DETERMINING THE PROBABILITY DISTRIBUTIONS OF COST AND TIME OVERRUN ARISING FROM DIFFERENT CONTRACTOR SELECTION STRATEGIES IN CONSTRUCTION PROJECTS.

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Doctor of Philosophy

ASTON UNIVERSITY

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THESIS SUMMARY

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Failing to adequately select the winning contractor can lead to problems in the project delivery phase such as bad quality and project delay; which ultimately results in cost overruns. There are two strategies involved with selecting contractors: one is the lowest tender, the other is called best value. Selecting the lowest tender is straightforward; the latter strategy would involve scoring the contractors' tenders on price and quality and ranking them.

The aim of this research is to provide a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies: lowest tender or best value tender. The research presents an approach by which a what-if scenario can be analyzed using educational facilities projects in the UK. A Monte Carlo Simulation model was developed to allow the evaluation of the probability distributions of cost, and duration arising from the different strategies; these are presented as probability curves.

The results show that the lowest tenderer would likely overrun in cost but the cost will be below the price of the best value tenderer. However, there is a higher probability that the lowest tender will exceed the clients' expected duration, perhaps by a significant amount.

The first contribution of the thesis is the development of a novel model of determining the probability distributions of cost and time involved with the different contractor selection strategies by using Monte Carlo simulation. The second contribution is a fresh way of looking at cost overruns. It is proposed that contractors' cost overrun for a project should be compared to the price of the next highest tender to gauge its real impact.

Keywords: Contractor selection, lowest price, best value tender, Monte Carlo Simulation.

DEDICATION

All Glory to God for leading and pulling me through.

I would like to thank the industry partners that provided data for this research.

Dr John Elgy – I'll forever be grateful to you!

Dr Gayan Wedawatta – Thanks for tolerating me!

Mom and Dad – Thanks for all you guys do and continue to do for me!

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LIST OF ABBREVIATIONS

ANN: Artificial Neural Network

BCIS: Building Cost Information Service

CESMM: Civil Engineering Standard Method of Measurement

COQ: Cost of Quality

ICE: Institution of Civil Engineers

MCS: Monte Carlo Simulation

MEAT: Most Economically Advantageous Tender

NBS: National Contracts and Law Survey

NRM New Rules of Measurement

PCA: Principal Component Analysis

PDF: Probability Density Function

RICS: Royal Institute of Chartered Surveyors

SMM7: Standard Method of Measurement

UK: United Kingdom

USA: United States of America

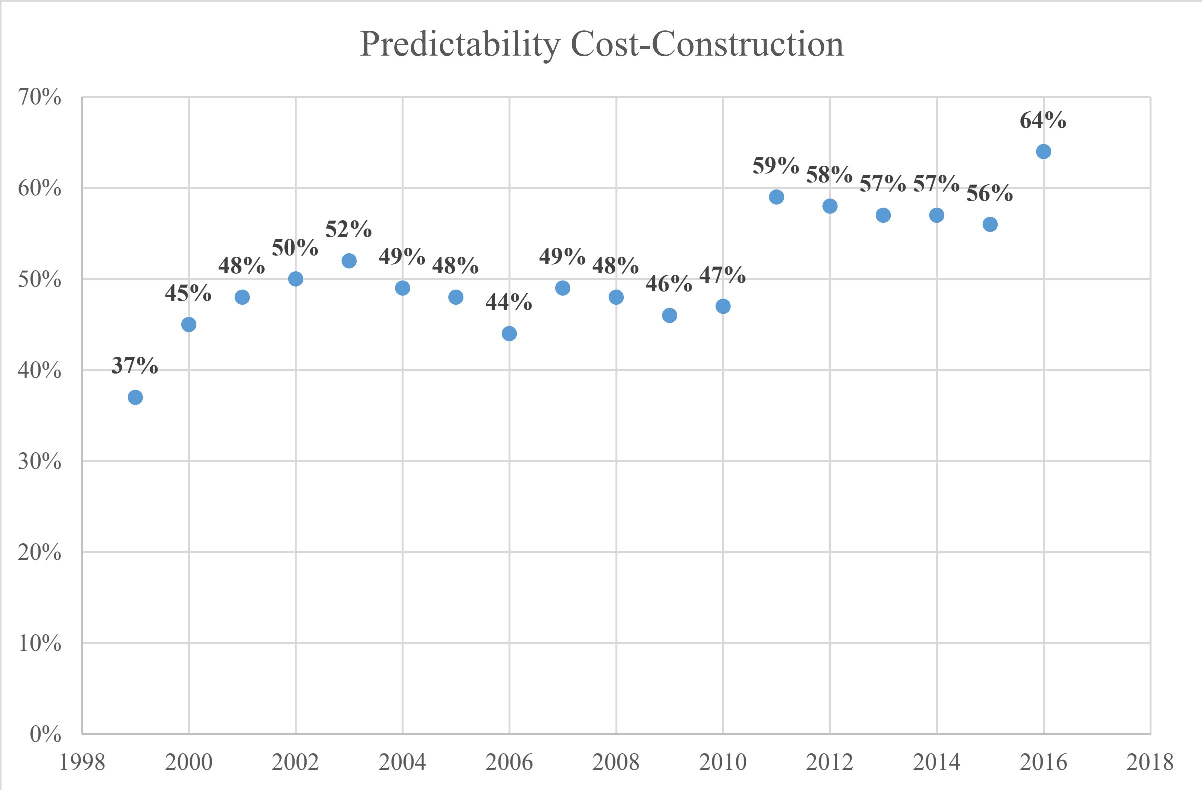
Chapter 1: INTRODUCTION

1.0 BACKGROUND

The selection of a contractor is one of the most important issues in construction projects; it can be argued that the success level of any construction projects largely depends on selecting the most appropriate contractor (El-Abbasy et al., 2013). Iyer and Jha (2005) suggested wrong contractor selection as one of the factors contributing to poor project performance. In Olaniran (2015) study on construction project performance in Brunei, Australia, 11 out of 22 reasons for poor project performance were linked to wrong contractor selection. Wrong contractor selection can lead to disputes, lengthy dispute resolution, project or contractor termination, low quality products and defects. Improper selection of the winning contractor may result to problems in the project delivery phase such as bad quality and delay in the expected project duration; which then ultimately results in cost overruns. Overruns: both time and cost are prevalent in the construction industry; most construction projects overrun their budgets and estimates. For example, Love et al. (2014), in their research of Australian projects found that construction projects overran by up to 70% more than their initial estimates. While the Western Australian Auditor General's Report (2012) found that the total cost of 20 projects were 114% more than the initial budget estimates. Furthermore, it reported that the New Children Hospital in Perth, Australia was 365% over-budget (A$207 million to A$962 million). The fact that the construction industry is a large industry with different types and sizes of projects, one would assume that these cost overruns happen in only certain types of projects; perhaps in larger projects. However, Love et al. (2014) points out that overruns occur irrespective of the size and type of the project.

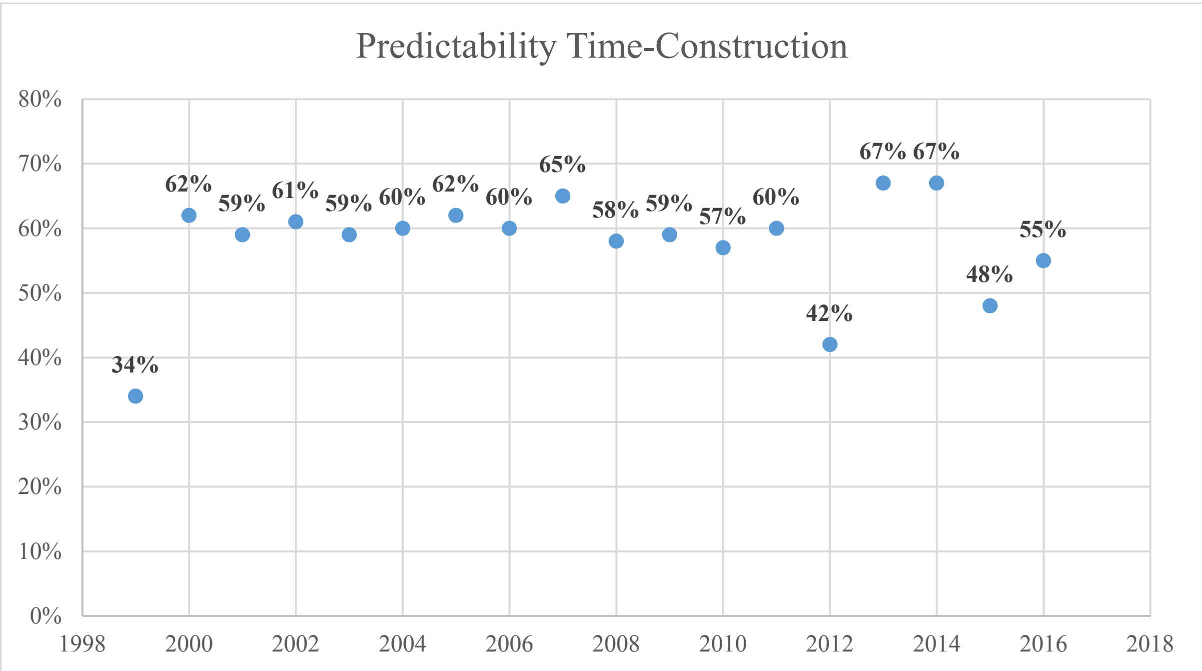
There are further examples of overruns in the industry: the London's Wembley Stadium (Richardson et al., 2006), The Channel Tunnel Project (Veditz 1993), Boston's Central Artery (Gelinas 2007), Edinburg's tram project (City of Edinburg Council 2014) etc. These are major examples of cost and duration exceeding its initial estimates. The Glenigan UK Industry Performance Report (2016) show that only 56% of construction project met or bettered the cost figure agreed at the start of the construction phase in 2015 (**Figure 1.1**). Furthermore, that only 48% of construction projects in 2015 met or bettered the length of time agreed at the start of the construction phase (**Figure 1.2**).

Figure 1.1: Percentage of projects completed within cost estimates



Source: Glenigan UK Industry Performance Report 2016

Figure 1.2: Percentage of projects completed within time estimates



Source: Glenigan UK Industry Performance Report 2016

Now it will be naive to claim that selecting the most appropriate contractor guarantees that the project runs on time and on budget, however, it does have an important role to play. Hence, the reason why there have been an influx of different multi-criterion methods to go with the lowest tender method in determining the best contractor. These multi-criterion methods have now been termed as awarding on "best value." In the United States (US hereafter), this is known as best value technically acceptable, in the United Kingdom (UK hereafter), the Most Economically Advantageous Tender (MEAT hereafter), and across Europe, the Economically Most Advantageous Tender (EMAT hereafter).

To further illustrate the importance of selecting the most appropriate contractor, the UK introduced new procurement methods: Cost-led, Two-stage open book, and Insurance procurement methods to innovate from the problematic Traditional procurement method, as well as the Management and Design and Build methods; which were more of a slight improvement to the Traditional method. The Traditional procurement method has long been considered problematic due to the fact that price had been the major factor in selecting contractors (Merna and Smith, 1990; Holt et al. 1995; Lahdenpera, 2013). Furthermore, this method separated the design stage from the construction stage, meaning that contractors had no part to play in the designing stage of the project and bore the majority of the risk in the construction of the project (Oztas and Okmen, 2004; ICE, 2016). While the client had to essentially get the designing flawless or else risk incurring huge costs if there were variations or significant changes required once the contractor has been appointed and design stage is complete. This results in an adversarial relationship between the client and the selected contractor that ultimately resulted in cost and time overruns. Therefore, more collaborative procurement methods were introduced to tackle the deficiencies in the conventional procurement methods.

With the influx of new procurement methods, brings more complexity in selecting the most appropriate contractor, different organisations have different method of doing so; there is no universal way to do it, and it is not as simple as awarding the contract to the lowest tender. It is due to the lack of simplicity that the industry has found it difficult to accept the idea; according to the UK National Contract Law and Survey (NBS, 2015) the Traditional procurement method is still the most used procurement method in the country; which indicates that the lowest tender method is still used more often. What this also indicates is that irrespective of new procurement methods, there will still be a tendency to award contracts to the lowest tenderer unless there is more evidence to make them choose otherwise. The lack of substantial evidence is not of a lack of trying; indeed, academics have combined different multi-criterion methods with different cost estimation software such as genetic algorithm and fuzzy logic, to name a few, to try and develop a significant evidence as to why awarding to the lowest tenderer may not usually be the best decision (Abdelrahman et al., 2008). However, there is still a lack of evidence to suggest what value these multi-criterion methods add over the lowest tender method.

This research is not advocating the universal use of best value rather it is questioning its value; essentially by asking 'is it always worth it?' The research would help clients understand the impact of their contractor selection strategy and how it influences construction and the overall outcomes of the project: Final Cost and Duration.

1.1 PROBLEM STATEMENT

Selecting the wrong contractor can lead to problems such as bad quality and project delay; which ultimately results in cost overruns. There are two strategies involved with selecting contractors: one is the lowest tender, the other is called best value. Selecting the lowest tender is still the most popular strategy as it is relatively straightforward, objective and transparent (Holt et al., 1994; Plebankiewicz, 2010; Huang, 2011; NBS, 2015). However, the criticism to it is that it usually fails to guarantee a contractor's quality performance. The best value strategy would involve the client scoring the contractors' tenders on price and its criteria for quality and ranking them. And, there is no set way to do this, there are different formulas for this, and the literature is rich with models developed to assign the best value contractor. But, with all these formulas and developed models, we are still none the wiser as to whether they will actually lead to a successful contractor performance and subsequently a successful project outcome. Project outcomes for this research is limited to cost and duration; a successful project outcome is when the contractor delivers the project within the expected cost and duration. There are various models developed to help with selecting the best value contractor (these models will be examined in Chapter 2), however only a handful of these models have substantially investigated the link between contractor selection strategy and project outcomes. So how can we justify to the client to go with the best value contractor who has a higher price? Is choosing the best value contractor with a higher price always worth it? Of course, there are situations where the best value contractor also has the lowest price. But in cases where they are different it needs justification. Justification in terms of how it will affect project's cost and duration and not just theoretical reasons why the best value strategy is better than the lowest tender strategy.

Therefore, if a client decides to use the best value strategy to select a contractor, and it turns out that the best value contractor does not have the lowest price, the proposed model would develop a what-if scenario analysis to investigate how the lowest tenderer would have likely fared in terms of cost and duration had it been awarded the contract instead. In doing so, the model also addresses another problem; usually clients are unable to identify a justifiably low tender. The proposed model would enable clients determine the probability distributions of outcomes associated with acceptance of the lowest tender.

This research does not advocate any specific contractor selection strategy; rather which strategy works where. There are cases where awarding to the lowest tendered contractor would not make sense, as it might cost the client even more money. While, there are other cases where awarding the contract to the MEAT might not make much of a difference; therefore, this thesis would provide a decision support tool to make decision makers more aware of the benefits and drawbacks of a decision and its ramifications in terms of cost and duration. Again, urging clients to select the best value tender, especially when the best value tender is not the lowest tender, needs justification. Justification in terms of how it will affect project outcomes: cost and duration, and not just theoretical reasons of why the best value strategy is better than the lowest tender strategy.

