decoration of windows above and below the canopy

3. Key Updates/Project Status

The project has progressed with the following carried out this period:

- ✓ Completion of snag items
- ✓ Station Handback
- ✓ Submission of Handback (H&S file)

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Commence works to platform 1	Blue	09/09/15	14/09/15	One week slip due to logistics issues with site set-up
Commence works to platform 2	Blue	09/09/15	14/09/15	One week slip due to logistics issues with site set-up
Commence works to canopy on platform 1	Blue	09/09/15	14/09/15	One week slip due to logistics issues with site set-up
Complete Construction	Blue	22/12/15	15/03/16	Completed
Station Handback	Blue	03/01/16	19/09/16	Handback signed off on **19/03/2016**

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	Work packages improperly sequenced.	Blue	Works completed
2	Budget may be insufficient for intended works	Blue	Works now complete
3	Budget overrun	Blue	Continued review of the workscope and specification to identify any available cost saving at final account

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

6. Budget

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
Clesher Contract Services	£400k	£524,309k	-£124,309k	Blue

7. Time

8. Work to be undertaken in next period

- None

9. Detailed Programme:
Start date 13/11/2014
Finished date: 16/03/2016

10. Key Decisions:

Key Project Decisions	Date Required
None Required	

Section-2D

Asset Management - Project Progress Report

CP 5 Renewals- AT station

1. Report Details

Report week ending:	01/11/15	Programme Number:	N/A	Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of the station including the following works;

- Platform 1 – replacement of the copers, installation of new tactiles and resurfacing the entire platform. The works also include the repair of the window reveals and walls to the station building and repairs to the fencing and new platform drainage
- Platform 2 –replacement of the copers, installation of new tactiles and resurfacing the entire platform. The works also include removal of vegetation and minor redecoration of the waiting shelter and new platform drainage

3. Key Updates/Project Status

Following award, the assurance and design process prior to executing the works has been progressing with the following carried out to date;

- ✓ Additional topographical survey carried out
- ✓ Stakeholder engagements including meetings with the Local Authority regarding environmental consents, engagement with the local adoptee with regards to effects and extent of flower dressing on the platforms

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Completion of design and submission for approval	Green	30/07/15	30/06/15	At the current pace we expect to design to be completed a month early
Commence works to platform 1	Green	07/08/15	07/08/15	On target
Commence works to platform 2	Green	14/08/15	14/08/15	On target
Complete Construction	Green	30/09/15	30/09/15	On Target
Handback of the station	Green	01/10/15	15/11/15	On target

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	**Possession availability**	Blue	Possession required activities completed
2	**Variation to cost of works and additional works**	Blue	Contracted quantities are best estimates, re-measure done and completed.
3	**Potential overall Budget overrun**	Blue	Close control of change process. Only Programme level approval for any change

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

6. Budget

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
	£625,539	£650,100K	-£24,461	Green

Asset Management - Project Progress Report

7. Time

Baseline date	Planned On site	Forecast completion	Current slippage (weeks)	RAG Status
07/08/15	07/08/15	30/10/2015	On target	Green

8. Work to be undertaken in next period

- Review and approval of design document F001
- Completion and submission of design documents F002 and F003
- Review and approval F002/3
- Submission of Works Package Plan (WPP)

9. Detailed Programme:
Start date:06/02/2014
Finish date 17/11/2015

Available

10. Key Decisions:

Key Project Decisions	Date Required

Section-2E

Asset Management – Project Progress Report

CP5 Renewals – G-Station

1. Report Details

Report Week Ending:	20/07/2016	Programme Delivery Manager:		Project Manager:		Project Status:	Green

2. Programme/Project Summary

The project involves the refurbishment of the station including the following works:

- Platform 1 – replacement of the copers, installation of new tactiles and resurfacing the entire platform. The works also include the demolition of a redundant structure on the platform and installation of new benches
- Refurbishment of the existing bridge including structural repairs, stair treads and surface replacement and complete redecoration

3. Key Updates/Project Status

The project has progressed with the following carried out to date:

- Continued redecoration (Top coat painting) of the footbridge
- Installation of new footbridge handrails (90% complete)
- Installation of the infill panels on the footbridge
- Installation of redesigned footbridge lighting (95% complete)

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Handback of platforms	Blue	30/11/15	28/06/16	Handed back
Complete foot bridge works	Green	22/12/15	30/08/16	Bridge re-opened on 04/04/16. All works now expected to be completed 27/07/16
Handback of foot bridge	Green	23/12/15	02/08/16	Footbridge will be progressively snagged as sections complete to reduce work required to hand back.
Blue RAG Status = complete				

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Description	Status (RAG)	Update
1	**Possession availability**	Blue	Cancelled possessions managed and mitigated as per the project risk management plan.
2	**Public interface with the footbridge**	Blue	Footbridge re-opened 04/04/16 with outstanding works (new handrail and permanent lighting to completed) Remaining works unlikely to attract complaints
3	**Unknown condition of the footbridge steelwork may result Project cost increase**	Blue	Extent of repairs required limited to complete cleat replacement, completed within budget
4	**Potential extension of time claim**	Blue	Early warning and improvement meeting held and recorded. Proactive commercial meetings held to avoid EOT
5	. Additional delay due to poor quality paintwork, contractor required to rub-down and repaint the bridge span	Blue	Additional works completed within required duration

6. Budget

Package	Budget	Forecast upon completion	£-/+	RAG Status
	£1,175,000	£1,267,000	-£175,000	Blue

Asset Management – Project Progress Report

Comments on Budget/Variance:	AGA have issued an early warning regarding the programme/cost over run.

7. Work to be undertaken in next period

None-

8. Detailed Programme:

Project start date:14/04/2015

Planned completion date: 03/08/2016

Available

9. Key Decisions:

Decision ID	Key Project Decisions	Date Required
	None	

- **R** - Red = Issues will stop project/seriously impacts project
- **A** - Amber = Issues/concerns currently being managed
- **G** - Green = No issues
- **B** - Blue = Complete

Section-2F

Asset Management - Project Progress Report

CP 5 Renewals- NM

1. Report Details

Report week ending:	01/04/16	Programme Number:	N/A	Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of the station including the following works;

- Platform 1 – realignment of the copers, installation of new tactiles and resurfacing the entire platform. The works also includes the repair and stabilisation to a rundown building by the station entrance and refurbishment of the window reveals on the platform
- Platform 2 –replacement of the entire platform using proprietary Dura-Composit platform deck and renovation of the platform shelter
- Refurbishment of the station subway, including the installation of Trespa cladding to the walls

3. Key Updates/Project Status

;

- ✓ Platform 2 has been complately renewed replaceing the dilapidate concrete deck with Dura composite platform including tactiles fencing and painting.
- ✓ The waiting shelter on platform 2 has been completely refurbished with new lined roof membrane and redecorated
- ✓ The refurbishment of the canopy on platform 1 is 90% complete with specially made wooden sections and dagarboards replaced to match existing and first coat of paint applied
- ✓ Glazing to the window reveals on platform 1

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Commence construction at Needham Market	Blue	11/04/15	11/04/16	Installation of new Dura platform 2 successfully completed to programme.
Commence works to platform 1	Blue	18/04/15	18/04/16	On target
Building works	Blue	08/04/15	12/05/16	Completed
Complete Construction	Blue	24/05/15	24/06/15	Hand-over back to Client

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	Unforeseen problems with removal of Platform 2 inhibit ability to re-instate whole platform	Blue	Contingency plans in place to make area closest to the subway operational for passengers from 13th April. This was not required as work progressed to best case schedule.
2	**Possession availability**	Blue	We continue to liaise with and interface with NR with regard to planned possessions
3	**Variation to cost of works and additional works**	Blue	Unforeseen problems incur authorised variation to spend. This has been realised with requirement to address repairs to canopy roof on platform 1 subject to confirmation of final costs.

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

6. Budget

Asset Management - Project Progress Report

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
Hammonds	£1.0m	£780k	£220k	Green

7. Work to be undertaken in next period

- Completion of platform 1 coper realignment, new tactile installation and resurfacing
- Installation of the Trespa panels and decoration of the subway
- Completion of redecoration to the canopy on platform 1
- Completion of the stabilisation and repairs to the redundant building by the station entrance on platform 1

8. Detailed Programme:
Start date:12/04/2014
Finish date 13/06/2015

Available

10. Key Decisions:

Key Project Decisions	Date Required

Section-2G

Asset Management – Project Progress Report

CP 5 Renewals – W Prepairs and refurbishment

1. Report Details

Report Week Ending:	20/08/2016	Programme Delivery Manager:		Project Manager:	Innoce	Project Status:	Green

2. Programme/Project Summary

The project involves repairs and refurbishment to the 2no island platforms in Witham Station;

- Platform 1&2 – Involves the spot replacements of defective copers, patch repairs to the platform sufface to remove uneven surfaces and tripping hazards, refreshment of the yellow and white platform lines and improvement of the polatform drainage
- Platforms 3&4 – Involves the total refurbishment of the platforms with complete coper/tactile re-guaging and replacement, complete platform re-surfacing and new platform drainage

3. Key Updates/Project Status

The project has progressed with the following carried out this period:

- Practical Completion issued
- Outstanding snags completed

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Complete Construction platform 1 & 2	Blue	28/02/16	28/05/16	Completed
Complete Construction platform 3 & 4	Blue	10/03/16	10/05/16	Completed
HandBack	Blue	25/03/16	25/07/16	Completed

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Description	Status (RAG)	Update
1	**Possession availability**	Blue	Possession required activities completed
2	**Cancelled possession**	Blue	Cancelled possessions managed and mitigated as per the project risk management plan
3	**Potential Variation**	Blue	Contracted quantities are best estimates, re-measure to be carried out during the works.
4	**Programme delays due to client authorized changes**	Blue	Works now complete

6. Budget

Package	Budget	Forecast upon completion	£-/+	RAG Status
22a	£850k	£1,309,560	-£459,560	Red
Comments on Budget/Variance:				

7. Work to be undertaken in next period

- None

8. Detailed Programme:
Start date:20/05/2015
Finished date 22/07/2016
Available

9. Key Decisions:

Section-2H

Asset Management - Project Progress Report

CP 5 Renewals - WY

1. Report Details

Report week ending:	19/09/15	Programme Number:	N/A	Project Manager:		Project Status	Green

2. Programme/Project Summary

The project involves the refurbishment of theexisting footbridge in the station which includes stripping back existing paintwork, repair to revealed metalwork , installation of new stair threads, drainage and overall redecoration. Handrail heights will be increased and mesh introduced in order to improve safety.