1.2 AIM, OBJECTIVES AND QUESTIONS

The aim of this study is:

To provide a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies.

To achieve this, a model will be developed that shows how the lowest tenderer would have likely fared in a project (in terms of Final Cost and Duration) that has been awarded to the best value contractor whose price is not the lowest price.

To achieve the aim, the objectives are to:

a) Identify and collect a reliable dataset of past projects:
that were all awarded to the lowest tender, and are all in the same sector.
b) Investigate the probability distribution of final costs and duration for construction projects:

by modelling the tenders to determine the total outcome cost and duration of projects arising from selecting contractors on lowest tender strategy.

c) Validate the model on recent project cases:
the model will then be validated on recent same sector projects that used the lowest tender strategy. The outcomes of these projects would have to fall within the envelope of outcomes predicted by the model.

d) Apply the model on best value selected tender projects:
the model can then be applied on same sector projects that used the best value strategy, where the best value contractor has a higher price. Applying the model in these projects would be able to show how the lowest tenderer would have likely fared in terms of cost and duration had it been awarded the contract instead.

An initial analysis of the literature review and methodology has led to these research questions that will guide the research in achieving its main aim.

1. *What are the sources of overruns stated in the existing literature?*
2. *Is there a relationship between contractor selection strategy and project outcomes?*
3. *What are the current procurement and tendering methods in the UK construction industry?*
4. *To what extent do these methods affect the contractor selection strategy?*
5. *Is Monte Carlo simulation the appropriate method of investigating the relationship between contractor selection and project outcomes?*

The research is essentially investigating the link between the contractor selection strategy and project outcomes: cost and duration. Overruns are a huge problem in construction, therefore, it is important to know what the sources of overruns given in the literature are. This enables us to know that there are other reasons why a project may overrun that had little or nothing to do with the contractor. That way the appropriate relationship between the contractor selection strategy and project outcomes can be established; this affected the kind of projects used for this research. Then we know that a contractor selection strategy in construction is part of a wider procurement and tendering structure. Therefore, it is important to know what these are and how the affect the contractor selection strategy used. Finally, in Question 5, it is important to know whether Monte Carlo Simulation (MCS hereafter) is the appropriate method to execute the aim and objectives; this was answered in Chapter 3.

1.3 OVERVIEW OF RESEARCH APPROACH

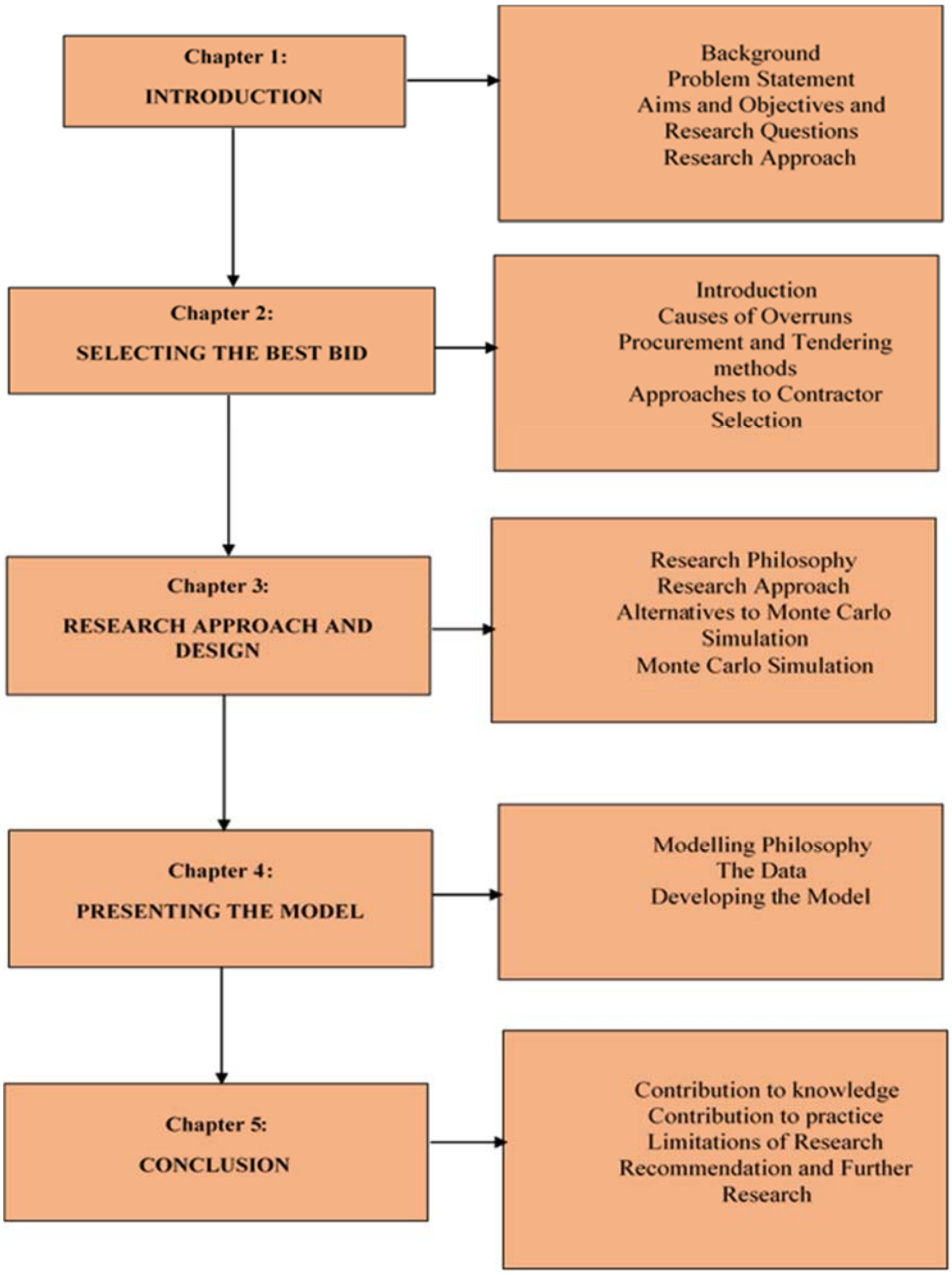
When deciding on the research approach, it is important to consider the type of problem that is under study and how best to answer the research question sufficiently. The research adopted, for the most part, a quantitative approach. While critiquing and exploring existing literature it was clear the there is little work on the actual probability distributions of either total costs incurred or project time. There are two ways these distributions can be determined; a review of all projects comparing the probability distributions of actual cost outcomes, or a MCS of the same project under different contractor selection strategy. The problem with a review of historic project outcomes is that no two construction projects are the same. However, by deriving statistics from the historic events, MCS will allow for the repeated simulation of hundreds of tenders for exactly the same project and produce probability distributions of the outcome.

Chapter 1 provided the background of the research, which included the definition of the research's main aim and objectives, as well as research questions. Then in Chapter 2, a review and critique of existing literature followed; which included various theories on the sources of cost overruns and the evaluation of tenders. Next, the simulation approach was designed in Chapter 3 and the results were presented and discussed (Chapter 4) before drawing conclusion and offering recommendations (Chapter 5). Chapter 3 will contain a more in-depth discussion of the research methodology and design.

1.4 THESIS STRUCTURE

The thesis is organised in five chapters as illustrated in **Figure 1.5.1**.

Figure 1.4.1: Thesis Structure



1.4.1 Chapter 1- Introduction

The chapter sets out the background and context of the research, introducing the problem statement. The aim and objectives of the research alongside the research questions are outlined.

1.4.2 Chapter 2- Selecting the best tender

The chapter first begins by examining the sources of overruns; critically evaluating the explanations for overruns to ascertain the effect a contractor plays in it. Then the research presents the different procurement and tendering methods that are used in construction projects, and how it affects the strategy by which a contractor is selected. Furthermore, the chapter critically evaluates models that have been developed in aiding to select the best value tender seeing that the lowest tender strategy is straightforward to execute.

1.4.3 Chapter 3-Research Methodology and Design

The chapter presents the consideration for adopting the research approach as well as the framework that will guide the modelling aspects of the research. Then alternatives tool to MCS are briefly presented. Finally, the background, applications, strengths and weakness of MCS are evaluated.

1.4.4 Chapter 4-Presenting the model

The model is developed and presented in this chapter. The model is developed using Dataset 1 of 120 UK educational facilities projects all of which selected the lowest tender from the Building Cost Information Service (BCIS). The model is then tested on a further 10 similar project that selected the lowest tender. Then it is validated with Dataset 2 of 20 recent project cases from an industry partner all of which selected the lowest tender. Before being applied on best value selected tender whose price is not the lowest price. The aim here is to provide a model capable of investigating how the lowest tender would likely fare in a project that selects the best value tender whose price is not the lowest price.

1.4.5 Chapter 5-Conclusions

In the final chapter, conclusions are made based on the findings from the literature review and model chapters. The aim and objectives that were set out in the opening chapter is revisited to see how far they have been achieved. Finally, the theoretical and practical contributions of the research are summarised; together with recommendations to further research.

1.4.6 References

The list of work cited in the thesis.

1.5 RESEARCH CONTRIBUTION

The contribution of this research is to the field of construction projects; specifically, at its earlier stage of selecting the contractor, as has been described previously. Although, we are at the beginning of the thesis, stating the contributions in advance is not only showing the reader what this thesis is aspiring to accomplish, but also showing the reader what to expect. The contributions are summarised as:

- **A novel model of determining the probability distributions of cost and time involved with the different contractor selection strategies.** This is done with the combination of MCS simulation and probability distribution. The MCS technique is not new, it allows people to account for risk in quantitative analysis and decision making; giving decision makers a probability distribution of possible outcomes. Probability distribution is the most basic type of statistical analysis that simply tallies or counts how frequently each value of a variable occurs among a set of measured objects. This sort of research is usually used to understand the differences in population, for example in classrooms. Nevertheless, using MCS and probability distribution to explore the effects of a contractor selection strategy on the overall cost and duration of the project is rare. The model will enable clients to decide whether it is worth selecting a best value contractor who has a higher price over the lowest tendered contractor. Another thrust of the research is in its ability to show clients when a strategy: in this case the lowest tender strategy can go horribly wrong and the likelihood of it happening.

- **Providing a new understanding of construction cost overruns.** Construction cost and overruns is a research area that has been investigated in the past and is sure to be investigated in the future. However, the bulk of current research has been replicative; offering theoretical reasons for the causes of overruns and lacking the necessary innovation in advancing the knowledge area. The contribution of this thesis is a fresh way of understanding cost overruns; it is proposed that contractors' cost overrun for a project should be compared to the price of the next highest tender to gauge its real impact.

Chapter 2: SELECTING THE BEST TENDER

2.0 INTRODUCTION

Selecting the most appropriate contractor is an important step in a project, as the decisions made during the early stages of the construction project has a significant bearing on the outcome of the project. However, it is not entirely responsible for a successful project. Nevertheless, Nureize and Watada (2011) say that contractor selection is a critical decision that has a significant influence on the project's success, hence, decision makers should consider using multiple criteria to award contract. Despite this fact, there is little to no research that shows a direct relationship between the selection strategy and the outcome of the construction project. Furthermore, the fact that contractor selection criteria are uncertain, as it varies depending on the type of projects, has resulted in many different attempts being developed to include economic and technical criteria in the contractor selection process (Abdelrahman et al., 2008).

This section will first investigate how project performance is measured in construction projects and how contractor selection affects it. As the thesis aims to offer a new understanding of cost overruns, it is important to understand the sources of cost overruns but also project delay. By doing so in this chapter, one will understand that though selecting the most appropriate contractor has an influence in the project's success, it is by no means the only reason. There are other reasons for overruns, and claiming appropriate contractor selection as the remedy for it will be naive; while ignoring the other reasons for it will only serve as the recipe for future overruns.

Therefore, though the research is specifically looking at the relationship between the evaluation of tenders and the project outcome, this chapter will discuss the various theoretical explanations of the overrun phenomenon. By doing so, it will then be able to discuss how tenders are currently evaluated. However, to discuss this the reader will first have to understand the procurement and tendering methods in the UK, as it plays an important role on how tenders will be evaluated. Then the conclusion points out the gap in the literature, acting as a link to the next chapters that presents a conceptual model of determining the probability distributions of cost and time arising from the different contractor selection strategies in construction projects.

2.1 CAUSES OF OVERRUNS

Wrong contractor selection strategy leads to all sorts of problems: disputes, lengthy dispute resolution, project or contractor termination, low quality products and defects. However, cost and time overruns are the most prominent problem in the construction industry. The construction industry sees many sorts of projects from housing, infrastructure, industrial, and commercial; whether it is to build, refurbish, or maintain. Some of these projects are simple, while others are more complicated; some are small, others are large, and some are scheduled to be completed under a year, while others may go on for multiple years. Basically, no matter the size of the project, they all have a chance of overrunning on their budget and estimates due to risk and uncertainty associated with executing a construction project. Sadly, construction projects make the headlines for the wrong reasons; mostly because of overrunning their budget and estimates.

Cost overrun refers to budget increase, cost increase, or cost growth (Love et al., 2013). The reasons for it are vast; one being failure to effectively manage risk and uncertainty (Okmen and Oztas, 2010) as alluded to earlier. While another might be due to the unrealistic cost targets and misguided trade-offs set by all parties involved between project scope, time and cost (Ahiaga-Dagbui and Smith, 2014). Flyvbjerg et al. (2002) study on the cost performance of 258 transportation projects in 20 nations worth US$90 billion found that nine out of ten projects in their sample outran their cost. The researchers grouped the sources of cost overruns into three groups: technical, psychological, and political-economic. There are a plethora of reasons giving in the literature as to why overruns may occur; the aim of this section is to critically evaluate the ones that come up the most in the existing literature. Below are tables that summarise the reasons for cost overruns from Flyvbjerg (2008) and Cantarelli et al. (2010).

Table 2.1.1: Causes of Cost Overruns Group and Explanations

Group	Explanations
Technical	Inaccurate and unreliable data. Technical complications in project leading to increased costs.
Psychological	Optimism bias; being overly-optimistic about the implementation of the project.
Political-economic	Strategic misrepresentation; overestimate benefits and underestimate costs.

Source: Flyvbjerg (2008). Adapted by researcher

Table 2.1.2: Causes of Cost Overruns Group and Examples

Group	Examples
Technical	Incomplete estimates, poor project design, scope changes, uncertainty, inappropriate organizational structure, inadequate decision-making process etc.
Psychological	Optimism bias among local officials, cognitive bias of people, cautious attitudes toward risk.
Political	Deliberate cost underestimation, manipulation of forecasts, private information.
Economical	Lack of incentives, lack of resources, inefficient use of resources, inadequate contract management etc.