3. Key Updates/Project Status

The project has progressed with the following carried out this period:

- ✓ Hydro-blasting completed, with all original paint stripped from the bridge structure
- ✓ Steel work repairs continues with further exposed defective steel members identified
- ✓ Priming of the exposed steelwork 90% completed
- ✓ Base coat of pain applied to 70% of the bridge structure
- ✓ Top coat of pain applied to 35% of the bridge structure
- ✓

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Contract Award	Blue	12/06/15	12/06/15	Letter of intent issued on 1st June 2015 to enable planning to commence. Atrium Purchase Order raised
Completion of design and submission for approval	Blue	15/07/15	25/07/15	Initial Design review meeting held and design specifications and parameters agreed
Commence works on site	Blue	15/07/15	15/07/15	This period reflects AGA planning of completing the project within the school holidays so as to minimise local disruption.
Complete Construction	Blue	21/09/15	12/10/2015	Completed

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Title	Status (RAG)	Update
1	**Possession availability**	Blue	We continue to liaise with and interface with NR with regard to planned possessions.
2	**Cancelled possession**	Blue	The possession of the sidings and the applied for possessions have been granted. The delay in closing the footbridge, however, might mean additional possession will be required
3	**Potential Variation**	Blue	Bridge is now being refurbished in-situ.
4	**Delayed completion due to adverse weather**	Blue	Application of the top-coat of paint has been disrupted on several occasion due to rain and damp weather. This is more critical in areas over the track that needs to be carried out during night-time possessions
5	**Disruption due to local resident complaints to the local authority**		Complaint by the local resident to the Local Authority caused the current 3 weeks delay to the approval of the closure application. Further complaint by thelocal resident might cause further disruption to the works. Continued liason with the local authorities and the local residents

Asset Management - Project Progress Report

R - Red = Issues will stop project/seriously impacts project
A - Amber = Issues/concerns currently being managed
G - Green = No issues

6. Budget

Contractor	Budget	Forecast upon completion	£-/+	RAG Status
	£1,230,000	£1,430,000	-£200,000	

7. Time

8. Work to be undertaken in next period
none
9. Detailed Programme:
Start date:12/08/2014
Finish date:14/12/2015

Available

10. Key Decisions:

Key Project Decisions	Date Required
None	

Section-2I

Asset Management – Project Progress Report

RY Station

1. Report Details

Report Week Ending:	03/09/2016	Programme Delivery Manager:		Project Manager:		Project Status:	Green

2. Programme/Project Summary

The project involves the refurbishment of the existing redundant Signal box on platform 2 including;
1. Repairs and replacement of structural timbers
2. Repairs to the timber cladding of the building
3. Complete redecoration
4. Redecoration of the canopy on platform 2
5. Refurbishment of the toilet adjacent to the signal box on platform 2

3. Key Updates/Project Status

The project has progressed with the following carried out to date:

- Redecoration of the canopy on platform 2 (100% complete)
- Redecoration of the signal box externals
- Completion of internal redecorations
- Fit-out of the signal box with new mess facilities
- Box-out of the Signal levers
- Completion of the toilet refurbishment
-

4. Key Milestones

Milestone Description	Status (RAG)	Baseline Date	Current Date	Reason for variance since last report
Completion of works	Blue	30/08/16	02/09/16	Works completed
Handback of the Signal Box	Blue	05/08/16	02/09/16	Handed back on 29/09/16
Blue RAG Status = complete				

5. Major Risks or Issues

Risk/Issue ID	Risk/Issue Description	Status (RAG)	Update
1	**Possession availability for canopy redecoration**	Blue	We continue to liaise with and interface with NR with regard to planned possessions. Possession required activities completed
3	**Unknown condition of the timber structure may result Project cost increase**	Blue	Contract includes significant repairs, close monitoring of the works and state of the remaining timbers
4	**Contractor's delay issues**	Blue	Materials procured with Supply Management team

6. Budget

Package	Budget	Completion cost	£-/+	RAG Status
SEE	£1,315,000	£1,542,251	-£227,251	Blue
Comments on Budget/Variance:		Remitted work is substantially more than the agreed budget.		

7. Work to be undertaken in next period

- Installation of 5 new cycle hoopsoutstanding from the CP5 renewals works

8. Detailed Programme:
Start date: 03/05/2015
Finish date:6/09/2016

9. Key Decisions:

Decision ID	Key Project Decisions	Date Required
	None	

R - Red = Issues will stop project/seriously impacts project

A - Amber = Issues/concerns currently being managed

G - Green = No issues

B - Blue = Complete

Section-3 Data Normalization

PojectID	PROJECT NAME	Contract_ Cost	Final_ Cost	Cost_ Overrun	Normalized data	PROJECT_ DURATION	Expected Duration	DURATION _DELAY	Unforseen_site _construction	Designer omission	Contractor_Caused delays_ and_Coordination_Issues	OwnerDriven Changes	Accelerated Schedules	Construction Coordination Issues	ProjectDelivery Method	TeamFormation Process
1	Poject A	2900000	4E+06	-1E+06	1400000	3	2	1	1	0	0	0	0	0	0	0
2	Project B	1E+09	2E+09	-1E+09	1000000000	5	4	1	0	1	0	0	0	0	0	0
3	Project C	8.5E+08	9E+08	-5E+07	50000000	4	3	1	0	1	0	0	0	0	0	0
4	Project D	5.5E+08	8E+08	-2E+08	200000000	5	4	1	0	1	0	0	0	0	0	0
5	Project E	4.1E+08	6E+08	-2E+08	165000000	6	5	1	1	0	0	0	0	0	0	0
6	Project F	5.2E+08	8E+08	-3E+08	255000000	6	1	5	0	0	1	0	0	0	0	0
7	Project G	7.4E+08	9E+08	-1E+08	116000000	7	6	1	0	1	0	0	0	0	0	0
8	Project H	8.7E+08	3E+09	-2E+09	1926000000	8	5	3	0	0	0	0	0	0	0	0
9	Ptoject I	1.3E+08	4E+08	-3E+08	286000000	7	6	1	0	1	0	0	0	0	0	0
10	Project J	1.8E+08	6E+08	-4E+08	390000000	7	6	1	0	1	0	0	0	0	0	0
11	Project K	9.8E+07	3E+08	-2E+08	184000000	7	6	1	0	1	0	0	0	0	0	0
12	Project L	1.1E+08	7E+08	-5E+08	549000000	7	6	1	0	1	0	0	0	0	0	0
13	Project M	2.4E+08	6E+08	-4E+08	395000000	7	6	1	0	1	0	0	0	0	0	0
14	Project N	4.8E+08	7E+08	-2E+08	246000000	7	6	1	0	1	0	0	0	0	0	0
15	Project O	4.9E+08	7E+08	-3E+08	259000000	7	6	1	0	1	0	0	0	0	0	0
16	Project P	2E+08	2E+08	-3E+07	33000000	7	6	1	0	1	0	0	0	0	0	0
17	Project Q	2.5E+08	5E+08	-3E+08	264000000	7	6	1	0	1	0	0	0	0	0	0
18	Project R	5.2E+07	2E+08	-1E+08	132000000	7	6	1	0	1	0	0	0	0	0	0
19	Project S	4.6E+07	3E+08	-2E+08	209000000	7	6	1	0	1	0	0	0	0	0	0
20	Project T	3.2E+08	1E+09	-6E+08	633000000	7	6	1	0	1	0	0	0	0	0	0
21	Project U	625539	650000	-24461	24461	1.8	1.1	0.7	0	0	0	0	0	0	0	0
22	Project V	500000	520803	-20803	20803	1.6	1.1	0.5	0	1	0	0	0	0	0	0
23	Project W	1175000	1E+06	-175000	175000	1.3	1	0.3	1	0	0	0	0	0	0	0
24	Project X	400000	524309	-124309	124309	1.3	1	0.3	0	0	0	0	0	1	0	0
25	Project Y	850000	1E+06	-459560	459560	1.2	1	0.2	0	0	1	0	0	0	0	0
26	Project Z	1315000	2E+06	-227251	227251	1.3	1	0.3	1	0	1	0	0	0	0	0
27	Project AA	347000	550000	-203000	203000	1.2	1	0.2	0	1	0	0	0	1	0	0
28	Project AB	1640000	2E+06	-103589	103589	1.3	1	0.3	0	1	0	1	0	0	0	1
29	Project AC	2.1E+08	3E+08	-6E+07	56000000	4	2	2	1	1	0	0	0	0	0	0
30	Project AD	1230000	1E+06	-200000	200000	1.2	0.9	0.3	0	0	0	0	0	1	0	0
31	Project AE	780000	1E+06	-220	220	1.2	1	0.2	1	0	0	0	0	0	0	0

Cont-Section-2J Data Normalization

PROJECT NAME	Contract _Cost	Final_Cost	Cost_Overrun	Normalized values	PROJECT_ DURATION	Expected Duration	RegulatoryPer mitting Process	Miscommunication betweenteams	UnclearProject Requirements	ScopeGaps	Project Complexity	Underperforming, Unqualified, inexperienced Staff	Lackofthoroughnessof preconstructionplanni ngestimating
Poject A	2900000	4300000	-1400000	1400000	3	2	0	0	0	0	0	0	0
Project B	1E+09	2E+09	-1000000000	1E+09	5	4	0	0	0	0	0	0	0
Project C	8.5E+08	9E+08	-50000000	50000000	4	3	0	0	0	0	0	0	0
Project D	5.5E+08	7.5E+08	-200000000	200000000	5	4	0	0	0	0	0	0	0
Project E	4.05E+08	5.7E+08	-165000000	165000000	6	5	0	0	0	0	0	0	0
Project F	5.21E+08	7.8E+08	-255000000	255000000	6	1	0	0	0	0	0	0	1
Project G	7.42E+08	8.6E+08	-116000000	116000000	7	6	0	0	0	0	0	0	0
Project H	8.74E+08	2.8E+09	-1926000000	1.926E+09	8	5	1	0	0	0	1	0	1
Ptoject I	1.26E+08	4.1E+08	-286000000	286000000	7	6	0	0	0	0	0	0	0
Project J	1.81E+08	5.7E+08	-390000000	390000000	7	6	0	0	0	0	0	0	0
Project K	98000000	2.8E+08	-184000000	184000000	7	6	0	0	0	0	0	0	0
Project L	1.1E+08	6.6E+08	-549000000	549000000	7	6	0	0	0	0	0	0	0
Project M	2.39E+08	6.3E+08	-395000000	395000000	7	6	0	0	0	0	0	0	0
Project N	4.84E+08	7.3E+08	-246000000	246000000	7	6	0	0	0	0	0	0	0
Project O	4.9E+08	7.5E+08	-259000000	259000000	7	6	0	0	0	0	0	0	0
Project P	1.96E+08	2.3E+08	-33000000	33000000	7	6	0	0	0	0	0	0	0
Project Q	2.46E+08	5.1E+08	-264000000	264000000	7	6	0	0	0	0	0	0	0
Project R	52000000	1.8E+08	-132000000	132000000	7	6	0	0	0	0	0	0	0
Project S	46000000	2.6E+08	-209000000	209000000	7	6	0	0	0	0	0	0	0
Project T	3.23E+08	9.6E+08	-633000000	633000000	7	6	0	0	0	0	0	0	0
Project U	625539	650000	-24461	24461	1.8	1.1	0	0	1	0	0	0	0
Project V	500000	520803	-20803	20803	1.6	1.1	0	0	0	0	0	0	0
Project W	1175000	1350000	-175000	175000	1.3	1	0	0	0	0	0	0	0
Project X	400000	524309	-124309	124309	1.3	1	0	0	0	0	0	0	1
Project Y	850000	1309560	-459560	459560	1.2	1	0	0	1	0	0	0	0
Project Z	1315000	1542251	-227251	227251	1.3	1	0	0	0	0	0	0	0
Project AA	347000	550000	-203000	203000	1.2	1	0	0	0	0	0	0	0
Project AB	1640000	1743589	-103589	103589	1.3	1	0	0	0	1	0	0	0
Project AC	2.12E+08	2.7E+08	-56000000	56000000	4	2	0	0	0	0	0	0	0
Project AD	1230000	1430000	-200000	200000	1.2	0.9	0	0	0	0	0	0	0
Project AE	780000	1000000	-220	220	1.2	1	0	0	0	0	0	0	1

Cont-Section-2J Data Normalization

PojectID	PROJECT NAME	Contract _ Cost	Final_ Cost	Cost_ Overrun	Normalized data	PROJECT_ DURATION	Expected Duration	DURATION _DELAY	Weather Condtion	Government Policies	Resources Availability	QualityAssurance Control	AdaptionoAdvance Technology	SocioEconomic Condition	Stakeholder sIssues
1	Poject A	2900000	4E+06	-1E+06	1400000	3	2	1	0	0	0	0	0	0	1
2	Project B	1E+09	2E+09	-1E+09	1000000000	5	4	1	0	0	0	0	0	0	1
3	Project C	8.5E+08	9E+08	-5E+07	50000000	4	3	1	0	0	0	0	0	0	0
4	Project D	5.5E+08	8E+08	-2E+08	200000000	5	4	1	0	0	0	0	0	0	1
5	Project E	4.1E+08	6E+08	-2E+08	165000000	6	5	1	0	0	0	0	0	0	0
6	Project F	5.2E+08	8E+08	-3E+08	255000000	6	1	5	0	0	1	0	0	0	1
7	Project G	7.4E+08	9E+08	-1E+08	116000000	7	6	1	0	0	0	0	0	0	0
8	Project H	8.7E+08	3E+09	-2E+09	1926000000	8	5	3	0	0	0	0	0	0	0
9	Ptoject I	1.3E+08	4E+08	-3E+08	286000000	7	6	1	0	0	0	0	0	0	0
10	Project J	1.8E+08	6E+08	-4E+08	390000000	7	6	1	0	0	0	0	0	0	0
11	Project K	9.8E+07	3E+08	-2E+08	184000000	7	6	1	0	0	0	0	0	0	0
12	Project L	1.1E+08	7E+08	-5E+08	549000000	7	6	1	0	0	0	0	0	0	0
13	Project M	2.4E+08	6E+08	-4E+08	395000000	7	6	1	0	0	0	0	0	0	0
14	Project N	4.8E+08	7E+08	-2E+08	246000000	7	6	1	0	0	0	0	0	0	0
15	Project O	4.9E+08	7E+08	-3E+08	259000000	7	6	1	0	0	0	0	0	0	0
16	Project P	2E+08	2E+08	-3E+07	33000000	7	6	1	0	0	0	0	0	0	0
17	Project Q	2.5E+08	5E+08	-3E+08	264000000	7	6	1	0	0	0	0	0	0	0
18	Project R	5.2E+07	2E+08	-1E+08	132000000	7	6	1	0	0	0	0	0	0	0
19	Project S	4.6E+07	3E+08	-2E+08	209000000	7	6	1	0	0	0	0	0	0	0
20	Project T	3.2E+08	1E+09	-6E+08	633000000	7	6	1	0	0	0	0	0	0	0
21	Project U	625539	650000	-24461	24461	1.8	1.1	0.7	0	0	0	0	0	0	1
22	Project V	500000	520803	-20803	20803	1.6	1.1	0.5	0	0	0	0	0	0	1
23	Project W	1175000	1E+06	-175000	175000	1.3	1	0.3	0	0	0	1	0	0	1
24	Project X	400000	524309	-124309	124309	1.3	1	0.3	0	0	0	0	0	0	1
25	Project Y	850000	1E+06	-459560	459560	1.2	1	0.2	0	0	0	0	0	0	1
26	Project Z	1315000	2E+06	-227251	227251	1.3	1	0.3	0	0	0	0	0	0	1
27	Project AA	347000	550000	-203000	203000	1.2	1	0.2	0	0	0	0	0	0	1
28	Project AB	1640000	2E+06	-103589	103589	1.3	1	0.3	0	0	0	0	0	0	1
29	Project AC	2.1E+08	3E+08	-6E+07	56000000	4	2	2	0	0	0	0	0	0	0
30	Project AD	1230000	1E+06	-200000	200000	1.2	0.9	0.3	1	0	0	0	0	0	1
31	Project AE	780000	1E+06	-220	220	1.2	1	0.2	0	0	0	0	0	0	1

Section-4 Item statistics(Factor analysis)

Item Statistics

Uncertainty factors	Mean	Std. Deviation	N
Unforseen Site Construction	3.6667	1.17727	39
Designer Omission	3.3333	1.30451	39
Contractor caused delay and coordinations issues	3.1026	1.09532	39
Owner driven Changes	3.2308	1.08728	39
Accelerated Schedules	3.0000	1.19208	39
Constructionn Coordination issues	2.7179	0.97194	39
Project Delivery Method	2.8462	1.24686	39
Teamformation Process	2.3333	0.86855	39
Regulatory Permitting Process	3.0513	1.14590	39
Miscommunication Between Teams	2.9231	1.22226	39
Unclear Project Requirements	3.2821	1.27628	39
Scope Gaps	3.4615	1.07229	39
Project Complexity	3.4872	1.21117	39
Underperforming Unqualified Inexperienced Staff	2.8974	1.27310	39
Lack of Thoroughness of Preconstruction Planning Estimating	3.3333	1.19942	39
Weather Condtion	2.7436	1.27151	39
Government Policies	2.7179	1.21284	39
Resources Availability	2.8462	1.01407	39
Quality Assurance Control	2.5641	0.96777	39
Adaption of AdvanceTechnology	2.4103	1.01872	39
Socio Economic Condition	2.4615	1.09655	39
Stakeholders Issues	3.2308	1.22392	39