Source: Cantarelli et al. (2010). Adapted by researcher

2.1.1 Risk and Uncertainty (Technical)

It is important to understand that risk and uncertainty are two different things, regardless of whether they are used simultaneously. The fact that they are used simultaneously is because the term "uncertainty" is used in most scientific literature concerning risk management (Ustinovicius et al., 2007). Vice-versa, uncertainty management is concerned as managing perceived threats and opportunities; including their risk implications, as well as managing the various sources of uncertainty which give rise to and shape risk, threat and opportunity

(Chapman and Ward, 2003; Ustinovicius et al., 2007). The fact remains that they are two different things: uncertainty is simply not knowing; in other words, the lack of certainty involving the likelihood of event. Smith (2003) rightly points out that risk arise from uncertainty, but later suggests that risk is often viewed as factors which have an adverse effect on achieving project success. However, the notion of risk is not always negative as Ross and Williams (2013) describes risk as “the threat or possibility that an action or event will adversely or beneficially affect an organisation's ability to achieve its objective.” However, they seem to contradict themselves by implying that risk “the consequence of a hazard, measured as the likelihood of the hazard and its severity”, should that hazard occur. The term “hazard” and “severity” makes the term “risk” come across as entirely danger, which might not always be the case.

Every construction project is different, with its own dynamics; Eden et al. (2005) points out that failure to understand the systemic and dynamic nature of projects leads to overruns. All construction projects (are likely to) experience unexpected situations and uncertainties, whether it is scope creep or design changes, or bad weather, or disputes. Therefore, risk and uncertainty are not the issue; failure to adequately manage and plan for them is the main issue. Cantarelli et al. (2010) rightly cites inadequate decision-making and planning process as technical explanations for overruns. This is supported by the technical explanation of Flyvbjerg’s (2008) reasons for overruns which refers to cost overruns being due to inaccurate and unreliable data; including other technical complications that arise in the project which leads to increased costs. Failure to plan for perceived risk leads to project failure, not the risk itself. There are some risks that cannot be avoided as Migilinskas and Ustinovicius (2006) and Chapman and Ward (2003) explains the three basic sources of risk and uncertainty:

- Known-unknowns: these are the events that have been identified as having the potential to happen and could uncertain significant events. But by knowing of the potential problems, it allows for contingency plans. For example, inflation, strike when a labour contract expires or adverse weather in winter (Ustinovicius et al., 2007).
- Unknown-unknowns: these are the events that arrive unexpectedly and the main contingency to this is relying on the manager’s experience.
- Bias: these are estimation errors which have severe consequences.

As alluded to earlier, known-unknowns can be adequately prepared for to prevent cost and time overruns despite the fact that it is dynamic and has an impact on the project. Migilinskas and Ustinovicius (2006) say that uncertainties often rise due to the lack of qualification and competence from the project manager's team; this is not entirely true as with the unknown-unknown situations, this should be deemed as an unfortunate circumstance since it could not be avoided. There are also situations whereby cost overruns should simply be viewed as cost escalation, two different phenomena as Love et al. (2013) explains that cost overruns should be distinguished for cost escalation; that escalation is an anticipated growth in budgeted cost due to factors such as inflation. Therefore, cost escalation can also apply to known-unknowns as there are situations whereby cost will have to increase; if it was anticipated it would be cost escalation, but if it was cited as a potential event at the initial stages of the project but not prepared for then this should be viewed as cost overrun. Finally, the third source, bias, as Migilinskas and Ustinovicius (2006) explains is a static risk that will remain consistent during its period of existence. This supports Flyvbjerg's (2008) work on optimism bias and strategic misrepresentation as reasons for cost overruns, which will be discussed in the next section.

2.1.2 Optimism Bias (Psychological)

Flyvbjerg (2008) offers optimism bias as a psychological explanation for cost overruns; this theory is primarily from behavioural studies and it is to do with the inclination for people to be overly positive when making predictions about the outcomes of future planned actions (Siemiatycki, 2010). Thus, in the context of construction projects, underestimating cost and overestimating benefits; including delivery days. One reason for optimism bias could be due to lack of information or information exchange between project participants to base realistic estimates. As Nicholas (2004) suggests that estimators usually should rely heavily on their own experience and historical information when preparing initial estimates. Which also explains why Flyvbjerg (2009) refers to optimism bias as delusion in the following way:

> *"Delusion accounts for the cost underestimation and benefit overestimation that occurs when people generate predictions using the inside view. Executives adopt an inside view of the problem by focusing tightly on the case at hand, by considering the plan and the obstacles to its completion, by constructing scenarios of future progress, and by extrapolating current trends. In other words, by using typical bottom-up decision-making techniques, they think about a problem by bringing to bear all they know about it, with special attention to its unique details. There are two cognitive delusions the inside view facilitates: the planning fallacy and a heuristic rule-of-thumb called anchoring and adjustment."*

Flyvbjerg et al. (2003) study of more than 200 transport mega projects in 20 countries on five continents found that development costs were on average 28% higher than forecasted. While recently in a project in Australia that rose from A$160 million to A$550 million at its completion, the Auditor General released a statement alluding to the fact that unrealistic estimates were made due to a lack of understanding of project needs (Auditor General, 2010). This again shows that one of the reasons for optimism bias is a lack of understanding of the project at hand. There are other cases, particularly with larger projects, where political and institutional factors create a situation where few project participants have a direct interest in avoiding unrealistic evaluations during the decision-making process (Siemiatycki, 2010; Altshuler and Luberoff, 2003; Ahadzi and Bowles, 2004). This is supported by Flyvbjerg (2007) study which suggests culture of rewarding estimators for accurate forecasting to alleviate the practice of being overly optimistic.

Rewarding estimators for accurate forecast however, is almost impossible as forecasts are often incorrect. Thus, other researchers such as: Love et al. (2012; 2013; 2014), Osland and Strand (2010) and Gil and Lundrigan (2012) challenge Flyvbjerg's (2008) explanations for cost overruns. They imply that the reasons for cost overruns are simple; project evolves and with that comes increase in costs. There is no doubt that, whether it is changes in scope or design, or changes in contractual arrangements, or contractor's cash flow, these all carry huge financial complications. However, implying that the only reason for cost overrun is project changing is naive. Projects changes may ultimately result to cost escalation; which should be distinguished from cost overrun as alluded to earlier. But it cannot be the only reason, construction projects are dynamic, it contains a level of risk and uncertainty; failure to manage them leads to cost and time overrun. Furthermore, the construction industry has long been known for its adversarial relationships between project participants (Boardman, 2004). This results in lack of information exchange as each participant tries to minimise its own risk; therefore, conflicts are bound to arise which will ultimately threaten the success of the project. The culture that seemingly exist in construction projects of participants fighting for their own self-interest supports Flyvbjerg's (2008) strategic misrepresentation reason for cost overruns which is discussed in the next section.

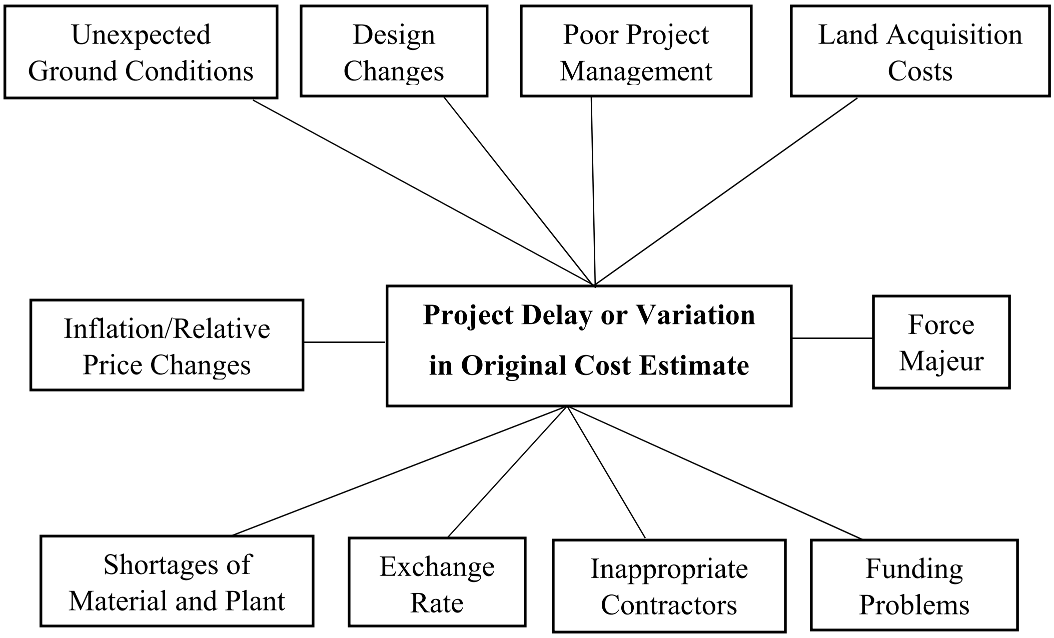
2.1.3 Strategic Misrepresentation (Political-Economic)

Strategic misrepresentation alludes to suspicion of foul play and corruption (Flyvbjerg 2008; Flyvbjerg, 2009). This is a situation where forecasters and planners knowingly overestimate benefits and underestimate costs to win projects or get funding approval; this refers to its political-economic explanations. Flyvberg (2009) refers to this as deception which is described in the following way:

> "Deception accounts for flawed planning in decision making in terms of politics and agency issues. The political and organizational pressures in executive decision making involve: *the principal agent problem* and *the sources of strategic deception*."

In Flyvbjerg et al. (2002) study on the cost performance of 258 transportation projects, it found that cost overruns were not randomly distributed in their sample but were rather systematic. This then led them to controversially assume foul play and corruption. This assumption has been refuted by Love et al. (2012) which implies that the industry should accept the fact that cost escalation is likely. Furthermore, Osland and Strand (2010) were critical of theoretical and methodological validity of Flyvbjerg work, and that is fair to do as it is difficult to use statistical analysis to know the difference between deliberate deception, technical error, and delusion. But strategic misrepresentation does exist, and one can argue that this works together with optimism bias; though optimism bias does not come with the motive of deceiving, it leads to underestimating costs. The UK government for example offered a Green Book supplementary guidance on optimism bias, recommending forecasters to add explicit adjustments to their estimated capital costs (HM Treasury, 2013). As alluded to earlier, with the construction industry lacking collaboration between project participants, optimism bias and strategic misrepresentation is entirely possible. Love et al. (2012) study rightly claim that negative events that occur before the project delivery stage leads to cost overruns. However, is it impossible to imagine an optimism bias client that wants to effectively complete its dream project at the lowest cost possible, falling for a contractor who has excessively underestimated costs to win the project? There is every chance of this happening; they both go hand-in-hand.

Figure 2.1.1: Overrun Factors



Source: European Commission (*Adapted by Researcher*)

Figure 2.1.1 (above) by the European Commission outlines factors that lead to cost and time overruns in their funded projects. The poor project management factor has an effect in all stages of the construction process that according to the European Commission leads to:

- a lack of planning and coordination;
- poor communication between members of the project team and the project sponsor;
- failure to identify problems and institute necessary design and programming changes;
- a lack of control over time and cost inputs.

The European Commission even go on to state in the report that a poor project with a good project management structure/contractor will be completed satisfactorily. This links back to Ustinovicius (2006) and Chapman and Ward (2003) (p.23) second explanation of the three basic sources of risk and uncertainty: Unknown-Unknowns; that there are events that arrive unexpectedly and the main contingency for these events is a good project manager/contractor. Thus, a good contractor may also be able to navigate through difficult situations such as the force majeure factor; which is also an unknown-unknowns risk uncertainty that includes: revolution, war, riot, extreme weather, earthquake, landslip, fire, and political and economic instability. Though contractors usually insure against such events happening (European Commission).

Factors such as Inflation and Exchange Rates can be considered a known-unknowns as this usually have the potential to happen and allows for contingency plans. The Design Changes factor also supports Cantarelli et al. (2010) (Table 2.1.2) technical causes of overruns which include poor project design and scope changes. While the shortages of material and plant supports Cantarelli et al. (2010) economical causes of overruns which highlights inefficient use or lack of resources as a factor for overruns.

The unexpected ground conditions factor is interesting as usually the ground conditions can be assessed by a desk-based review, however, the actual site conditions for the full extent of a project are not usually determined until construction begins (European Commission). Thus, it is possible that difficult review is overlooked by initial review and that may result in an unknown-unknowns event arising in which the main contingency for it will be a good project manager/contractor.

The funding problem and land acquisition costs factors for cost overruns will usually surface in public contracts; though it is entirely plausible with private clients. In the funding problems factor, the overall lack of finance to complete a project, or the delays in the payment for services by the project sponsor can lead to significant problems arising that will ultimately delay project duration (European Commission). Problems in this factor can also arise if funds allocated to one project have been diverted to other project within a programme or development and if the payment of invoices is slow. The contractor may then commit less resources to a project or even cease to work altogether (European Commission). The land acquisition costs factor is a situation where the land on which a project will be built is not always owned by the project sponsor, highly unlikely with a private client, but not surprising with public contracts. In this case, local government authorities can usually purchase the land in accordance with legal statutes. The statutes usually require the land (and any properties on it) are valued and that compensation is paid to the owner based on the valuations. Negotiating a compensation is not always straightforward and can ultimately lead to a delay in project duration. Compensations are usually agreed until the end of the projects and in many cases, it is greater than the original estimate by the project sponsor (European Commission). This factor supports Cantarelli et al. (2010) and Flyvbjerg's (2008) psychological causes of overruns which include optimism bias among local officials; project sponsor in this case, being optimistic in this case about the cost of the land in question, only to find out it costs more at the end of the project.

In the inappropriate contractors' factor, the European Commission states:

"Contractors are selected on the basis of price, experience in undertaking particular types of project and their track record in producing high quality work within budget and on time. Problems may arise where there is a high level of development activity being undertaken in a particular region and the better contractors are not available to bid for the work at that time. Alternatively, the tender review process may not have been undertaken by the personnel with the best understanding of the services required. As a consequence, firms which are not the most experienced in that field of activity are chosen, often with implications for the quality and cost of a project. In most cases there is a trade-off between price, experience and track record but the desire to accept the lowest tender does not always lead to a project that is completed within time and budget. There are cases of contractors and sub-contractors who go into liquidation during the construction period. This can lead to significant delays and extra costs arising as the project sponsor has to re-tender the remaining work. Identifying a new contractor to complete another contractor's work is difficult because of the possible liabilities that the new contractor would have to accept for another company's work."

It is interesting that the European Commission does not highlight the under-estimation of costs to win the project as part of the description of an inappropriate contractor but instead states it as "Other Factors":

"Other Factors

In addition to all the categories listed above, experience shows that problems also arise from premeditated under-estimation of initial costs simply to obtain initial approval for a project. This can lead to major projects being approved, and started, in the knowledge that actual costs will be very much higher than the "agreed" estimate. Once started, a high profile infrastructure project is often politically difficult to stop. So, when the true costs do become apparent, it is difficult for authorities to refuse the additional funding required to complete the project."

This of course supports Cantarelli et al. (2010) and Flyvbjerg's (2008) political-economic causes of overruns, which include: strategic misrepresentation, manipulation of forecasts, overestimate benefits and underestimate costs. However, this same question is asked again, is it not plausible to imagine an optimism bias client that wants to effectively complete its dream project at the lowest cost possible, falling for a contractor who has excessively underestimated costs to win the project? It is possible. Furthermore, though cost is an important factor that gauges whether a project is successful or not, it is not the only factor.