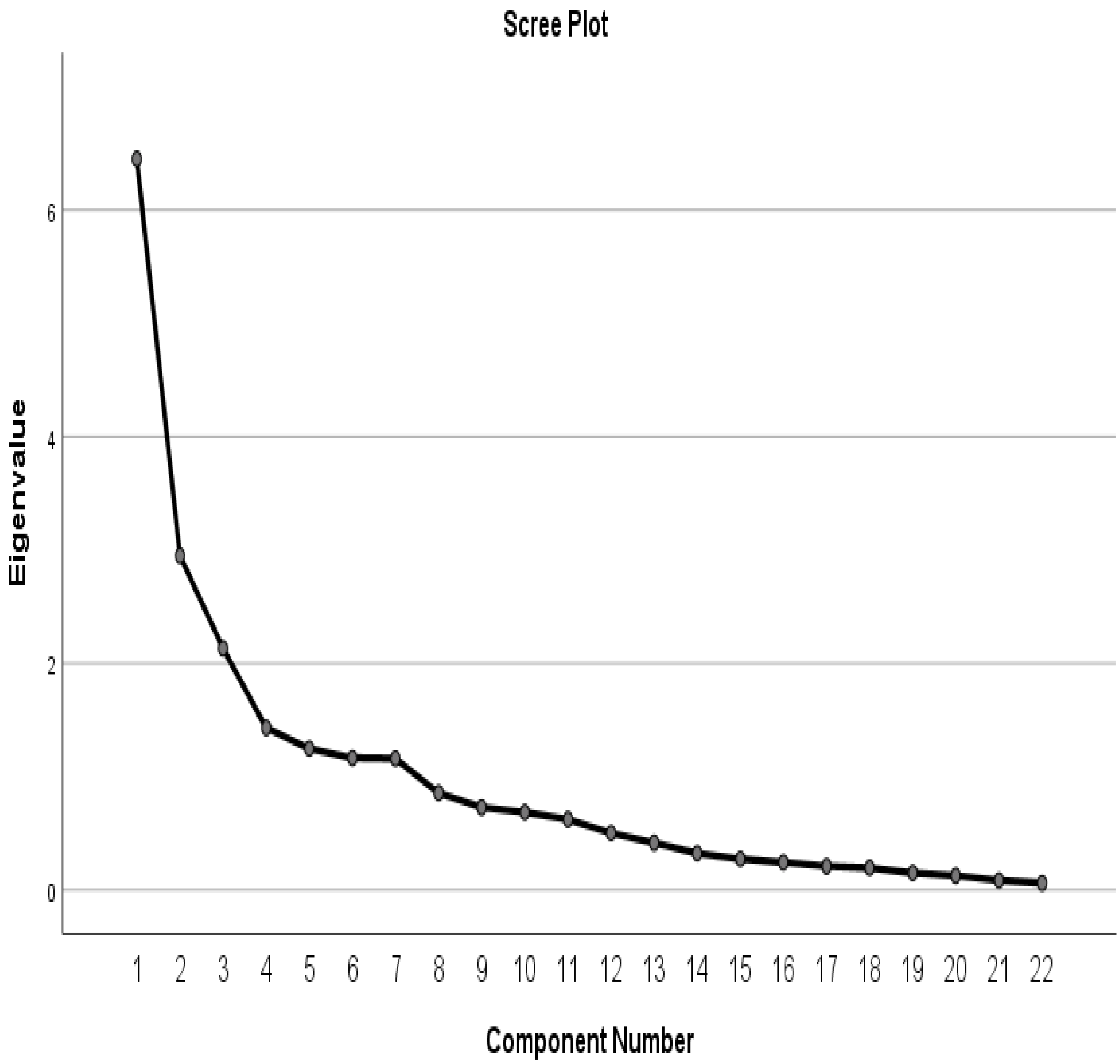
Section-4A Cronbach Alpha

Scale Statistics			
Mean	**Variance**	**Std. Deviation**	**N of Items**
65.6410	**171.289**	**13.08773**	**22**

Section-4B Showing Total Variance Explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.450	29.320	29.320	6.450	29.320	29.320	3.793	17.242	17.242
2	2.950	13.408	42.729	2.950	13.408	42.729	2.574	11.700	28.942
3	2.132	9.690	52.418	2.132	9.690	52.418	2.469	11.221	40.163
4	1.430	6.502	58.920	1.430	6.502	58.920	2.400	10.911	51.074
5	1.247	5.670	64.590	1.247	5.670	64.590	1.930	8.774	59.848
6	1.163	5.288	69.878	1.163	5.288	69.878	1.906	8.664	68.512
7	1.158	5.265	75.143	1.158	5.265	75.143	1.459	6.631	75.143
8	0.855	3.887	79.030						
9	0.728	3.308	82.339						
10	0.685	3.114	85.452						
11	0.622	2.830	88.282						
12	0.502	2.281	90.563						
13	0.415	1.888	92.451						
14	0.323	1.469	93.920						
15	0.274	1.243	95.163						
16	0.243	1.103	96.267						
17	0.209	0.949	97.216						
18	0.194	0.884	98.099						
19	0.149	0.678	98.777						
20	0.125	0.567	99.344						
21	0.084	0.382	99.726						
22	0.060	0.274	100.000						
Extraction Method: Principal Component Analysis.									

Section-4C Showing the Screen plot



Section-5A System thinking scale score estimation table

Head of Project	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						55

Cont-Section-5A

Building Surveyor/Project Engineer	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.			2			2
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success	0					0
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.				3		3
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
Total						58

Cont-Section-5A

Risk Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.			2			2
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
Total						72

Cont-Section-5A

Head of project	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.		1				1
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.		1				1
.I recognize system problems are influenced by past events.		1				1
I consider the past history and culture of the work unit.		1				1
I consider that the same action can have different effects over time , depending on the state of the system.			2			2
TOTAL						53

Cont-Section-5A

Architect/Project Engineer	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time ,depending on the state of the system.					4	4
TOTAL						62

Cont-Section-5A

Operation Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						73

Cont-Section-5A

Commercial Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.		1				1
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.					4	4
TOTAL						60

Cont-Section-5A

Civil Engineer	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.				3		3
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						61

Cont-Section-5A

Project/Telecom Consultant	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.			2			2
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.	0					0
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						55

Cont-Section-5A

Engineering Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success		1				1
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.		1				1
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.					4	4
TOTAL						67

Cont-Section-5A

Project Controller	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.				3		3
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						62

Cont-Section-5A

Project Delivery Officer	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.				3		3
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.					4	4
TOTAL						63

Cont-Section-5A

Project Delivery Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.		1				1
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						64

Cont-Section-5A

Head of Project	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
depending on the state of the system.			2			2
TOTAL						55

Cont-Section-5A

Head of Project	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
depending on the state of the system.			2			2
TOTAL						55

Cont-Section-5A

Project Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.			2			2
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						54

Cont-Section-5A

Project Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.			2			2
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						54

Cont-Section-5A

NetworkRail Planner	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						58

Cont-Section-5A

NetworkRail Commercial Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.		1				1
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.					4	4
TOTAL						63

Cont-Section-5A

Central Alliance-Planner	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						58

Cont-Section-5A

DirectRail-Engineering Director	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.			2			2
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.						0
I try strategies that do not rely on people's memory.				3		3
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						57

Cont-Section-5A

DirectRail-Project Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						65

Cont-Section-5A

Amey-Project Planner	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.			2			2
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.		1				1
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						52

Cont-Section-5A

Gateshead Council-Project Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.						0
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time , depending on the state of the system.			2			2
TOTAL						59

Cont-Section-5A

Engie.Estimator	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.			2			2
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						52

Cont-Section-5A

London Bridge Station-Snr Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.			2			2
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						64

Cont-Section-5A

Gateshead Council-Project Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.						0
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time , depending on the state of the system.			2			2
TOTAL						59

Cont-Section-5A

Turner/Townsend-Snr Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.			2			2
TOTAL						68

Cont-Section-5A

Wood Snr Project Planner	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.				3		3
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.				3		3
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time , depending on the state of the system.				3		3
TOTAL						60

Cont-Section-5A

Northumbria Water Lead Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.			2			2
I consider the relationships among coworkers in the work unit.			2			2
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.			2			2
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.						0
I consider that the same action can have different effects over time, depending on the state of the system.					4	4
TOTAL						58

Cont-Section-5A

Northumbria Water Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem			2			2
I think understanding how the chain of events occurs is crucial.			2			2
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.			2			2
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time , depending on the state of the system.			2			2
TOTAL						66

Cont-Section-5A

Northumbria Water Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.			2			2
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.			2			2
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time, depending on the state of the system.					4	4

Cont-Section-5A

Diageo-Project Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.			2			2
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.						0
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.						0
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other						0
I think about how different employees might be affected by the improvement.						0
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.					4	4
TOTAL						58

Cont-Section-5A

Group Tegual Limited Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.				3		3
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time , depending on the state of the system.				3		3
TOTAL						64

Cont-Section-5A

Essex & Suffolk Water Proj Mgr	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.				3		3
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.				3		3
I think that systems are constantly changing.			2			2
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success		1				1
I keep the mission and purpose of the organization in mind.		1				1
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.		1				1
TOTAL						60

Cont-Section-5A

Augustusham Design Engineer	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.					4	4
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues					4	4
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.					4	4
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.					4	4
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other					4	4
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.					4	4
I consider that the same action can have different effects over time ,depending on the state of the system.					4	4
TOTAL						79

Cont-Section-5A

Siemena Planner	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation					4	4
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.					4	4
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.					4	4
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success				3		3
I keep the mission and purpose of the organization in mind.				3		3
I think small changes can produce important results.				3		3
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.			2			2
I try strategies that do not rely on people's memory.				3		3
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						64