The project duration is another important factor; and the causes of delay can also be seen in Cantarelli et al. (2010) and Flyvbjerg's (2008) study and the European Commissions outlined factors. For example, Cantarelli et al. (2010) poor design reason for cost overruns does not only affect the cost but also the completion time. In the traditional procurement method that will be explained fully in Section 2.2, contractors are not allowed at the design stage of the project. The procurement method insinuates that the design and drawings will be perfect by the time it reaches the contractor which is obviously rare. Therefore, when the project delay is caused by poor design, this is no fault of the contractor.

Another reason for time overrun which is not directly related to the contractor is delay in progress payment. When there is a delay in payment this is the fault of the client; Sambasivan and Soon (2007) and Frimpong et al. (2003) pointed out that delay in payment by the client would eventually cause cash flow problem and financial difficulties to the contractor. However, it is also the responsibility of the client to evaluate and ensure the financial competence of the contractor before awarding the contract; instead of just awarding to the lowest priced contractor. Contractors should have enough cash before they undertake any project. Mulla and Waghmare (2015) in their study of the factors influencing cost and time overruns in India, found delay in payment as the most important factor influencing time and cost overruns. In Olaniran (2015) study on construction project performance, project delay was the most important issue stemming from awarding contracts on price alone. This was previously stated in Assaf and Al-Heijj (2006) study of projects in Saudi-Arabia, which indicated that awarding contracts on price alone caused delays in construction projects.

According to Mulla and Waghmare (2015), the two main reasons for delay that is attributed to the contractor are poor site management and poor planning. Sambasivan and Soon (2007) also point out that lack of contractors' experience can delay a project; including the lack of coordination between contractors and their sub-contractors. Walker (1995) in a survey conducted with Australian project representative found contractors' planning capability as an important factor influencing time overrun. Kumaraswamy and Chan (1998) study on time delays in Hong Kong projects found poor site management, and unforeseen ground conditions as the main reasons for time overruns. Al-Khalil and Al-Ghafly (1999) study on public utility projects in Saudi Arabia found ineffective planning by the contractor as a significant delay factor. Material shortages can also be attributed to poor planning by the contractor. This is when contractor and its suppliers fail to anticipate demand. Material shortages can also be due to extenuating circumstances where there are road traffic jams or severe weather conditions that affects the transportation of materials on site.

2.1.4 Link between contractor selection and overruns

Olaniran (2015) study on construction project performance in Brunei, Australia, found that 11 out of 22 reasons for poor project performance were linked to wrong contractor selection. Furthermore 8 out of those 11 reasons were ranked in its top ten reasons for poor project performance (see Table 2.1.3). Their number 1 ranked reason is reduced profit margin for the contractor and Chao and Liou (2007) specifically say that selecting contractors on price alone increases the risk of profit reduction and often leaves the contractors with a loss.

Table 2.1.3: Contractor's related reasons for poor project performance

Reasons for project performance problems	Rank
Contractor's inadequate understanding of project scope	9
Reduced profit margin for the contractor	1
Contractor's poor project monitoring and controlling	2
Contractor is not competent	3
Contractor's lack of project communication skills	4
Contractor's error in cost estimates and schedules	5
Contractor's low commitment to the project	7
Contractor's lack of stakeholders' management skills	8
Contractor's poor risk and liability assessment	11
Contractor's lack of project administration/management skills	13
Contractor's lack of necessary technology	19

Source: Olaniran 2015 (Adapted by researcher)

Furthermore, in Flyvbjerg (2008) and Cantarelli et al. (2010) reasons for overruns given in Table 2.1.1 and 2.1.2, wrong contractor selection is hidden in the Psychological and Political-Economic factors that lead to overruns. It is important to note that the one responsible for wrong contractor selection is the client and not the contractor. Causes such as ill/death or weather conditions are unforeseen negative events that may lead to overruns and is no fault of the contractor. Also delay in payment, design and scope changes, which depending on the procurement method (discussed in Section 2.3), is no fault of the contractor. However economical causes of overruns, given in Table 2.1.1 and 2.1.2 are because of wrong contractor selection, it starts with the client and has a domino effect. A lack of incentive and resources results in inadequate planning. There is a lack of incentive for forecasters to provide accurate estimates and as a result underestimation forecast is done for their own self-interest; underestimating costs also increases the chance of winning the contract and getting the project started (Cantarelli et al. 2010). This adversarial relationship is fuelled by the traditional procurement method, which is examined in the next section, but the fact remains that having the wrong basis for contractor selection has a domino effect that results in contractors underestimating costs and overestimating profits. In other words, clients' overemphasis on cost when selecting contractors leads to an unhealthy competition of seeing who can underestimate the most costs to look more attractive and win the contract. Table 2.1.4 summarises some of the studies considered that lead to Crantelli et al. (2010) analysis of overruns' causes and explanation.

Table 2.1.4: Previous research on causes of overruns

Group	**Study**
Technical	Morris (1990), Nijkamp and Ubels (1999), Lee (2008), Wachs (1982), Fouracre et al. (1990), Kaliba et al. (2008)
Economical	Pickrell (1992), Wachs (1989), Odeck (2004), Hall (1980), Mansfield et al. (1994), Kahneman and Lovallo (1993), Bruzelius et al. (2002), Arvan and Leite (1990)
Political	Arvan and Leite (1990), Wachs (1987), Nijkamp and Ubels (1999)
Psychological	Bruzelius et al. (2002), Arvan and Leite (1990), Kahneman and Lovallo (1993), Fouracre et al. (1990), Mackie and Preston (1998)

Source: Cantarelli et al. (2010). Adapted by researcher

The next section looks at the procurement methods in the UK construction industry, as stated earlier, adverse relationships are fuelled by the procurement methods. However, the main reason for looking at them in the next section is because contractor selection happens within this context.

2.2 UK PROCUREMENT AND TENDERING METHODS

The definition of procurement will always be different depending on the sector in question; for example, procurement in construction is applied differently to agriculture or manufacturing. In other sectors, it is the process of purchasing goods or services, while in construction procurement is the entire structure by which a building is procured. A more recent definition by Udom (2012) gives a simplistic but balanced depiction of procurement; which is that it is a series of processes and activities that operates to secure the construction of a predefined built structure. While Van Weele (2010) gives an all-around depiction of what the processes are: determining the specifications; selecting the contractor/supplier(s); contracting; ordering; project delivery, and evaluation.

This section will begin by giving a brief description of the UK procurement and tendering methods according to the Institute of Civil Engineers (ICE, 2016) and Government Construction Strategy (2012). The two widely recognised procurement methods: traditional and design-build, are considered enablers for adversarial relationships between clients and contractors; particularly the traditional method. For example, a survey conducted by the Chartered Institute of Building (CIOB, 2010) found that in 59% of projects that overran in cost, and in 60% of projects that overran in time, the traditional procurement method was used. Furthermore over 50% of respondents believed that the procurement method directly contributed to the projects incurring overruns. And according to NBS (2015) these two methods are still the most used in the industry (see Table 2.2.1). The basis for discussing new methods in the UK, is because it has been introduced by the government to revamp cons and solve the problems associated with previous methods. However, the main reason for presenting these methods (as stated earlier) is because contractor selection happens within this context.

Table 2.2.1: The procurement method most frequently used in projects

Procurement method	Clients, Consultants, and Contractors %
Traditional	47
Design & Build	39
Other	14

Source: NBS 2015 (Adapted by researcher)

2.2.1 Procurement Methods

The **traditional** procurement method, sometimes referred to as 'design bid build' (or 'bid build' by contractors) remains the most commonly used method of procuring building works (Cooke and Williams, 2009); this has long been the standard practice in the construction industry (NBS 2015). In this method, the client first appoints consultants to design the project in detail, and then prepare tender documentation, including drawings, work schedules and bills of quantities. The contractor on the other hand is not responsible for the design, other than temporary works, although some traditional contracts do provide for the contractor to design specific parts of the works. But for the most part, the contractor is appointed only once the design is complete, they are not able to help improve the buildability and packaging of proposals as they develop (Lupton et al. 2009). It is a low risk method of contracting for the client, as the contractor takes the financial risk for construction. However, if design information is incomplete at tender, or if significant variations are required after the contractor has been appointed, the cost to the client can be significant. Because of this, and because of the separation of design and construction, traditional procurement is adversarial. (ICE, 2016).

Management contracting is a procurement route in which the works are constructed by many different work contractors, who are contracted to a management contractor. The management contractor is generally appointed by the client early in the design process so that their experience can be used to improve the cost and buildability of proposals as they develop, as well as to advise on packaging (and the risks of interfaces). The contractor is paid based on the scheduled services, prime costs and management fee (Lupton et al. 2009). It also enables some works contracts to be tendered earlier than others, and sometimes, even before the design is completed (for example piling might commence whilst the detailed design of above ground works continues). This can shorten the time taken to complete the project, but does mean that there will be price uncertainty until the design is complete and all contracts have been let. (ICE, 2016)

Design and build is a generic term describing a procurement route in which the main contractor is appointed to design and construct the works, as opposed to a traditional contract, where the client appoints consultants to design the development and then a contractor is appointed to construct the works (Ashworth, 2012). It can appeal to clients as it gives a single point of responsibility for delivering the entire project. (ICE, 2016).

The **Private Finance Initiative** method (PFI) a single integrated supply team is appointed with design, construction and facilities management expertise to design and build a development and then to operate it for a period of time. A special purpose vehicle (SPV), of which the integrated supply team is part, finances the project and leases it to the government for an agreed period (perhaps 30 years) after which the development reverts to government ownership. This method is only suitable for large scale projects such as infrastructure projects, hospitals, and schools. (ICE, 2016). This procurement method is usually used for long term project, or when a client has a series of projects to be carried out over a period of time; therefore, a framework agreement is usually needed with this method. A framework is an agreement with contractors/suppliers to establish terms governing contracts that may be awarded during the life of the agreement; this will help reduce procurement timescales, transaction costs and foster continuous improvement within long term relationships (Constructing Excellence, 2016).

The UK government then developed three new procurement methods in 2012 to cultivate early contractor involvement, transparency and integration; hoping to eliminate adversarial relationships. This was also done to increase project performance and obtain value.

In the **Cost Led** procurement, the project details are clearly identified and a ceiling cost calculated. Typically, an integrated supply team (one or more) is identified through a framework agreement and the team work together to complete the project at below the ceiling cost (Government Construction Strategy, 2012). In subsequent similar projects within a framework, Cost Led Procurement offers the opportunity for further reduction of costs. The project is offered to suppliers outside the framework if none of the existing teams can deliver the project below the ceiling cost. (ICE, 2016).

Integrated Project Insurance (IPI) is an innovative insurance product which gives the IPI model its name. It collectively insures the client and all the other Alliance partners: consultants, specialists, manufacturers, construction managers and their supply chains. (ICE, 2016). Udom (2012) say that combining insurance policies can save approximately 2.5% on cost and commercial risks (Oteng and Park, 2013). The major advantage to this method is that it removes adversarial relationships, especially when disputing costs overruns. It aims to foster a target gain and pain share environment that will further encourage the industry to be more efficient and cost effective.

Finally, in the **Two-stage open-book bidding**, an outline tender and benchmark cost are provided to prospective project teams. Following the first stage, the project team work with the client to develop the proposal and the contract is then awarded at the second stage. This allows the client to work at an early stage with a single, integrated team and allows faster mobilisation. Two-stage, open-book can be used on single projects or a programme of works. (ICE, 2016; Government Construction Strategy, 2012).

2.2.2 Tender Methods

A tender involves a submission of a bid from a prospective contractor/supplier in response to an invitation to tender. In the context of construction, the main tender process is generally for the selection of the contractor that will construct the works (ICE, 2016). The following are the most common form of tendering in the UK:

- **Open tendering** allows anyone to submit a tender to supply the goods or services that are required. Generally, the client will advertise the invitation to tender in a relevant newspaper or any relevant social media domain; providing pertinent project details and informing the tenderers of the closing place, date and deadline of tender submission. This form of tendering offers an equal opportunity to any organisation to submit a tender. It has been criticised for attracting tenders / expressions of interest from large numbers of suppliers, some of whom may be entirely unsuitable for the contract and as a result it can waste a great deal of time, effort and money. It can force contractors to lower their tender prices to gain advantage over their competitors (May et al., 2001). However, open tendering offers the greatest competition and has the advantage of allowing new or emerging suppliers to try to secure work. (ICE, 2016; Griffith et al., 2003).
- **Selective tendering** is fundamentally different from open tendering as it only allows a limited number of contractors/suppliers to submit tenders by invitation. A pre-selected

list of possible suppliers is prepared that are known by their track record to be suitable for a contract of the size, nature and complexity required. Therefore, a pre-qualification process must be employed beforehand to select contractors/suppliers that meet or exceed predetermined criteria. Consultants or experienced clients may maintain 'approved' lists of prospective contractors/suppliers and then regularly review performance to assess whether suppliers should remain on the list. This can give clients greater confidence that their requirements will be satisfied and should reduce the wasted effort that can be involved in open tendering. It may be particularly appropriate for specialist or complex contracts, or contracts where there are only a few suitable firms. However, it can exclude smaller contractors/suppliers or those trying to establish themselves in a new market. (ICE, 2016; Griffith et al., 2003).

- **Negotiating tendering** is usually with a single supplier and may be appropriate for highly specialist contracts, or for extending the scope of an existing contract. It can reduce the costs of tendering and allow early contractor involvement; as well as increasing the speed with which price can be obtained for work. However, the competitive advantage of a formal tendering process is compromised, and unless the structure of the negotiation is clearly set out there is the potential for an adversarial atmosphere to develop, even before the contract has been awarded. (ICE, 2016; RICS, 2014).
- **Single-stage tendering** is used when all the information necessary to calculate a realistic price is available when tendering commences. An invitation to tender is issued to prospective contractors/suppliers, who are all given the chance to tender for the project based on identical tender documentation. The tenders are then prepared and returned, a preferred contractor/supplier is selected and following negotiations they may be appointed. (ICE, 2016; RICS, 2014). According to RICS (2014) this was the most common type of tendering strategy at the time for obtaining price for the whole of the construction works.
- **Two-stage tendering** allows for the early appointment of a contractor/supplier, prior to the completion of all the information required to enable them offer a fixed price. This is to enable the adoption of a more collaborative approach between clients and contractors, while still aiming to deliver value for money (Rawlinson and Langdon, 2006). In the first stage, a limited appointment is agreed to allow work to begin and in the second stage a fixed price is negotiated for the contract. (ICE, 2016; RICS, 2014).

Along with deciding on the procurement and tendering method, clients or decision-makers must also decide on the payment method; there are a few of them but the most popular in the UK is fixed price or lump sum (NBS, 2015; see Table 2.2.2). In this payment mechanism, a lump sum price is agreed before the work begins. If the actual cost of the work exceeds the agreed price, then the contractor bears the added cost. On the other hand, if the cost is less than the agreed price, contractor makes a profit.