Cont-Section-5A

Highway England PMO Director	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation			2			2
I look beyond a specific event to determine the cause of the problem					4	4
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.				3		3
I think recurring patterns are more important than anyone specific event.					4	4
I think of the problem at hand as a series of connected issues			2			2
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.					4	4
I think that systems are constantly changing.		1				1
I propose solutions that affect the work environment, not specific individuals.					4	4
I keep in mind that proposed changes can affect the whole system.			2			2
I think more than one or two people are needed to have success					4	4
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other			2			2
I think about how different employees might be affected by the improvement.					4	4
I try strategies that do not rely on people's memory.					4	4
.I recognize system problems are influenced by past events.					4	4
I consider the past history and culture of the work unit.			2			2
I consider that the same action can have different effects over time, depending on the state of the system.		1				1
TOTAL						61

Cont-Section-5A

Northumbria Programme Manager	NEVER	SELDOM	SOME OF THE TIME	OFTEN	MOST OF THE TIME	TOTAL
I seek everyone's view of the situation				3		3
I look beyond a specific event to determine the cause of the problem				3		3
I think understanding how the chain of events occurs is crucial.				3		3
.I include people in my work unit to find a solution.				3		3
I think recurring patterns are more important than anyone specific event.				3		3
I think of the problem at hand as a series of connected issues				3		3
I consider the cause and effect that is occurring in a situation.				3		3
I consider the relationships among coworkers in the work unit.			2			2
I think that systems are constantly changing.				3		3
I propose solutions that affect the work environment, not specific individuals.				3		3
I keep in mind that proposed changes can affect the whole system.				3		3
I think more than one or two people are needed to have success			2			2
I keep the mission and purpose of the organization in mind.					4	4
I think small changes can produce important results.					4	4
I consider how multiple changes affect each other				3		3
I think about how different employees might be affected by the improvement.				3		3
I try strategies that do not rely on people's memory.			2			2
.I recognize system problems are influenced by past events.				3		3
I consider the past history and culture of the work unit.				3		3
I consider that the same action can have different effects over time, depending on the state of the system.				3		3
TOTAL						59

Section-5B Questionnaire (Bristol online survey)

Improving costing in infrastructure project to accommodate uncertainties.

Page 1: Demographics

A-Name of your organization?

B-Your professional position?

C-Number of employees in your organization?

D-Size of project budget handled by your organization?

E-Type of infrastructure project handled in your organization?

Cont-Section-5

F-Years of Project management experience you have?

Have you been involved in a government infrastructure(construction) project?

Cont-Section-5

Page 2: Infrastructure project uncertainty management

1-Does your organization identify uncertainties during the project initiation stage?

- ☐ Yes
- ☐ No
- ☐ Not sure

2-Is uncertainty management carried out in your organization on infrastructure projects with following durations.

- ○ < 6 months
- ○ > 12 months
- ○ 6-12 months
- ○ None of the above

3-Is infrastructure project uncertainty identified in your organization concurrently with risk or separately during the project initiation stage?

- ☐ Yes
- ☐ No
- ☐ Not sure

4-Are the cost management team involved in infrastructure project uncertainty/risk identification during the initiation stage?

- ☐ Yes
- ☐ No
- ☐ Not sure

Cont-Section-5

5-What is the scope of the infrastructure uncertainty identification process during the initiation stage?

- [ ] Flexible and iterative
- [ ] In house standardised process
- [ ] Generic formal process
- [ ] Informal process
- [ ] Not too sure

6-Is there a dedicated uncertainty management team in your organization?

- [ ] Yes
- [ ] No

7-What is the key focus in your organization when identifying uncertainties during the project initiation stage?

- [ ] Known,unknown uncertainties
- [ ] Unknown,unknown uncertainties
- [ ] Opportunity management
- [ ] Threat management
- [ ] Other

If you selected other, please clarify further

8-What is the level of documentation of identified uncertainties during the project initiation stage in your organization?

- [ ] Documentation reported and used for the purpose of initial cost estimate
- [ ] Analysis documented and used throughout the project duration
- [ ] Documented informally
- [ ] Other

Cont-Section-5

If you selected other, please clarify further

[ ]

9-What are the techniques used for identifying uncertainties in your organization during the project initiation stage?

- [ ] Expert knowledge
- [ ] Facilitated workshops
- [ ] Multi criteria decision analysis
- [ ] Brainstorming
- [ ] Other

(You can select more than one option). If you selected other, please clarify further.

[ ]

10-Please rate the uncertainty factors listed below according to their impact on infrastructure project cost estimation. Note:1-2(Very low),3(Medium) & 4-5(High)

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5
The unforeseen site and Construction issues	☐	☐	☐	☐	☐
Design error or omission	☐	☐	☐	☐	☐
Contractor Caused Delays and Coordination issues	☐	☐	☐	☐	☐
Owner Driven Changes	☐	☐	☐	☐	☐
Accelerated Schedules	☐	☐	☐	☐	☐
Construction Coordination Issues	☐	☐	☐	☐	☐
Project Delivery Method	☐	☐	☐	☐	☐
Team Formation Process	☐	☐	☐	☐	☐

Cont-Section-5

Regulatory Permitting Process	☐	☐	☐	☐	☐
Miscommunication between teams	☐	☐	☐	☐	☐
Unclear Project Requirements	☐	☐	☐	☐	☐
Scope Gaps	☐	☐	☐	☐	☐
Project Complexity	☐	☐	☐	☐	☐
Underperforming/unqualified/inexperienced staff	☐	☐	☐	☐	☐
Lack of thoroughness of pre-construction planning, estimating	☐	☐	☐	☐	☐
and scheduling.	☐	☐	☐	☐	☐
Weather condition	☐	☐	☐	☐	☐
Government policies	☐	☐	☐	☐	☐
Resources availability	☐	☐	☐	☐	☐
Quality assurance/control	☐	☐	☐	☐	☐
Adaption of advanced technology	☐	☐	☐	☐	☐
Socio-Economic condition.	☐	☐	☐	☐	☐
Stakeholder issues	☐	☐	☐	☐	☐

If you are aware of any other top priority uncertainty factors that are not stated above, kindly state them below

11-Have you undertaken any dedicated training on uncertainty management in your current or previous organization?

☐ 1-Yes
☐ 2-No

If you selected "yes" to the above question, please provide details of the training undertaken

Cont-Section-5

12-Do you think inadequate identification of uncertainties during the project initiation stage will have an impact on the initial cost estimate?

- ☐ Strongly disagree
- ☐ Disagree
- ☐ Slightly disagree
- ☐ Slightly agree
- ☐ Agree
- ☐ Strongly agree

13-Do you think robust uncertainty identification during the initiation stage will improve the quality of the initial project cost estimate?

- ☐ Strongly disagree
- ☐ Disagree
- ☐ Slightly disagree
- ☐ Slightly agree
- ☐ Agree
- ☐ Strongly agree

Cont-Section-5

Page 3: Infrastructure project risk management

14-What is the key focus of the risk identification process in your organization during the project initiation stage?

- ☐ 1-Threat
- ☐ 2-Opportunities
- ☐ 3-Unknowns
- ☐ 4-All of the above
- ☐ 5-Other

If you selected other, please clarify further.

15-What is the scope of the risk identification processes during the initiation stage of your project?

- ☐ 1-Standardised formal process
- ☐ 2-Generic informal process
- ☐ 3-Flexible and iterative process
- ☐ 4-Other

If selected other, please clarify briefly. You can add other scopes not mentioned on the list above.

16-What techniques do your organization utilize in identifying risk during the initiation stage?

- ☐ 1-Expert judgment

Cont-Section-5

☐ 2-Analytical technique
☐ 3-Facilitated workshop
☐ 4-Meeting
☐ 5-Other

If you selected other, please clarify further.

[ ]

17-Is there a dedicated risk management team in your organization?

☐ 1-Yes
☐ 2-No
☐ 3-Not sure

If you selected not sure, please clarify further.

[ ]

18-In your organization are the estimators involved in identifying risk during the project initiation stage?

☐ 1-Yes
☐ 2-No

19-Do you think the risk management process utilized in your organization is adequate to mitigate the impact of cost overrun?

☐ 1-Strongly disagree ☐ 2-Disagree ☐ 3-Slightly disagree

Cont-Section-5

☐ 4-Slightly agree ☐ 5-Agree ☐ 6-Strongly agree

20-Do you generally implement risk management in all your project regardless of the duration??

☐ 1-Yes
☐ 2-No

21-Can you briefly describe the process you utilize in identifying risk during project initiation stage?

Cont-Section-5

Page 4: Infrastructure project cost estimation

22-What are the key factors considered in your organization when producing a robust initial cost estimate during the initiation stage?

23-What are the main factors that impact cost estimation during project initiation stage?

24-What are the key resources involved in cost estimation during project initiation stage?

25-How do you estimate your cost estimate during the project initiation stage?

- ☐ Historical data assessment
- ☐ Professional Experience
- ☐ By analytical technique
- ☐ Expert judgement
- ☐ Benchmarking
- ☐ Other

If you selected other,please expatiate further

26-How is your contingency cost estimate determined during the project initiation stage?

- ☐ Expert judgement
- ☐ Analytical technique
- ☐ Other technique

Cont-Section-5

If other technique selected,please clarify further

[ ]

27-How is your management reserve estimated during the project initiation stage?

- ☐ Expert judgement
- ☐ Analytical technique
- ☐ Other technique

If other technique selected,please clarify further

[ ]

28. What is the major source of cost data for estimating during the initiation stage?

- ☐ In-House Cost data base
- ☐ Quotations from subcontractors or suppliers.
- ☐ Cost indices/schedule of rates
- ☐ Other

Cont-Section-5

Page 5: The system thinking scale

Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots…Today systems thinking is needed more than ever because we are becoming overwhelmed by complexity." – Peter Senge, The Fifth Discipline This is a brief introduction to system thinking so as to enhance your response to the below questions on the aforementioned subject. A widely accepted and conventional approach is used to understand the perception of system thinking by professionals.No right or wrong answers to the questions.