Table 2.2.2: The price mechanism most used in projects in 2015

Price Mechanism	Client%	Contractor%
Fixed price or lump sum	53	64
Target Cost	22	20
Re-measurement	17	12
Cost re-imbursement	3	0

Source: NBS 2015 (Adapted by researcher)

The traditional method of procuring in the industry has long had its problems worldwide and not just in the UK. Seemingly, the use of the management, the design and build, and the private finance initiative procurement model has done little to help the UK construction industry. In 2011, the UK Government's Plan for Growth; together with Budget 2011 emphasised the importance of an efficient construction industry to the growth of the UK economy; the government wants to become more intelligent with greater knowledge of balancing cost and quality, thus achieving better value for money (Oteng and Park, 2013). Therefore, a Construction Strategy was set up to find out ways of improving the performance of the industry. The conclusion the came to, was that the Government procurement practices were stale, expensive, time consuming, and bureaucratic and that new procurement models had to be introduced (Oteng and Park, 2013).

The new procurement methods introduced seem to be working so far, at least in all its trial projects (Cabinet Office, 2015). Improvements can be noted, at least from the description of the models, for example the integrated project insurance method, this method aims to eliminate the adversarial blame culture that the industry has long been known for; especially when it comes to disputing cost overruns. However, only time will tell whether these new procurement methods are successful. The early indication from looking at these new methods, is that the government are going around in circles; Oteng and Park (2013) pointed out how these new methods are so cost centred that it may eventually lead the industry back to the traditional procurement method of procuring projects. Furthermore, the government may be putting their whole attention at the wrong place in their bid to develop the perfect procurement method to solve the problems in the industry; as Rawlinson and Langdon (2006) pointed out how procurement methods fall in and out of favour depending on the trends in the industry. The problem may not be the procurement method itself; it may be down to the obsession of hiring contractors and other project participants based on the lowest tender price.

With that in mind, we can now look at the tendering methods; the three most used form of tendering the UK are in this order: single stage, two stage, and negotiation (NBS, 2015; see Table 2.2.3). However, there is also an increase in the use of selective tendering in the UK.

Table 2.2.3: The tendering method mostly used in projects in 2015

Tendering method	**Clients, Consultants, and Contractors %**
Single Stage	77
Two-stage	57
Negotiation	45
Design Competition	10
Reverse Auction	2

Source: NBS 2015 (Adapted by researcher)

The problem with the selective tendering method is that even though the selected contractors on the list are chosen based on their capabilities, the awarding of the contract is based solely on price. Furthermore, it may be difficult to justify why a certain contractor should be on the list over another; the ICE (2016) alluded to the fact that contractors may be excluded from the approved list for unknown reasons, due to personal preferences or a lack of awareness. If it is due to personal preference then it is in line with Wachs (1990) and Flyvbjerg's (2008) claim of foul play and corruption. Also, this tendering method is likely to cultivate an oligopoly, and it may be difficult to offer clients a value for money with a restrictive tendering method (Ofori, 1990). The single-stage tendering method on the other hand, which is the most used in the UK has one obvious flaw to it: the notion that the client has all the information necessary to calculate a realistic price at the beginning of the project is almost impossible, and will likely result in disputes down the line of the project life cycle. It is no surprise that this form of tendering matches well with the traditional method of procurement; the two methods in tandem will continue to encourage clients to select the lowest tender. However, it is imperative that technical criteria and tender price should be considered in contractor selection. It is equally important to show clients whether considering technical criteria along with tender price and not just solely price, is worth it. This leads us to the next section of the thesis that discusses the basis for contractor selection strategies.

2.3 APPROACHES TO CONTRACTOR SELECTION

2.3.1 Lowest or Best Value Tender

Contractors can be selected based on price only (lowest tender), or on a combination of price and quality; the latter is called best value or most economically advantageous tender (MEAT) (Bergman and Lundberg, 2013). For the best value strategy, clients will have to determine which quality (i.e. non-price) criteria to include, how to score each dimension, how to weigh each quality dimension to come to a final overall score, how much to weigh quality against price, and which formula to use to combine the quality score and the price into one overall score, so that the tenders can be ranked (Mateus et al., 2010). The concept of best value procurement was introduced a while ago, however due to the high degree of competition that the industry faces, procurement personnel are usually held responsible for decisions; thus, is very difficult for them to select contractors for anything else than the one offering the lowest price (Abdelrahman et al. 2008). However, Palaneeswaran and Kumaraswamy (2001) have argued that basing the final choice of contractor solely on the lowest price, does not guarantee the delivery of the required outcome in terms of cost, time and quality. This is because, they believe that most clients ignore the fact that the same contractor performs differently in a dissimilar environment. Furthermore, Kashiwagi and Byfield (2002) say that though lowest price criterion is an objective and transparent approach, it fails to guarantee the quality of the contractor's performance. Olaniran (2015) points out that reduced quality is one of the problems that is triggered by using the lowest tender strategy. Thus, the lowest tender price may not correspond to the most economic choice in the long term; in other words, may not result in a lower whole life cycle cost. This is because selecting contractors based on the lowest tender price motivates contractors to provide minimally acceptable construction products (Kashiwagi and Byfield 2002). But recently we are seeing the use of selective tendering in the UK, particularly in the private sector, whereby clients have a list of preferred contractors; perhaps due to familiarity and trust, or because those contractors have passed a prequalification process. Thus, these clients usually select the lowest tender out of their list, would that also be considered as failing to consider quality? Furthermore, if the project fails to deliver the required outcome because of going with the lowest tenderer, i.e. cost overruns, was the cost incurred higher than the next lowest tender or all the bids tendered for the contract? This is not to say that the difference between the lowest tender and the next lowest tender is a good indication whether a project will overrun or not, as Hinze et al. (1992) pointed out in their research done on 468 Washington construction projects, that the difference between the lowest tender and the second-lowest tender does not appear to provide any measure by which cost overruns can be predicted. However, if a client selects the lowest tender and the project overruns in cost, but the cost overrun is still lower than the second-lowest tender, did the client make the right choice? In hindsight, there are obviously processes like negotiated tendering (see Section 2.2.2), which can get the second-lowest tendered contractor to reduce their tender price through value-engineering or bill of reduction. This is usually open to two or three of the lowest tenders anyway (CIPS, 2013).

However, the fact that the lowest price strategy is objective and transparent, makes it more straightforward and easy to implement than the MEAT strategy. Constructing Excellence (2011) say that by accepting the lowest tender, it will be perceived that the client is able to demonstrate that it obtains good value with taxpayers' funds; which will be necessary when applying for new investment funds. Furthermore, the benefit to the contractor/supplier is that though tender prices may be insufficient to cover the cost of delivering the works, it can be easily recovered through the pursuit of claims and disputes once the contract has been secured (Constructing Excellence 2011).

The MEAT strategy aims to offer client best value. But what is "best value"? The concept is vague and there may not be a commonly agreed meaning to it (Choi, 1999). Kashiwagi and Savicky (2003) say that owners are reluctant to pay more for best value if they do not understand what best value is. This may be one of the main reasons why it has not been accepted in the construction industry. The Constructing Excellence (2011) reports:

"Some organisations consider this process to be the best option because, as they say below, why change to anything else?

- *According to the National Audit Office (2001), one out of every four Government projects completed in the late 1990s was finished on time, and one in three was* *delivered within budget. Wouldn't changing to a different route risk reducing these odds that we have found acceptable for all these years?*

- *Change would mean losing the influence we, as client, are able to exert over a project. At the moment, we are able to define exactly what we want and then employ others to design and define component interaction and assembly before the contractors are appointed. It's accepted that few of us have ever actually built anything, but our designers have done lots of projects in the past so surely, they can be relied on to know what works and what doesn't?*
- *Acknowledged, buildings are more complex now, and there is a lot more design associated with components and products with a much greater focus on whole life costs. However, there must be lots of things that have stayed constant over the same period of time so why change now?"*

Best value, though it was introduced to the UK in 1999, represents change from the norm. It is alright to change, but what happens when clients do not know what change they are getting into? They will be less receptive to that change. The traditional procurement method, which uses the lowest tender award criterion, is still the most used procurement method in the UK (NBS, 2015). Researchers (Abdelrahman et al., 2008; Gransberg and Ellicott 1997; Akintoye et al., 2003; Yu and Wang 2012) say that best value is a procurement strategy which aims at strengthening the long-term performance of a project through selecting the contractor that is most advantageous to the client. There are various definitions to the term best value, however AGC and NASFA (2008) definition gives us a general perception of what best value is:

"A Best Value Selection is a selection process for construction services where total construction cost, as well as, other non-cost factors are considered in the evaluation, selection, and final award of construction contracts."

According to Stilger et al. (2015) there are over thirty-eight different formulas one can use to calculate the best value contractor; all of which may provide a different winning contractor if used. Selecting contractors on this method raises questions on what value refers to: does it refer to the level of service to the price of the service? Or does it refer to the qualification of the contractor and its ability to bring value by being part of the project team? Furthermore, does the client have enough resources to handle managing a best value process? Therefore, selecting contractors on best value is not as straightforward and objective as selecting on the lowest tender; this probably explains the reason why the UK industry hasn't entirely bought into it yet.

On the other hand, price only may not correspond to the most economic choice in the long term; in other words, may not result in a lower final cost, what it does is to motivate contractors to provide minimally acceptable construction products (Kashiwagi and Byfield, 2002). One important thing to add about best value is that there are cases where the best value contractor also has the lowest price; the UK government has factored this fact into its contract award provisions (Crown Commercial Service, 2015). AGC and NASFA (2008) highlights the two types of submittals in the best value selection process:

• **“Two-Step” Best Value Selection Process**: Step One, Qualifications submittal received; then in Step Two, the Technical and Price Proposals are received

• **“One-Step” Best Value Selection Process**: Step One, Qualifications, and Technical and Price Proposals all received at the same time.

However, the process frequently used in the construction industry and is commonly referred to as “best value” is the prequalification process. “*Prequalification involves determining, in advance of asking for a price for the cost of the work prior to the formal selection process, whether the firms interested in competing on the project have sufficient qualifications to participate”* (AGC and NASFA 2008). So, in this process, the contractors submit their qualifications to meet the clients’ minimum criteria. If contractors are approved they make the clients’ shortlist, and the lowest price contractor is then selected; without any further technical criteria evaluated for projects. Although performances are regularly reviewed to assess whether the contractors/suppliers should remain on the list, this is selective tendering. The assumption to this sort of process is that all prequalified firms are equal and can deliver a project as well as any of the others. There are cases where this is true, but there might be other projects where the differences in the abilities of the firm may be vital to the success of the project. Also, there is the chance that clients will hardly update their contractors’ shortlists, due to familiarity and trust; which may not necessarily be a flaw. But to go back to AGC and NASFA (2008) definition, total construction costs as well as other non-cost criteria should be considered in the evaluation, selection, and final award of construction contracts, not just in the pre-evaluation. The major questions to answer for best value selection process are: How important is price? What non-cost criteria should be considered in the selection and final award of the contract in addition to the overall price proposal? Past performance? Relevant experience? Technical ability? Sustainability? Health and safety? Innovation? Resource availability? Management skills and systems? Table 2.3.1 shows several contractors’ selection criteria identified in previous studies.

Table 2.3.1: Contractor selection criteria for tender evaluation from selected journal articles

Authors	Contractor selection criteria
Moselhi and Martinelli (1990)	Bid amount, annual life cycle cost, number of years in business/bid amount, volume business/bid amount, financial credit/bid amount, previous performance, project management organisation and technical expertise.
Liu *et al.*, (2000)	Bid price or cost, time, quality, managerial safety accountability, competence and contractors' sufficiency
Fong and Choi (1999) and Cheng and Li (2004)	Price, Past performance, Health and Safety record, Financial capability, Current workload, Reputation, Past relationship, and Resources.
Waara and Bröchner (2006)	Bid price, quality assurance system, technical design, environmental characteristics, operations cost, project duration, contractors' capabilities, financial capacity, health and safety, conformity with bidding documents.
Abdelrahman et al., (2008)	Bid price, contract time, warranty, unauthorised delay time, rejected claims, quality, lane rental cost, traffic control, and employees
Huang, (2011)	Financial standing, technical ability, management capability, quality, safety, senior management and current projects/backlog.
El-Abassy et al., (2013)	Price, duration, risk sharing with the owner, financial stability, working capital, % of previous work completed on time, past relationship with the owner, response to claims, health and safety records, experience with similar types of projects, contractor's staff experience, and equipment availability.

The evaluation criteria and its weightings indicate what best value is to the client; with the contractor achieving the highest score being appointed. However, the ICE (2016) reported that some saw the best value approach, which was first introduced in the UK through the Local Government Act in 1999, as a way of further increasing bureaucracy. Although in 2011, the coalition government introduced guidance that went some way to watering down the requirements of the Act (ICE 2016).

2.3.2 Models to assign the Best Value Contractor

Table 2.3.2 shows some of the studies conducted to try to develop the right approach for selecting contractors/suppliers on best value. Weber et al. (1991) group these approaches into three main categories: mathematical programming, linear weighting, and statistical/probabilistic; though other studies have come up with approaches that do not particularly fit into any of these theories.

Table 2.3.2: Approaches to Best Value Contractor Selection

Group	Study
Mathematical Programming	Yu et al. (2013), Weber and Current (1993), Chaudhry et al. (1993), Ghodsypour and O'Brien (2001), Kumar et al. (2003)
Linear Weighting	Mandal and Deshmuk (1994), Kwong et al. (2002), Bayazit and Karpak (2005), Abdelrahman et al. (2008), Cheng and Li (2004)
Statistical/Probabilistic	Mummalaneni et al. (1996), Verma and Pullman (1998), Tracey and Tan (2001), Love et al. (2013)
Other Methods: Simulation, Fuzzy Logic, Activity Based Cost (ABC), and Total Cost of Ownership (TCO)	Lo and Yan (2009), El Asmar et al. (2009), Bendana et al. (2008), Bevilacqua and Petroni (2002), Kwong et al. (2002)

Yu and Wang (2012) research on best value developed a mathematical model that can be consulted to determine whether a best value contractor selection should be favoured against a price only contractor. Their research paper proposed an index named Price Elasticity of Performance (PEP hereafter) to help procurers reach an objective decision in selecting the most appropriate contractor. Yu and Wang (2012) say that the heterogeneity of the market is a critical factor in selecting the most appropriate contractor; their take is that price only is useful in certain situations. They (Yu and Wang, 2012) define heterogeneity as "the different quality (conceived by the consumers and measured by a set of predefined selection criteria) of contractors (in a tender competition) that reaches equilibrium of price in the market." So, the PEP was mathematically formulated by them not only to measure the heterogeneity of the market but also of an individual contractor. PEP was defined as the ratio of percentage of changes in the committed performance of a work (by the contractor) because of change in price (Yu and Wang, 2012). This is a simple analysis of their model; it was an aggregate index market PEP (Em), which is proposed to measure the heterogeneity of the market; this provides a criterion for determining a more appropriate contractor selection method. Therefore, if Em is greater than 1.0, the market is considered more heterogeneous and the best value should be adopted for contractor selection. If Em is less than 1.0, the market is considered less heterogeneous and the lowest priced contractor method should be used for contractor selection. Their methodology of assessing the market may be deemed confusing and time consuming for procurement personnel; it may require specialist skill. However, the method is a good way to choose whether contractors should be selected through price only or best value. Also, it shows that choosing the lowest tender method is also a form of achieving best value if the market has been properly assessed and the project needs correctly specified.