29.I seek everyone's view of the situation.

- ☐ Never ☐ Seldom ☐ Some of the time
- ☐ often ☐ Most of the time

30. I look beyond a specific event to determine the cause of the problem.

- ☐ Never ☐ Seldom ☐ Some of the time
- ☐ often ☐ Most of the time

31. I think understanding how the chain of events occurs is crucial.

- ☐ Never ☐ Seldom ☐ Some of the time
- ☐ often ☐ Most of the time

Cont-Section-5

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

33. I think recurring patterns are more important than anyone specific event.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

34. I think of the problem at hand as a series of connected issues

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

35. I consider the cause and effect that is occurring in a situation.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

36.I consider the relationships among coworkers in the work unit.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

37. I think that systems are constantly changing.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time

Cont-Section-5

☐ often ☐ Most of the time

38.I propose solutions that affect the work environment, not specific individuals.

☐ Never ☐ Seldom ☐ Some of the time
☐ often ☐ Most of the time

39. I keep in mind that proposed changes can affect the whole system.

☐ Never ☐ Seldom ☐ Some of the time
☐ often ☐ Most of the time

40.I think more than one or two people are needed to have success

☐ Never ☐ Seldom ☐ Some of the time
☐ often ☐ Most of the time

41. I keep the mission and purpose of the organization in mind.

☐ Never ☐ Seldom ☐ Some of the time
☐ often ☐ Most of the time

42. I think small changes can produce important results.

☐ Never ☐ Seldom ☐ Some of the time
☐ often ☐ Most of the time

Cont-Section-5

43. I consider how multiple changes affect each other.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

44. I think about how different employees might be affected by the improvement.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

45. I try strategies that do not rely on people's memory.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

46.I recognize system problems are influenced by past events.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

47. I consider the past history and culture of the work unit.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

48.I consider that the same action can have different effects over time,

depending on the state of the system.

- [ ] Never
- [ ] Seldom
- [ ] Some of the time
- [ ] often
- [ ] Most of the time

Cont-Section 5

Page 6: Need for cognition scale

Instructions: Kindly indicate your agreement with each of the following statements, using the scale provided.

Note: There are no right or wrong answers.

49.I would prefer complex to simple questions

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- Strongly agree

50.I like to have the responsibility of handling a situation that requires a lot of thinking.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- Strongly agree

51.I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- Strongly agree

52.I try to anticipate and avoid situations where there is likely a chance I will have to think in-depth about something.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- Strongly agree

Cont-Section 5

53.I find satisfaction in deliberating hard and for long hours

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- 6-Strongly agree

54.I only think as hard as I have to.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- 6-Strongly agree

55.I prefer to think about small, daily projects to long-term ones.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- Strongly agree

56.I like tasks that require little thought once I've learned them.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- 6-Strongly agree

57.The idea of relying on thought to make my way to the top appeals to me.

- Strongly disagree
- Disagree
- Slightly disagree
- Slightly agree
- Agree
- Strongly agree

58.I really enjoy a task that involves coming up with new solutions to problems.

Cont-Section 5

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Slightly disagree
- [ ] Slightly agree
- [ ] Agree
- [ ] Strongly agree

59.Learning new ways to think doesn't excite me very much

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Slightly disagree
- [ ] Slightly agree
- [ ] Agree
- [ ] 6-Strongly agree

60.I prefer activities to be filled with puzzles that I must solve

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Slightly disagree
- [ ] Slightly agree
- [ ] Agree
- [ ] 6-Strongly agree

61.The notion of thinking abstractly is appealing to me.

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Slightly disagree
- [ ] Slightly agree
- [ ] Agree
- [ ] Strongly agree

62.I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require a lot of mental effort.

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Slightly disagree
- [ ] Slightly agree
- [ ] Agree
- [ ] 6-Strongly agree

63.I am more relieved than satisfied after completing a task that required a lot of mental effort.

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Slightly disagree

Cont-Section 5

☐ Slightly agree	☐ Agree	☐ Strongly agree

64.Its enough for me that something gets the job done;I don't care how or why it works.

☐ Strongly disagree	☐ Disagree	☐ Slightly disagree
☐ Slightly agree	☐ Agree	☐ 6-Strongly agree

65.I usually end up deliberating about issues even when they do not affect me personally.

☐ Strongly disagree	☐ Disagree	☐ Slightly disagree
☐ Slightly agree	☐ Agree	☐ 6-Strongly agree

66.Thinking is not my idea of fun.

☐ Strongly disagree	☐ Disagree	☐ Slightly disagree
☐ Slightly agree	☐ Agree	☐ Strongly agree

5C Semi-structured interview(Curto et al., 2022)

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED:RAIL INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 13years

SIZE OF PROJECT INVOLVED:£55B

POSITION OF PARTICIPANTS: Scope baseline and Earned Value Manager

1. Is infrastructure project uncertainties identified in your organization during initiation stage?
   Ans:Yes
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans:Yes, when you look at big programme like HS2 which contains smaller project
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans:There has been group discussion with all the stakeholders involved to identify risks.
4. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans:Yes absolutely.
5. Does your organization indulge in infrastructure project uncertainty management during initiation stage?

   Ans:Yes
6. Does your organization considers holistic view for short term infrastructure project?

   Ans:In term of infrastructure project,I haven't worked on project of that duration so can't comment on that.
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED:RAIL INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE:7years of Experience

SIZE OF PROJECT INVOLVED:£200,000

POSITION OF PARTICIPANTS: Head of Project

1. Is infrastructure project uncertainties identified in your organization during initiation stage?
   Ans**:Yes so how we do it we(I am trained in Prince2) can have an initiation where we identify infrastructure projects. We currently going to process arriving at all of our infrastructure projects trying to align all the project with company strategy. The deliverables will be basically aligned to company's strategy.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans:**Yes**

   Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans:Yes concurrently
3. Does your organization indulge in infrastructure project uncertainty management during initiation stage**?**

   Ans: Yes so, I tell you a story here.We didn't use to however what we start is a stakeholders didn't have a better idea on how to do it. So we do get them more involved at the initiation stage now because support the stakeholders so the project sponsors should be in charge with business case and approve business case so we find a lot of them with using inadequate document for the business case. So it is most better for them to get involved in the project earlier and it makes the project delivery easier.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED; RAIL INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 34YRS

SIZE OF PROJECT INVOLVED:£200M

POSITION OF PARTICIPANTS: HEAD OF PROJECT

1. Is infrastructure project uncertainties identified in your organization during initiation stage?
   Ans: Erm,what we do, highways England project department is quite a young in the industry. What we try to instil is risk management and in my experience, Project managers are always keen to deliver project on time, budget but I will question whether they take risk management seriously enough, whether is part of their day to day thinking, that's something we try to drive in Highways England.So we investing in risk system called exert team and all of our project have risk management plan. All our project has risk management plan and should define all the roles involved in the project. It should also define what happens and when. We've had the exert team for 6month and what I want the project management to do is data quality system (Data Completeness).We tell the people to do risk management. We check the risk register, stage gate but are they on the weekly/monthly basis identifying the risk and assigning owners/managing them as well and am not convinced they are doing it.What am pushing for is data completeness/quality out of the system so that we can look at all our project and say how many risks are open/new risk created this month are they doing their actions on time. So that we can test whether project manager are paying attention to it or leaving it too late or leave it active risk management on ongoing basis. I believe if you do it on an ongoing basis you take ownership of your actions and manage them out you will be more successful. The challenge is at the early stage of the project we talk about unknown/unknown and it is not always easy to identify all the risks. That's one of the challenges and why is the reason we need 3point estimate to know what range we working with. Too often we focus on one number rather than being on a range and what we should be saying we are on a range. If you imagine uncertainty as a cone or hopper further more developed is the project the lesser the uncertainty in the project. I don't think the uncertainty management is inadequate is just because the project management focuses too much on one number rather than recognizing boundaries(Upper & Lower).Unknowns/Unknowns uses estimating data base which tells you more about similar projects. Expert opinion is based on history. So they compare with similar project (benchmarking). This is subjective and not précised. It is definitely not perfect.
2. Do you identify infrastructure project uncertainties for short term project during

   initiation stage?

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: STRUCTURE AND EARTH WORKS (CIVIL WORKS-IN RAIL SECTOR)

YEARS OF EXPERIENCE: 17YRS

SIZE OF PROJECT INVOLVED: £1,000,000.00

POSITION OF PARTICIPANTS: COMMERCIAL MANAGER/QUANTITY SURVEYOR

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

   Ans: I would say yes. It would be and we go through numbers of factors as we put in through a and meet together for delivery work. We have certain stages which we go through where normally a project cannot pass almost stage gate we call it.It is a milestone for delivery so there are certain products where we couldn't actually go further until satisfy those products.

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: Yes we do.

3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: We can do probably as a team. We almost brainstorming as you go through and in this company we do risk readiness reviews as from both safety, delivery and cost impact. Mostly safety is the main driver, can we do this project successfully safely and how much is it going to be. What potentially those risk and the cost impact on the project.

4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?

   Ans:

5. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans: Definitely Yes

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: RAIL INFRASTRUCTURE & DEFENCE

YEARS OF EXPERIENCE: 14years

SIZE OF PROJECT INVOLVED:200M

POSITION OF PARTICIPANTS: Commercial manager-B

1. Is infrastructure project uncertainties identified in your organization during initiation stage?
   Ans:I am not too sure of questions but break down a little bit. Are we talking about company specifics or customers etc. Individuals are accountable by law to be compliant with the regulations involved in the infrastructure project.
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: Yes is part of the process is not just about, there is certain criteria that needs to be met. We have to make sure the compliance meets the necessary requirements. It saves money and time to do it and it is precaution and criteria for a project.
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?