Yu et al. (2013) research is quite like that of the Yu and Wang (2012) but this time it measures the Price Elasticity of Quality (PEQ hereafter) of a product or service offered by contractors in a tendering process. One measures the performance of contractors, the other measures the quality/services offered by contractors. The research also involved using a mathematical model; Yu et al. (2013) was a mixture of graph plotting and mathematical equations to determine the contractor with the best quality or service. Just like the previous research, it may be confusing at first and time consuming; the practicability of using this sort of methodology in construction organisation is one that should be questioned. It is complicating, and like most models, there are several assumptions that are made that isn't entirely the case in the real world, such as the perfect competitive market assumption when there is no perfect market in the construction industry. Additionally, one must consider whether these mathematical models will be applicable in every type of construction projects.

Many other tools have been developed to help in selecting the best value contractor such as simulation, simple weighting, analytical network process (ANP), analytical hierarchy process (AHP), simulation and multi-utility theory. Lo and Yan (2009) developed simulation models to analyse contractors' pricing behaviour and dynamic competition process under the qualification based system (QBS). The strength of this research is that it is possible to identify unrealistic tenders using the model. Furthermore, El Asmar et al. (2009) used simulation to quantify criteria and combine them into a single score when assessing contractors. The major drawback to this research is the assumption that it could be used in all types of projects to assess contractors. Construction projects usually differ; clients' needs also differ and models should be able to take this into consideration. Having said that, there are methods that exist and were introduced a while ago that are being used as contractor selection approaches to account for the clients' needs or the specific needs of the project at hand. The AHP, being one, is a popular technique used for ranking and prioritising criteria used in selecting contractor; it can analyse multi-criteria problems according to pairwise comparison scale. According to Fong and Choi (2000) the technique identifies contractors with the best potential to deliver satisfactory outcomes in a final contractor selection process which is not based simply on the lowest tender. One of the main benefits of this tool is that it can be combined with other tools to assist decision makers such as fuzzy logic and ANP. The ANP, is an extension for the AHP to allow for interdependencies between criteria in selecting contractors (Cheng and Li, 2004). Abdelrahman et al. (2008) introduced a concept of best value modelling that was specific to each project. It combined the AHP and the weighted average method to quantify the qualitative effect of subjective factors in selecting the contractor. This study was relatively easy to understand and implement, however there is a high level of subjectivity to this study. The weights given to the criteria was the researcher's discretion, even at that there is no real evidence that the criteria used to select the contractors will result in project success. Although it is fair to add, that the main purpose of their study was to assist in selecting the best value contractor not whether the best value contractor will be successful or not. Similar studies have also been undertaken like Kwong et al. (2002) and Bevilacqua and Petroni (2002), which used the combination of a scoring system and fuzzy theory for ranking the best value tenders. Bendana et al. (2008) also developed a fuzzy logic assessment model, where they analysed both the qualitative and quantitative issues that influence whether a contractor is suitable to win the project. Zadeh (1965) first introduced the concept of fuzzy set, which basically transforms linguistic variables that are ill-defined into traditional quantitative terms (El Agroudy et al. 2009). In this type of study contractors are scored in each criterion as Low, Medium, and High (1, 2, and 3). Then depending on the number of criteria used to assess the contractors, let us say for example 5, this usually results in a final score for each contractor between 5 and 15. So if a contractors' score is between 5 and 9 they will be considered Poor. 10 and 13 will be considered Good, while 14-15 is Very Good. This is just an example of a scale used, each client can subsequently use their own scale. However, using this example, one can question how sensitive the scores are to subjectivity; with the fact that at 9 a contractor is considered Poor and at 10 Good. Assuming the choice of the contractor boiled down to 9 and 10 contractors, with the latter at a higher price. How can it possibly be justified to the client to select the contractor with the score 10 at a higher price, when it's supposed 'quality score' is just one point above a contractor with a lower price? How much of a difference does that one point make in the project outcome? The strength of this technique however is that it can be tailored to the owners' requirement; the client should have the power to score contractors the way they like, but whether that results in project success usually remains unclear until the end of the project.

Other research has proposed the use of multi-criteria evaluation model for contractor selection; Topcu (2004) for one incorporated this method for construction contractor selection in the Turkish public sector. A major strength of these models is the capacity to allow more factors that are likely to influence a contractor's performance to be taken into consideration. Zavadskas et al. (2008) demonstrated this in its research by developing a contractors' assessment and selection based on the multi-attribute method. There are also models that have been developed to assess the contractors after project completion. Hancher and Lambert (2002) developed an evaluation system to evaluate the performance of contractors at the end of each year of project duration. Minchin and Smith (2005) also produced a quality based performance rating system model that generated an index for each contractor to represent contractor's quality over a specified frame. Despite the vague nature of quality, the research has at least tried to establish a link between contractor selection and the outcome of the project by assessing the contractors. By doing so, clients can take these assessments into consideration for future projects.

It is also worth mentioning that the use of subcontractors in the construction industry has been steadily on the rise. Main contractors are now subcontracting majority of the works of a project which means that subcontractors should be assessed as well. Albino and Garavelli (1998) have proposed a neural network process for subcontracting rating. While, Arslan et al. (2008) developed a web based subcontractor evaluation system called WEBSES for the Singaporean construction industry that evaluated contractors based on combined criterion.

2.4 SUMMARY

Literature review on the sources of cost overruns did not entirely reveal contractor selection as one of the main sources of cost overruns; although from the explanation given one would be able to see how wrong contractor selection plays a part. Take for example two of the main sources of overruns: optimism bias and strategic misrepresentation; this involves project participant, knowingly or unknowingly, underestimating the cost of carrying out the works to win contracts or funding. This is a product of wrong contractor selection. On the other hand, literature review on the various approaches to contractor selection, did little to show the effect that a contractor selection strategy has on the outcomes of construction projects as majority of these research tended to be subjective and based on self-perception questionnaires. However, there are a plethora of research that are aimed to determine the best value contractor, whether they are mathematical models, or linear weighting models, or statistical approach; all of which include cluster analysis, simple weighting, AHP, fuzzy set theory, discriminant analysis, etc. (Waara and Bröchner 2006; Tsai et al., 2007; Lambropoulos 2007). However, these methods do little to show the effect a contractor selection strategy: either lowest tender or best value, has on the outcome of a construction project: final cost and duration. This refers back to the problem statement in Section 1.1. El-Abassy et al. (2013, pp 766) in their research that developed a model used to select the best value contractor recommends a further study:

"if the developed model determined the best contractor for a project whose submitted price is not the lowest price, then an analysis should be done to show what-if scenarios for the contractor with the lowest price if he/she is awarded the contract instead. The analysis can include the response to claims for this contractor, the rework that may occur during the project because of inadequate past experience, for example, or any other weak points for the contractor with the lowest price that may result in an extra cost beyond the original price. These extra costs might include (1) rework because of bad quality, (2) delays because of incompetence, (3) short life cycle because of bad quality material, (4) operation and maintenance problems because of inadequate experience, and (5) many claims because of bad management."

The research will carry out this further study, but not by assuming that the lowest tenderer comes with all these problems. Rather by using historic data and analysing how they have performed in the past, to predict how they will likely perform in the future. Yu and Wang (2012) say that the market should dictate what strategy to select; meaning that there are times when it is best to go for the lowest tender strategy. Olaniran (2015) also mentions that in simple projects with no special quality desired, awarding contracts on price alone may be a logical action. This research will establish the link between contractor selection strategy and project outcomes; one that eliminates biases and subjectivism. El-Abassy et al. (2013) insinuated that selecting the lowest tenderer will incur extra costs for "*(1) rework because of bad quality, (2) delays because of incompetence, (3) short life cycle because of bad quality material, (4) operation and maintenance problems because of inadequate experience, and (5) many claims because of bad management."* This might be true, but there is no empirical and objective evidence to prove this claim. Table 2.4.1 shows that the bulk of the literature are subjective and aimed to develop models that select the best value contractor. This research is empirically investigating which strategy works where. Furthermore, there are research in Table 2.4.1 that established the link between contractor selection strategy (selecting the lowest tender) and project outcome. But, these research carried out surveys, which allows some subjective responses. By analysing historic data that have used either the lowest tender or best value strategy, it enables the development of an objective method that establishes a link between the selection strategy and project outcome. In doing so, this research will offer justification on how a selection strategy affects project outcomes. Furthermore, this research will also offer an empirical support to Yu and Wang (2012) claim that no one strategy fits all; we can know which strategy works where.

Table 2.4.1 Literature Review Summary

Research	Quantitative	Qualitative	Subjective	Objective	Contractor Selection Approach	Established link between contractor selection strategy and performance
Proposed Model	✓			✓		✓
Assaf and Al-Heijj (2006)	✓	✓	✓			✓
Olaniran (2015)	✓	✓	✓			✓
Mulla and Waghmare (2015)	✓	✓	✓			✓
Sambasivan and Soon (2007)	✓	✓	✓			✓
Walker (1995)	✓	✓	✓			✓
Kumaraswamy and Chan (1998)	✓	✓	✓			✓
Al-Khalil and Al-Ghafly (1999)	✓	✓	✓			✓
Palaneeswaran and Kumaraswamy (2001)	✓	✓	✓		✓	
Kashiwagi and Byfield (2002)		✓		✓	✓	
Moselhi and Martinelli (1990)	✓		✓		✓	
Liu *et al.*, (2000)	✓		✓		✓	
Fong and Choi (1999) and Cheng and Li (2004)	✓		✓		✓	
Waara and Bröchner (2006)	✓		✓		✓	
Abdelrahman et al., (2008)	✓		✓		✓	

Research	Quantitative	Qualitative	Subjective	Objective	Contractor Selection Approach	Established link between contractor selection strategy and performance
Huang, (2011)	✓		✓		✓	
El-Abassy et al., (2013)	✓		✓		✓	
Stilger et al. (2015)	✓		✓		✓	
Gransberg and Ellicott 1997		✓	✓			
Yu et al. (2013)	✓		✓	✓	✓	
Kwong et al. (2002)	✓		✓	✓	✓	
Cheng and Li (2004)	✓		✓	✓	✓	
Lo and Yan (2009)	✓		✓	✓	✓	
El Asmar et al. (2009)	✓		✓	✓	✓	
Bendana et al. (2008)	✓		✓	✓	✓	
Bevilacqua and Petroni (2002)	✓		✓	✓	✓	
Kwong et al. (2002)	✓		✓	✓	✓	
Zavadskas et al. (2008)	✓		✓	✓	✓	
Topcu (2004)	✓		✓	✓	✓	
Arslan et al. (2008)	✓		✓	✓	✓	
El Agroudy (2009)	✓		✓	✓	✓	

The next chapters will now aim to provide a conceptual model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies. Up to date there has been no quantitative assessment of the probability distribution of the outcome cost and duration of either selection strategy. The client may want to know not just the expected outcome cost of a strategy but also what would be the probability of a strategy leading to an extremely high final cost. Such a probability distribution can point out whether there is a chance that one selection criteria would give the lowest cost on average but could, on occasions, give to outcome costs so high that far exceeds the budget.

Chapter 3: RESEARCH METHODOLOGY AND DESIGN

3.0 INTRODUCTION

This chapter first begins with a short description of the two-research approach: qualitative and quantitative, and the reasons for adopting the quantitative research approach. Then the simulation framework that helped structure the modelling aspect of the research is presented. Next, the different cost modelling techniques are examined, as well as the background, applications, strengths and drawbacks of MCS.

3.1 RESEARCH PHILOSOPHY

Research philosophy is a way by which data concerning a phenomenon can be gathered, analysed, and used. According to Mkansi and Acheampong (2012) there is a heightened difficulty in conducting research due to the incoherent classification of research philosophies such as epistemology, ontology, and anxiology. Researchers such as Saunders et al. (2009), Ritchie and Lewis (2003) and Guba and Lincoln (1994) have used different meanings to characterize these research paradigms.

Epistemology according to Saunders et al. (2009) is what is considered acceptable knowledge in a field of study; in other words, what is known to be true. Ontology is the researcher's view of the nature of reality or being. Saunders et al. (2009) say that there are two aspects of ontology: objectivism and subjectivism. The latter is when social phenomena is created from the perception and consequent actions of the social actor concerned with its existence. While objectivism is the existence of social entities irrespective of the social actors concerned with their existence. (Saunders et al., 2009). Axiology is a research philosophy that is concerned with the role that the researchers' own value plays in all the stages of the research process. Heron (1996) claims that the only way a research can be deemed credible is by stating your own personal value in relation to the topic that you are studying. Heron (1996) states that our values are the guiding principles of all human action.

From this different stance of research philosophy there are several perspectives that can be derived. The four main perspectives are positivism, realism, interpretivism, and pragmatism. Positivism is the belief that reality can be observed and described from a neutral standpoint without interfering with the phenomena being studied. The finding derived from this study should be isolated and can be repeatable (Remenyi et al., 1998). Realism is like positivism, Saunders et al. (2009) say that *"The philosophy of realism is that there is a reality quite independent of the mind"*. Interpretivism on the other hand, involves the subjective interpretation and intervention to a research study. The strength of this study is that researchers usually adopt a compassionate stance, one that tries to see things from others point of view. This type of study is usually applicable in business environments where projects are usually complex and unique. Finally, pragmatism states that the research question is solely responsible for deciding the research philosophy adopted. It advocates an agile approach that may involve combining the positivist and interpretivist philosophy, or quantitative and qualitative research approach. This is known as the mixed method approach.