   Ans: We identify it together. It is worded in my organization. Risk is what going to happen and we don't do independently rather concurrently.
4. Do you think identification of infrastructure project uncertainties is necessary for project?

   Ans:Yes for sure.
5. Does your organization indulge in infrastructure project uncertainty management during initiation stage?

   Ans:Well we will do. We don't' call it uncertainty management but risk which we manage throughout.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: Railway Infrastructure Enhancement project

YEARS OF EXPERIENCE: 13years of Experience

SIZE OF PROJECT INVOLVED:>10M

POSITION OF PARTICIPANTS: Commercial Manager **A**

1. Is infrastructure project uncertainties identified in your organization during initiation stage?

   Ans:Yes.Infrastructure project uncertainties are identified during initiation stage using personalized process known as stage gate process. It takes the project from feasibility then option selection. Feasibility-Initiation stage (Concept formulation). Undertaken a few desktop base analysis so the project is being done achieve it purpose. There are 8 stages. Each stage undertakes an estimate and risk analysis. Each stage has some extent of uncertainties. Uncertainties start from initiation stage. As the project progresses, the scope expands and budget refined etc. Uncertainties manifest as assumption and risk.

2. Do you identify infrastructure project uncertainties for short term project during initiation stage?

   Ans: Schemes are designed and implemented, go through design stage. Undertake budget estimate, assumption and refined. Benchmarking projects. Understanding how project will work and cost based on the information collated from benchmarking. Understand what the work is and understanding the cost estimate of the project. How the work is going to be delivered.Uncertainty remaining used to create contingency value. So project budget is made after all these process are done. The project goes through governance where management makes decision on project.Is easy to know the estimate cost of the work but the methodology is not known. The methodology of the project needs to be understood because that might spring out a lot of uncertainties.

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: RAIL SECTOR

YEARS OF EXPERIENCE:

SIZE OF PROJECT INVOLVED:

POSITION OF PARTICIPANTS: RISK MGR

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **I'm not entirely clear of the questions, but explain a little. Are we discussing specifics about the business or customers, etc. The law holds everyone responsible for adhering to the rules governing the infrastructure project.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?**Yes, that is a component of the procedure, but there are other requirements as well. We must confirm that compliance complies with all required regulations. It is a precaution and a project requirement that saves time and money.**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently? **We both recognise it. In my company, it is written that way. Risk is what will occur, and we act concurrently rather than independently.**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**Yeah for sure**
5. Do you think identification of infrastructure project uncertainties is necessary for project**? We will, of course. We manage risk throughout rather than calling it uncertainty management.**
6. Does your organization considers holistic view for short term infrastructure project?
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?**To some extent**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED:RAILWAY INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 13YRS

SIZE OF PROJECT INVOLVED:300M

POSITION OF PARTICIPANTS: QUANTITY SURVEYOR

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **Yes, I would agree. It would be, and we would consider a variety of variables as we worked through a delivery task together. We go through stages that a project would often not be able to pass, or as we like to say, stage gates. There are some goods that must be satisfied before we can move on because it is a delivery milestone.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?Y**eah, that is a component of the procedure, but there are other requirements as well. We must confirm that compliance complies with all required regulations. It is a precaution and a project requirement that saves time and money.**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?Yes
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**Yeah for sure.**
5. Do you think identification of infrastructure project uncertainties is necessary for project? **We will, of course. We manage risk throughout rather than calling it uncertainty management.**
6. Does your organization consider holistic view for short term infrastructure project?**Not really**
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage? **Yes, let me put it that way: a system**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: RAILWAY INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 8YRS

SIZE OF PROJECT INVOLVED:200M

POSITION OF PARTICIPANTS: PROJECT CONTROL ENGR

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **YES, Using a customised approach known as the stage gate process, infrastructure project uncertainties are discovered at the beginning stage. It starts with project feasibility and moves on to option selection. stage of feasibility-initiation (Concept formulation). conducted a few desktop-based analyses to ensure the project's success. 8 stages are present. An estimation and risk analysis are conducted at each level. There are some uncertainties at each stage. Uncertainties begin at the initial stage. The project's scope and budget are adjusted as it goes along. Assumption and risk are manifestations of uncertainty.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?**Yes**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?**Yes, concurrently because risk is created by uncertainty.**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**Yes**
5. Do you think identification of infrastructure project uncertainties is necessary for project?**Yes I do**
6. Does your organization considers holistic view for short term infrastructure project? **Yes. expanding the rail network It follows a typical lifespan.**
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage? **Yes, I believe it will enhance infrastructure project management. IF IT IS INCLUDED IN A MANNER WITHIN THE ORGANIZATIONAL APPROACH**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: RAILWAY INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 14YRS

SIZE OF PROJECT INVOLVED:£200m

POSITION OF PARTICIPANTS: PROGRAMME MGR

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **Yes. At the planning stage of infrastructure projects, risks are identified using the stage gate process, a customised approach. Project viability is the first step, followed by option selection.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?Yes, **Before being developed and put into action, schemes go through the design stage. Make an educated guess, a supposition, and a new budget. benchmarking programmes. being aware of the project's expected costs and operations based on benchmarking data**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?**We used to do it concurrently in my last project**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**Yes**
5. Do you think identification of infrastructure project uncertainties is necessary for project?**Yeah**
6. Does your organization considers holistic view for short term infrastructure project?**I have never been involved in a short term project**
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage**? Yes, I believe it will improve the management of the infrastructure project if it is incorporated into an organisational strategy.**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: RAILWAY INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE:

SIZE OF PROJECT INVOLVED:£3.2B

POSITION OF PARTICIPANTS: PM

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **Unfortunately, I've never worked on a small project, so most projects I've worked on tend to be a minimum of 12 months. So on the railway there is project. Don't get me wrong, there are projects that only last three to six months, but they still might take a whole year of planning. So to remove a section of railway you know from. A to B to take out that small section. It might only take you a couple of weeks to do the job, but the planning that goes into it and the risks and things that you have to sort of manage and design still might take 12 months. Alright. So yeah, I'd have to say in response to that that regardless of the longevity of the actual physical construction works, the planning initiation the the risk. The commercial everything that goes into that planning phase would still be the same sort of duration. The same sort of things would be considered. This, you know, very similar approach. Alright, thank you very much.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage? **Well, with most jobs there should be some element of lessons learned. So when you move from one project into the next, you should do a review of the law. You know what went? Well? What didn't go so well? So a lot of things might be a generic sort of approach, and you know to these are going to be the problems and things that you need to to look at again, but then also collectively as a group, people with different experiences or or root knowledge. So some people know Manchester better than others. So collectively, we'd work together to identify these uncertainties, rather than just the project manager on their own. It definitely needs to be a group activity. What I consider to be a risk or uncertainty you might see as something else. You might identify something that I've missed, so it's always done as a as a collective and shouldn't really ever be done as a sort of individual action.**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED:RAILWAY INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 13Yrs

SIZE OF PROJECT INVOLVED:350M

POSITION OF PARTICIPANTS: Planning Eng

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **Yes, in such case, we can have an initiation stage where we identify infrastructure projects (I am trained in Prince2). We are now working on completing all of our infrastructure projects while attempting to integrate every project with the corporate strategy. The deliverables will essentially be in line with the business strategy.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?**YES**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?**No Just risk**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage**? I think so from where we are because, in particular, the money we spent on projects and infrastructure can make up a significant portion of our budget. Therefore, in terms of resources, personnel, and money, ermm where have to identify all our projects really to ensure that we are investing in the right projects in order to align with the company's strategy. Be aware that we have a variety of projects of various types, with infrastructure projects being one of them. To ensure that the business is focusing on the proper things, it is vital to identify each one.**
5. Do you think identification of infrastructure project uncertainties is necessary for project?**Yeah**
6. Does your organization consider holistic view for short term infrastructure project?**Not sure**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: RAILWAY INFRASTRUCTURE

YEARS OF EXPERIENCE: 13

SIZE OF PROJECT INVOLVED:£350M

POSITION OF PARTICIPANTS: PLANNER

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **The project department at my organisation, where I work, is relatively new to the market. Risk management is something we attempt to instil, and in my experience, project managers are always eager to execute projects on time and under budget, but I will question if they take risk management seriously enough or whether it is part of their regular way of thinking. As a result, we have invested in a risk management system called the exert team, and each of our projects has one. Every one of our projects has a risk management plan that should outline each of the project's tasks. It should specify when and what happens.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage? **In general, we don't work on projects of that length. Once you have a very good design and have done an analysis of what you believe the risk to be, you complete a short-term project. Once that design is complete, you can start building.**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently? **That's the culture I want to instil in our programme, as I've already stated, and it's a continuous effort. Uncertainty comes to mind immediately. When a project reaches its final stage, we review the risk register or workshop, which is a representation of the risks we anticipate after we pass through the estimating department and compare it to previous projects, etc.**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**I would like to think so**

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED: INFRASTRUCTURE(RAIL)

YEARS OF EXPERIENCE: 12

SIZE OF PROJECT INVOLVED:30M(29Thousand staff strength)