3.2 RESEARCH APPROACH

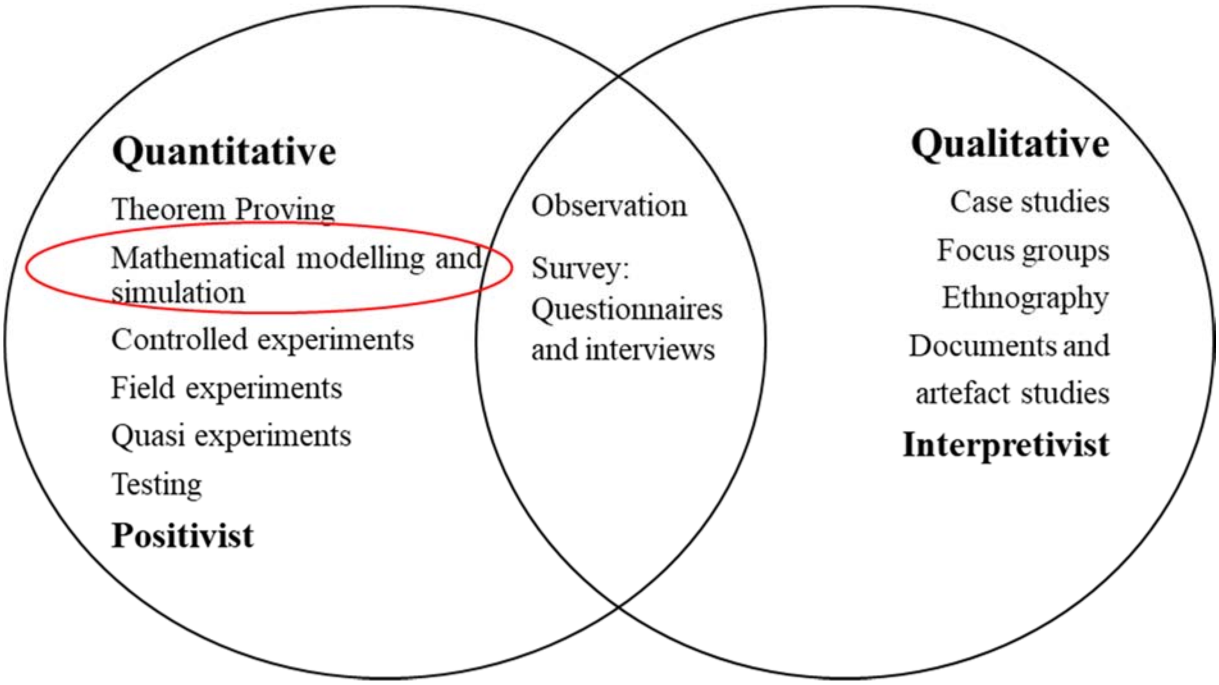
In a thesis, it is often the case that a research approach is classified as qualitative, quantitative, or both; in which case, it is termed as mixed methods. The qualitative research method focusses on discovering and understanding the experiences, perspectives, and thoughts of participants; it seeks to find out what people's perceptions are of different social human phenomena (Creswell 2009; Harwell, 2011). According to Denzin and Lincoln (2005), *"qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world. They turn the world into a series of representations, including field notes, interviews, conversations, photographs, recordings, and memos to the self. At this level, qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them."* This method of research conducted through case studies, ethnographic work, interviews, etc. From the definition given on the qualitative research method, this method is difficult to replicate or be generalised as the results are usually obtained by participants. Fellows and Liu (2008) noted that a good qualitative study often forms a prelude to quantitative methods.

Quantitative research methods on the other hand seeks to maximise objectivity, causality, replicability, and generalisability of findings, and are typically interested in prediction (Bryman, 2012). The generalisation aspect is the extent in which the conclusions and findings drawn from the research can be extended to other population and settings. Furthermore, in this type of research, the researcher will set aside their personal biases, experiences, and perceptions to ensure objectivity in the conduct of the study and the conclusions that are drawn. This is to ensure that the study can be repeated using the same methods, different experimenters, subjects, and fields. This is an important step to validate the research and test the generalisability of its findings. The key features of many quantitative studies are the use of instruments such as tests or surveys to collect data, and reliance on probability theory to test statistical hypotheses that correspond to research questions of interest (Harwell, 2011). The drawback to this type of research, is that there is the assumption that it offers the only truth that exists, independent of human perception (Lincoln and Guba, 1985). According to Trochim and Land (1982), the quantitative research method is the "*glue that holds the research project together. A design is used to structure the research, to show how all of the major parts of the research project—the samples or groups, measures, treatments or programs, and methods of assignment—work together to try to address the central research questions."* Creswell (2009) presents three criteria for choosing a quantitative approach, it says that the quantitative method should be chosen if the research problem calls for:

a) the identification of factors that influence an outcome; or
b) the measureable utility of an intervention; or
c) understanding the best predictors of an outcome.

The mixed method approach basically is a combination of the qualitative and quantitative method in a way that compensates each of their weaknesses. Greene (2007) say that the mixed research method allows for the *"opportunity to compensate for inherent method weaknesses, capitalize on inherent method strengths, and offset inevitable method biases."* Johnson and Onwuegbuzie (2004) say that *"mixed methods research is formally defined here as the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study. Mixed methods research also is an attempt to legitimate the use of multiple approaches in answering research questions, rather than restricting or constraining researchers' choices (i.e., it rejects dogmatism). It is an expansive and creative form of research, not a limiting form of research. It is inclusive, pluralistic, and complementary, and it suggests that researchers take an eclectic approach to method selection and the thinking about and conduct of research."* From these definitions, there are advantages of mixing both methods, however this comes with more complexity.

Figure 3.2.1: Research Strategies, Choices, and Philosophy



Source: De Villiers (2005, Adapted by researcher)

Figure 3.2.1 outlines the research strategy, choice, and philosophy of this study. This study was predominantly a quantitative approach. There were some elements of a qualitative approach especially in the early stage of the research, but not enough to be considered a mixed method approach. A critique of existing literature on construction overruns and contractor selection approaches and strategies laid the platform on which to develop a method of seeing how a contractor selection strategy affects the outcome of a construction project. The reason for using a quantitative method approach is that this study will predominantly involve analysing numbers; using tenders to produce probability distributions of project outcomes, and to offer empirical evidence on how a contractor selection strategy affects the outcome of a project. Existing studies are rich with methods and approaches of selecting a contractor which can be interpreted differently depending on the client involved (see Table 2.4.1). What this study is doing is putting subjectivism, pre-conceived notions and perceptions (see Table 2.4.1) aside to purely analyse historic data on how projects have fared under these two strategies. The study will establish a link between contractor selection strategy and project outcomes based on historic data and not from a perceptive standpoint that states that the best value strategy should always be picked over the lowest tender strategy. However, as this research is not advocating for one strategy over another, it cannot be viewed as a purely positivist research. The research aims to show the client the probability distribution of possible outcomes involved with going for a strategy, not to predict the outcome. Therefore, whatever strategy the clients decide to adopt is up to them, meaning that the results cannot be considered law-like generalisations. Clients would likely interpret the findings differently.

3.2.1 Research Design

The research question is usually considered the driving force behind the choice of a research design and any changes made to the element of a design as the study unfolds. The identification of a research design is important as it communicates key features of a study. (Harwell, 2011). Yin (2009) say that research design provides the structure that guides the collection and analysis of data. This research collected historical cost data on 120 educational facilities projects from the Building Cost Information Service (BCIS hereafter) of the Royal Institution of Chartered Surveyors (RICS hereafter) database. This was then followed by the development of the model mainly using MCS. In using educational facilities projects for this study, it was found that most projects used selective tendering to pick contractors (see Section 4.2). So, in other words clients have their preferred list of contractors and when there is a project, they usually go with the lowest tender from their preferred list. These contractors would have passed some sort of pre-qualification test, or are familiar with the client because of past dealings. However, this does not qualify as selecting on a best value basis. This is essentially picking the lowest tendered contractor with more confidence that it can meet the project outcomes based on familiarity and trust. Therefore, by urging clients to select the best value tender, especially when the best value tender is not the lowest tender, would need justification. Justification in terms of how it will affect project outcomes and not just theoretical reasons why the best value strategy is better than the lowest tender strategy.

Furthermore, the use of the BCIS database allows this study to analyse a big number of projects that companies were unable to release due to different reasons such as the sensitivity of the data needed and the time constraints involved in handing over this number of projects. The BCIS harboured all the standard information needed to carry out this study, however there is always the risk that companies only released projects that fared better as opposed to ones that went wrong.

3.2.2 Simulation Design

Literature review on the sources of overruns did not entirely reveal contractor selection as one of the main sources of cost overruns; although from the explanation given one would be able to see how wrong contractor selection plays a part (see Section 2.1). On the other hand, literature review on the various approaches to contractor selection, did little to show the effect that a contractor selection strategy has on the outcomes of construction projects (see Table 2.4.1). The study created a model that analyses a what if scenario, to see what the possible outcomes could be if a project that was meant to be awarded to the best value contractor whose price is not the lowest price, was awarded to the lowest price contractor instead. A Monte Carlo approach was used for this study, this approach can explore all the possible outcomes to a selection strategy under certain bounds of variability expressed to it (Wang et al., 2012). The approach can show the minimum and the maximum values possible for each strategy, which in turn, will help clients make better decisions regarding which strategy to select. To reiterate, the certain bounds of variability expressed to the model was taken from 120 educational facilities projects in the BCIS database.

This part of the chapter (**3.2.2**) details the steps followed in the experimental phase of this research to develop the final model. These steps are supported by Gilbert and Troitzsch (2005) stages to a simulation based research.

3.2.2.1 Developing a Theoretical Derived Research Question of Interest

Paxton et al. (2001) say that the validity and utility of a simulation study is only as strong as the quality of questions being assessed. A Monte Carlo study is ineffective when there is a lack of strong theory guiding the design and analysis of the simulation. Paxton et al. (2001) likened a Monte Carlo study without a strong theory as looking for a needle in a haystack. Therefore, it was vital that the research question of this study was tied to statistical theory and that the simulation served as a method to collect data to empirically evaluate the research aim. Monte Carlo studies can be a difficult proposition, with multiple conditions and massive amounts of resultant data. Thus, by carefully identifying and selecting the research hypotheses, the scope of the simulation can be more focussed and manageable.

The model will investigate how the lowest priced contractor would likely fare on a project that is or has already been awarded to the best value contractor in terms of cost and duration. There is a general assumption that a high overrun cost is correlated to an unduly low tender price (see Section 2.4; El-Abassy et al., 2013). Therefore, the projects selected from the database were all projects that selected the lowest tender; in order to investigate how the lowest tenderer generally fared. Furthermore, as there are different sectors in the construction industry, the model results could not be generalised; it had to be sector specific. The method itself is applicable to other sectors in the industry, however only educational facilities projects were selected. This is because, the model had to be validated on recent past projects, which was made available by industry partners. Had a different sector been chosen, past projects on that sector would be needed to validate the model, and this was unavailable.

3.2.2.2 Creating Representative Models

Another drawback of Monte Carlo studies is a lack of external validity, a goal of maximizing external validity should be as important as the goal of optimally testing a proposed research. Paxton et al. (2001) also points out how there are situations in which the research demands a particular model and external validity is less important. As explained in the previous section, the construction industry is very sector specific, and due to time constraints only one sector could be used. However, a number of sensitivity analysis was conducted on the model to mainly see how changes in the correlations inputted into the model has an effect on the results. The idea being that each sector is likely to have a different correlation between variables.

3.2.2.3 Designing Specific Experimental Conditions

Once the target model was established, the next step was to determine the conditions to vary in the simulation. The condition that varied in this study were the distributions of the variables, therefore an appropriate distribution had to be chosen. There are different probability distributions applicable to this research, each classified as either open-ended or close-ended distributions. Close-ended distributions such as the triangular distribution, implies that the outcome of a project cannot exceed the minimum and the maximum limit set in the model. This is an unrealistic assumption in real world projects as there are unforeseen issues that may come up that causes a project to exceed its limit. Graves (2001) suggested using an open-ended distribution such as the lognormal distribution which would at least allow the maximum estimated limit to be exceeded, making it applicable to real world projects.

3.2.2.4 Choosing Parameters

There are different parameters that are used to determine the performance of construction projects. However, according to Angus et al. (2005) construction projects have traditionally measured project performance success by cost, time, and quality.

- **Cost:** This is the final cost of the project not the tender price.
- **Time:** The actual duration of the project
- **Quality:** Reliability of the contractor/project? Client satisfaction?

In the UK Glenigan Report there are nine key performance indicators (KPI; see Table 3.2.2.4). As the research is investigating the effects a strategy has on project outcomes, it means that the study is only interested in the construction phase of the project where the contractor is responsible. Furthermore, the KPIs in Table 3.2.1 indicate, just as Angus et al. (2005) stated, that cost, time, and quality are traditionally the measuring tool of project success. As one may argue that the parameter Quality covers all the other performance indicators.

Table 3.2.0.1: UK Glenigan Report KPIs

Key Performance Indicators
Client satisfaction-Service
Client satisfaction-Product
Defects-Impacts at Handover
Predictability Cost-Project
Predictability Cost-Design
Predictability Cost-Construction
Predictability Time-Project
Predictability Time-Design
Predictability Time-Construction

Cost and time are two of the most important objectives which can be easily quantified. Quality on the other hand is difficult to quantify; how does a contractors' quality score affect the project cost? Klerides and Hadjiconstantinou (2010) mentions how time and cost trade-off have been researched for a long time, but on the other hand only a handful of research has developed time-cost-quality trade-off. Though the aim of this research was not to develop one, it does show the level of difficulty associated with understanding quality.

Improving quality is the best way to increase clients' satisfaction; although this must be done at the lowest possible cost as well. For this to happen, Schiffauerova and Thompson (2006) say that the costs needed to achieve quality should be reduced and this is only possible if the quality is identified and measured. There are various definitions of quality, as this is a vague term that has its different meaning to different people. Therefore, the idea here is not to try to give a broad definition of what quality is, rather to find a way to cost and measure it. Quality measurement plays an important role in the cycle of never ending improvement; this measurement is considered as a spark for improvement. Waje and Patil (2012) say that no improvement can be made if there are no measurements applied and analysed to assist in identifying opportunities for improvement.

Quality is a factor that should influence the decision made by the client, and paying attention to it when planning is considered economic. Though the process of costing quality may be challenging, the concept was first introduced in 1951 by Juran; this concept is called the 'cost of quality' (COQ hereafter). COQ is the 'price for non-conformance.' (Crosby, 1979). It is the cost incurred because of not delivering the product or service right in the first place. Below are the four categories of COQ, and its brief description (Waje and Patil, 2012):

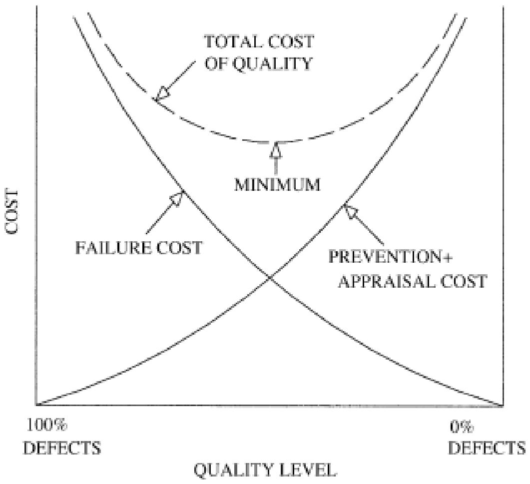
- *"Internal failure cost is a cost that would disappear if no defects existed prior to shipment to the customer. These costs include rework, scrap, re-inspection, re-testing, corrective action, redesign, material review, material downgrades, vendor defects, and other like defects.*
- *External failure cost is a cost that would disappear if no defects existed in the product after shipment to the customer. These costs include processing customer complaints, customer returns, warranty claims and repair costs, product liability and product recalls.*
- *Appraisal costs are incurred while performing measuring, evaluating, or auditing to assure the quality conformance. These costs include first time inspection, checking, testing, process or service audits, calibration of measuring and test equipment, supplier surveillance, receipt inspection etc.,.*
- *Prevention costs are related to all activities to prevent defects from occurring and to keep appraisal and failure to a minimum. These costs include new product review, quality planning, supplier surveys, process reviews, quality improvement teams, education and training and other like costs."*

Therefore, **quality cost** is usually calculated as:

$$\textbf{Quality Cost} = \boldsymbol{Prevention\ costs} + \boldsymbol{Appraisal\ costs} + \boldsymbol{Failure\ costs}$$

There have been economic and mathematical models developed to find the optimum COQ, however according to Kazaz et al. (2005), Brown and Kane (1984) is the most frequented in the literature. Below is their basic model.