POSITION OF PARTICIPANTS: SNR PROJ

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **YES I MEAN THERE ARE VARIOUS LEVELS OF UNCERTAINTIES IDENTIFIED IN THE PROJECT.Can you tell me a bit more about this question because there are different levels that we actually go through that process of identification.so what a clients put out to be done is followed thoroughly by the contractor.They go through the process so actually profiling the job as they see it.It is whether it fit them or not based on the risk,but potentially may be carried so that's the first point that you actually go through the process.As it go through the tender,this is referred to as registered, preferably uncertainty register.If the job is won,it goes to the project team who identifies the potential uncertainties at the early stage.At the tender stage the project management team and construction team comes together to analyse what can go wrong in the project.They both go through the project lifecyle then anticipate and identify all the uncertainties they may impact the project. Examples ground condition, market condition(due to the impact of Covid pandemic).So all these needs to be identified so as to map-out plans.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?**I'm not going to lie as I have always been involved in long term project but done 1.5yrs project.Within the projects they are divided into smaller part which are dealt with separately as a project then plugged back into the major one. You will try to identify and quantify what you actually have. And you know what you gonna face? So that for me there are two states you do a qualitative analysis initially of what sort of risks? And then you're trying to quantify them to the best of your abilities, either by putting money against it all by putting time, depending why it's going to be the impact of the uncertainty.**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently? **Say I would say concurrently I would say concurrently I would just**

1. **explaining the process so definitely concurrently. Maybe like. If you're trying to do some identification of some uncertainties and risk, do you do them concurrently or independently? Do you identify them separately, or do you see them as one? And. Usually when you go through the air exercise of risks, you will capture the risk independently. However, when you actually go through the process and you conclude and or will she going through that process you may realize that some of these risks are actually linked. And then when you create the links or you actually. Merge these two risks under one. And so there's no such a thing as being completely independent risks. There is always gonna be an overlap. It can be a time overlap. It can be a space overlap. We can be many other things.**
2. Does your organization indulge in infrastructure project uncertainty management during initiation stage? **All they see it as risk management. Sorry you do. You actually believe that risk management is different to uncertainty? OK. So I'm I'm asking for your own opinion now. I'm not saying you should believe my own opinion, no no, no, no. I'm just axing from your own opinion. For for me. unCertainty is a risk. So if I don't understand something, is a potential risk that I need to somehow capture. Either from a qualitative perspective initially when I'm done here, I don't have so much understanding about it, and then as I go down the line. I actually trying to quantify it in something that is more than table by an uncertainty is a risk. That's how I say it, and that's how I perceived it. OK, you know, for my studies and and later on throughout my career because I started project management. And as well as my background is from civil engineering structures slash structural engineering. So for me I'm certainty is always risky if I don't understand something. If there is something that can know I'm not certain about it, it's a race turning to face some sort of way. It may not mean anything to me at some point, but at the moment in time**

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **Yeah, we tried. So in all aspect show.**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage**? Yeah. Maybe we don't put as much time into it as we do for long term projects, but it is always something you've got to consider at the beginning. So. Because a lot of professionals are not quite right there. It be like are confused between risk and uncertainties.**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently? **As much as we can. I mean you can't plan for every uncertainty, but the ones what like weather conditions, things like that. So like if we're planning for a job in the winter instead of the summer, there's different uncertainties you have to take in. So are you gonna be? Like unable to do one thing in the winter because of the weather. So we we're trying to. But I mean I think it's something that people should pay more attention to than we actually do. So we don't really spend as much time on it as we should be.**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**YEAH**
5. Do you think identification of infrastructure project uncertainties is necessary for project? **YEAH**
6. Does your organization considers holistic view for short term infrastructure project? **Yeah we do. I mean obviously short term projects are a lot different to long term projects, so it might just be a quick exodus size of quick bullet point, whereas long term project we would spend a lot more time on that**.
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?YEAH

1. Do you think inadequate infrastructure project uncertainty management can cause cost overrun? **Yeah, I mean if you don't farm for uncertain news, then the cost of rectifying it at a later stage of economical**
2. What are the main factors that impact a robust infrastructure project cost estimation process**? Well, I mean, I used to consider everything so from how you're gonna deliver a project, especially on a project this size. So you've got not only your wrists as well, but if you employ lots of subcontractors, you've got the risks of those as well, so. Time. Time. Environmental factors, so. Whether special it would be long term. Human errors**
3. Is risk management enough to mitigate impact of cost overrun in infrastructure project? **I don't think if anything's ever gonna be enough to minimise, to minimise it,**
4. Do you think unidentified risk emanates from infrastructure project uncertainties?**YEAH**
5. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?
6. Does your organization considers holistic view of infrastructure project prior to cost estimation during project initiation stage?
7. Does your organization have a standardized or internally devised infrastructure project cost estimating method**? Method mainly just generalized. General standardized. Yeah, standardized so.**
8. Does your organization do an infrastructure project cost estimation for a short d
9. Do you think infrastructure project uncertainties impact on cost estimating methods?**YEAH**

NAME OF PARTICIPANTS:

TYPE OF PROJECT INVOLVED: RAILWAY PROJECTS

YEARS OF EXPERIENCE:

SIZE OF PROJECT INVOLVED:100M

POSITION OF PARTICIPANTS: CONST MGR

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **YES**
2. Do you identify infrastructure project uncertainties for short term project during initiation stage?**YES**
3. Do you identify infrastructure project uncertainties and risks independently or concurrently?**I think I will say both**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage?**Yes,I would say Yes**
5. Do you think identification of infrastructure project uncertainties is necessary for project?**Of course**
6. Does your organization considers holistic view for short term infrastructure project?
7. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage**? They look at everything that might impact on the project. Maybe like the external and internal and make their informed decision. so with the different type of the the approach. When you estimate the project, different tools and techniques using yeah.**
8. Do you think inadequate infrastructure project uncertainty management can cause cost overrun**?Yes**
9. What are the main factors that impact a robust infrastructure project cost estimation process? **, lack of information is just that. Yeah, it's a lack of information. There is a lot of yeah like understand like with regards the the specially with the**

1. **groundworks where you've got unknown foundation you've got unknown conditions and you've got like there's a lot of unknowns. Basically because everything is like yeah. Until you know until you start thinking you don't know what what you're hitting in around even you've got the best like kind of techniques you're using to like do the GPR through various. You always find, for example, some cables or some old foundations, or like you know we center London. You got a lot of archeology or you got a lot of environmental things that you need to consider is, you know it's always.**
2. Is risk management enough to mitigate impact of cost overrun in infrastructure project? . **Is definitely helping, but I will not say they will be able like fully eliminate. OK. Like all the risks, because it's always. Something when someone. Never thought about. Even if the 25 years experience because of the uncertainty or like something new like for example no one would thought about, for example, protestors jumping into the the side. But then you have protestors, which is, you know, is the big risk for the project because the job has to stop or otherwise you know you've got the premiums to pay. You got the subcontractor to working and you cannot do anything with that. For example, yeah. So sometimes is there you put like best mitigation for the risk. Yeah, and you share the risk with a with the some of the risk is going into the client. Some of the risk going to the contractor. But there is always something you know, like where is between. The contractor will will say oh, that's nothing to do with me. The same client would say or you should like. Assume that if you know I mean**
3. Do you think unidentified risk emanates from infrastructure project uncertainties?**YES**
4. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?

NAME OF PARTICIPANTS

TYPE OF PROJECT INVOLVED:RAILWAY INFRASTRUCTURE PROJECT

YEARS OF EXPERIENCE: 13Yrs

SIZE OF PROJECT INVOLVED:350M

POSITION OF PARTICIPANTS: Planning Eng

1. Is infrastructure project uncertainties identified in your organization during initiation stage? **Yes, in such case, we can have an initiation stage where we identify infrastructure projects (I am trained in Prince2). We are now working on completing all of our infrastructure projects while attempting to integrate every project with the corporate strategy. The deliverables will essentially be in line with the business strategy.**
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3. Do you identify infrastructure project uncertainties and risks independently or concurrently?**No Just risk**
4. Does your organization indulge in infrastructure project uncertainty management during initiation stage**? I think so from where we are because, in particular, the money we spent on projects and infrastructure can make up a significant portion of our budget. Therefore, in terms of resources, personnel, and money, ermm where have to identify all our projects really to ensure that we are investing in the right projects in order to align with the company's strategy. Be aware that we have a variety of projects of various types, with infrastructure projects being one of them. To ensure that the business is focusing on the proper things, it is vital to identify each one.**
5. Do you think identification of infrastructure project uncertainties is necessary for project?**Yeah**
6. Does your organization consider holistic view for short term infrastructure project?**Not sure**

1. Do you think systemic approach will improve infrastructure project uncertainties identification during project initiation stage?
2. Do you think inadequate infrastructure project uncertainty management can cause cost overrun?
3. What are the main factors that impact a robust infrastructure project cost estimation process? **The primary factor, in my opinion, is the delivery's scope. A major issue that affects the cost is what we're aiming to accomplish in terms of timeframe.**
4. Is risk management enough to mitigate impact of cost overrun in infrastructure project? **It may lessen the effects.**
5. Do you think unidentified risk emanates from infrastructure project uncertainties?
6. Do you think infrastructure project uncertainty management will mitigate the impact of cost overruns?
7. Does your organization considers holistic view of infrastructure project prior to cost estimation during project initiation stage**? Naturally, by changing as much as possible, we can avoid the majority of risks. The project's potential problems are all listed.**
8. Does your organization have a standardized or internally devised infrastructure project cost estimating method? **No**
9. Does your organization do an infrastructure project cost estimation for a short d
10. Do you think infrastructure project uncertainties impact on cost estimating methods? **Yes**

What factors do you consider in carrying out robust infrastructure project uncertainties in your reputable organization**? There is a wide spectrum, I guess. We usage requirements, the time of year, and weather can all have an impact. Take**