Figure 3.2.2.4: The basic model of cost of quality



Source: Kazaz et al. (2005)

According to **Figure 3.2.2.4**, prevention and appraisal cost have one curve that has an inverse relationship with the cost of failure. Thus, the optimum cost of quality is where the increasing costs of prevention and appraisal curve converges with the decreasing failure cost curve. To minimize total quality cost, the curve must reach a point where the prevention and appraisal curve equals the cost of failure. The total quality cost curve represents the sum of the two curves, and the minimum point of that is sometimes referred to as the optimum point. (Kazaz et al., 2005).

From the subsequent review, it seems that the method for quantifying quality is to subtract the initial tender price from the final cost. While this is straightforward and clear, is this universal? Quality is a subjective term, it has already been raised in sections **3.2.2.2** and **3.2.2.3** about how the construction industry is likely to differ from sector to sector. Quality on the other hand is also likely to differ from client to client, hence, the parameters set for this research is **Final cost**, and **Actual duration**.

3.2.2.5 Choosing an Appropriate Software Package

There is no doubt that there are numerous software packages that can be used to carry out this Monte Carlo study, however it is not the intention of this thesis to carry out a software critique. In choosing the software, these questions were asked:

1. Which was fit for purpose?
2. Is it relatively cheap?
3. How adequate is the researcher in using the software?

MATLAB R2014b and Mathematica were the main options for this study. The researcher chose MATLAB due to familiarity as a prior MSc research thesis was conducted by the researcher using this software.

3.2.2.6 Executing the Simulations and File Storage

Running a MCS for the first time, one is unlikely to realise how much data will be created. Therefore, once the target model and the parameters were established, the simulation was first executed to gauge the amount of outputs created from the simulation. Files were saved, grouped and named to enable the researcher know what is what, and what was done after the simulation was completed.

3.2.2.7 Troubleshooting and Verification

Once the simulation was executed, several checks were done to provide verification that the simulation worked; this included multiple realisations and iterations. As well as testing and validating the model using unseen data that was set aside for that purpose.

3.2.2.8. Result Summary and Presentation

Once the simulation was completed, results obtained, and the model verified, the researcher was then able to present the results. The researcher was spoilt for choice when it came to the method of presenting results as MCS produces a lot of output data. The aim here was to help clients make decision on which strategy to choose when selecting contractors, so the idea was to keep the presentation as straightforward and concise as possible.

3.3 ALTERNATIVES TO MONTE CARLO SIMULATIONS

Oberlander and Trost (2001) say that accurate cost estimates for construction projects are extremely important to the sponsoring organisation; budget estimates are needed to manage project costs. While there is a universal agreement that cost estimates need to be reliable, the fact is that they are hardly accurate. Despite this fact a reasonable forecast of final costs of construction projects are needed to justify the projects on economic ground and efficiently allocate the capital required to carry out the project (Baccarini, 2005 and 2006). Therefore, an appropriate estimation method is vital, cue the concept of cost modelling. The most simple and straightforward definition of cost modelling was given by Ashworth (1999), which states that cost modelling are techniques used to forecast the estimated cost of a proposed construction project. Ashworth (1999) and Fortune and Cox (2005) also categorised the different types of cost model. Though it is not the intention of the researcher to carry out a critique of these models, a straightforward description and example of its application were given:

1. **Traditional Methods**: - This is estimating the cost of final cost based on comparable cost of past projects, using the standard form of measurement. Examples of this include: Bill of quantities, superficial method, and functional unit method. Platforms such as Standard Method of Measurement (SMM7) by RICS, Civil Engineering Standard Method of Measurement (CESMM) by the Institution of Civil Engineers, New Rules of Measurement (NRM) by RICS, and BCIS by RICS have all been established to help industry professional estimate the cost of projects based on comparable past projects.

   In a study done by Akintoye and Fitzgerald (2000) about the UK's estimation practice, it was reported that the traditional method of estimation was the most used method in construction companies. Although this study is over a decade old, it shows that this method may still be popular amongst industry professionals due to the ease of use; the National Construction Contracts and Law Survey (NBS, 2015) suggests that it is still the case.
2. **Mathematical Models**: - Monte Carlo is included amongst these types of model but was explored in more detail in the next section. Other examples of mathematical models are: statistical modelling such as regression analysis and parametric models. Regression analysis is the most common of these models used to carry out previous research (William, 2003; Lowe et al., 2006). Regression model have been used since the 1970s (Ashworth, 1999; Baccarini, 2006), this model allows explicit relationship between dependent and independent variables to be analysed. Skitmore and Patchell (1990) say that these models primarily focus on the best predictors of tender price. Although this has now been extended to model final cost. Lowe et al. (2006) used 286 building project information collected in the UK to develop construction cost of buildings; performing both forward and backward stepwise analyses to produce a total of six models. The study reported a best model performance of 19.3% Mean Absolute Percentage Error (MAPE hereafter) with R^2 of 0.661.

   Odeck (2004) used regression analysis to investigate the statistical relationship between actual costs and estimated costs at the detailed planning stage of 620 road Norwegian construction projects, collected between 1992 and 1995. The study revealed a cost growth of 7.9% ranging from -59% to +183%. The analysis showed that most of the overruns were predominantly among smaller projects compared to larger ones. This stepwise regression analysis identified two independent variables: estimated cost and completion time R^2 of 0.21.

Sonmez (2004) used 30 continuing care retirement community projects built by a contractor in the US in 14 different locations between 1975 and 1995 to conduct a regression analysis. This study was used to estimate project cost, containing five variables: project year, location, building areas, percentage of health and common areas, and total area per unit R^2 of 0.949.

Kim et al. (2004) used data of construction costs of 530 residential buildings built by general contractors between 1997 and 2000 in South Korea to perform a regression analysis to predict final costs of residential construction projects. The analysis was performed on 490 projects with the remaining 40 projects used to validate the model with MAPE of 6.95%. One thing to add to Kim et al. (2004) study is that the projects used to validate their model was from the same sector. As previously mentioned the construction industry is sector specific, therefore it is possible that their study would not have produced such good results had their model been tested on another sector such as highway projects for example.

3. **Knowledge-based models**: - These models include expert systems, case-based reasoning, and price. Skitmore (1986) was amongst the early pioneers of adopting expert systems in construction research. This type of model uses a domain specific knowledge and heuristics to simulate the reasoning of an expert in that field to perform an intelligent task (Adeli, 2003). Case-based approach (CBR) uses a knowledge-base containing past project case to help estimate the cost of a similar projects. The difference between these models and the traditional models is that these models are more domain specific compared to the traditional platforms that are industry specific. These models consider the fact that project execution will vary even between construction companies in the same sector.
4. **New wave models**: - The most notable of these models are the Artificial Neural Networks (ANN hereafter); this is an information processing technique that simulates the biological brain and its interconnected neurons (Chen and Hartman, 2000). According to Baccarini (2005) ANN administers a mechanism that learn and acquire problem-solving capabilities from training examples by detecting hidden relationships among data and generalising solutions to new problems. Researchers (Chen and Hartman, 2000; Sonmez, 2004; Kim et al., 2004) compared the application of ANN to predict cost performance to regression analysis, and they often found that ANN produced more accurate predictions. According to Baccarini (2005) here are some examples of the application of ANN:
    - *"Chen & Hartman (2000) used ANN to predict the final cost of completed oil and gas projects from one organisation using 19 risk factors as the input data. It was found that 75% of the predicted final cost aligned with the actual variance i.e. where the ANN model predicted an overrun/underrun, an*

overrun/underrun actually occurred. The prediction accuracy of ANN outperformed multiple linear regression.

- *Chau et al. (1997) used 8 key project management factors to predict the final cost of construction projects. It was found that more than 90% of the examples did not differ by more than one degree of deviation from the expected.*

- *Gunaydin & Dogan (2004) used 8 design parameters to estimate the square metre cost of reinforced concrete structure systems in low-rise residential buildings and found that the ANN provided an average cost estimation accuracy of 93%."*

These methods provide a single estimate of final cost. This research however is investigating the whole probability distribution of final cost and duration per a given contractor selection strategy. Cost estimates need to be reliable to effectively manage a project. **Section 3.3** looked at the different types of cost modelling. The traditional method of estimating cost which includes: Bills of Quantities, superficial method, and functional unit method are still popular amongst clients due to their ease of use (NBS, 2015). Furthermore, there are platforms established by RICS to help clients estimate the cost of projects based on comparable past projects. This method is like this research in that it looks at historic data to help predict final cost. The difference is that this research is not trying to predict the final cost of a project; rather to give the client the probability distribution of costs to expect. Furthermore, the research will assess the effect a strategy (low price versus best value) has on the outcomes of a project. To do this, the study had to examine past projects that have selected contractors on a particular strategy to see how they normally fare. We see this main difference in other cost models that were looked at in **Section 3.3**; studies have used regression analysis and artificial neural networks to predict cost using the same concepts of using historic data. The aim of these models was to accurately predict cost; however, the fact is that they are hardly accurate. For example, Lowe et al. (2006) study reported a best model performance of 19.3% Mean Absolute Percentage Error (MAPE). MAPE is a measure of prediction accuracy of a forecasting method in statistics. Kim et al. (2004) also reported a performance of MAPE 6.95%. While their MAPEs are enough to validate their research, the error might cost client hundreds of thousands of pounds depending on the size of the project; in other words, the MAPE does not tell us whether it is good or bad. Furthermore Tofallis (2015) study of the different measure of forecast accuracy found MAPE measure to be biased as it usually leads to predictions that are too low. When you compare Tofallis's conclusion to the reasons of overruns by Flyvbjerg (2008) and Cantarelli et al. (2010) in **Section 2.1**; MAPE would not help matters. It will only further encourage habits like optimism bias; overestimating benefits and underestimating costs. Therefore, the two-main difference of this research to other models and MCS studies are:

1. **It considered the strategy used to select a contractor. Therefore, it did not analyse past projects alone, but past projects and its adopted contractor selection strategy (lowest price or best value).**
    - Why? This is because the model is producing probability distribution of a project's likely outcomes given a contractor selection strategy (lowest price or best value). By solely analysing projects without considering the strategy, it would imply that the strategy used to select a contractor does not matter. In other words that the results the model would generate is the same for both the lowest priced contractor or best value contractor whose price is not the lowest price. Furthermore, by solely analysing projects without considering the strategy, the thesis does not differentiate itself from existing literature. In the existing literature, we see that researchers analysed a bulk of past projects in a specific sector to predict the cost of future projects in that sector. Thereby saying regardless of whether the contractor is the lowest tenderer or the best value tenderer, this is what the final cost will be. In this thesis however, instead of claiming the final cost/duration will be this, a probability distribution of final outcomes is given instead. Therefore, analysing projects that selected contractors on a strategy allows for the comparisons of strategies (lowest tender or best value tender).

2. **It is not aiming to predict the final cost and duration of a project, rather to predict the probability distribution of final outcomes (final cost and final duration) given a contractor selection strategy.**
    - Forecasts should be used as a tool to aid its users in deciding, not a tool that replaces the decision-maker. In a dynamic environment such as construction it is dangerous to rely on a tool that aims to predict an outcome. By predicting an outcome outright, this says to the client that there is no possibility that the outcome can come below or above the estimates. However, by generating a probability distribution of outcomes, not only are the clients able to know the likely outcome to expect, but they are also able to know the risks associated with that strategy.

3.4 MONTE CARLO SIMULATION

MCS is a tool that can quantify the effects of risk and uncertainty in project costs and duration, giving the project manager a statistical contributor of project performance. The models developed in the thesis are based on the Monte Carlo approach. This section of the thesis provided a brief history of the approach, its application across various disciplines including construction management, as well as the advantages and disadvantages of the method.

3.4.1. Brief History

Stanislaw Ulam, according to Eckhardt (1987), was credited as the inventor of this method especially in using computers to make the calculations when he was working on the US' Manhattan Project during World War II. Together with Jon von Neuman and Nicholas Metropolis, they transformed statistical sampling "*from a mathematical curiosity to a formal methodology applicable to a wide variety of problems.*" (Eckhardt 1987). Metropolis, according to Kwak (2009) was the one responsible for naming the methodology after the casinos in Monte Carlo, and subsequently went to publish a paper on the method in 1949 with Ulam (Metropolis and Ulam, 1949). Kwak (2009) gives a simple description of the model:

"A model or a real-life system or situation is developed, and this model contains certain variables. These variables have different possible values, represented by a probability distribution function of the values for each variable. The Monte Carlo method simulates the full system many times (hundreds or even thousands of times), each time randomly choosing a value for each variable from its probability distribution. The outcome is a probability distribution of the overall value of the system calculated through the iterations of the model."

3.4.2. Applications

MCS has undertaken successful studies in areas such as modelling complex systems in biological research, engineering, geophysics, meteorology, computer applications, public health studies, and finance. See Kwak (2009) for a detailed review of MCS across these disciplines.

3.4.2.1. Application in Construction

MCS studies in construction is generally mentioned in project management literature under the topic of risk management, schedule management, and budgeting (Kwak, 2009). Regarding project management, the Project Management Institute (2004) defines Monte Carlo as *"a technique that computes or iterates* *the project cost or schedule many times using input values selected at random from probability distributions of possible costs or durations, to calculate a distribution of possible total project cost or completion dates."* Here's Kwak's (2009) description on how Monte Carlo can aid in estimating project's cost and time:

"It aids the project manager in answering questions such as, "What is the probability of meeting the project due date?" and, "What is (say) the 90 percent confident project duration?"

In time management, Monte Carlo simulation may be applied to project schedules to quantify the confidence the project manager should have in the target project completion date or total project duration. Project manager and subject matter experts assigns a probability distribution function of duration to each task or group of tasks in the project network to get better estimates. A three-point estimate is often used to simplify this practice, where the expert supplies the most-likely, worst-case, and best-case durations for each task or group of tasks. The project manager can then fit these three estimates to a duration probability distribution, such as a normal, Beta, or triangular distribution, for the task. Once the simulation is complete, the project manager is able to report the probability of completing the project on any particular date, which allows him/her to set a schedule reserve for the project. The above can be easily completed using standard project management software, such as Microsoft Project or Primavera, along with Monte Carlo simulation add-ins, such as @Risk or Risk+.

In cost management, project manager can use Monte Carlo simulation to better understand project budget and estimate final budget at completion. Instead of assigning a probability distribution to the project task durations, project manager assigns the distribution to the project costs. These estimates are normally produced by a project cost expert, and the final product is a probability distribution of the final total project cost. Project managers often use this distribution to set aside a project budget reserve, to be used when contingency plans are necessary to respond to risk events."

Below are examples of application for this approach in construction:

- Wall (1997) collected 216 office building from the BCIS database of RICS to outline the issues that should be recognised when using Monte Carlo methods. The study concluded that lognormal distributions are superior to beta distributions in representing a data set. Furthermore, the result of this study shows that the effect of excluding correlations is more profound than the effect of choosing between lognormal and beta distribution to represent a data set.
- Clark (2001) details another example of a Monte Carlo application provided by the Honeywell Performance Polymers and Chemical, which used the tool to estimate contingency on 47 projects ranging from US$1.4 million to US$505 million. In this study "*contingency is be set at 50% probability level (median), based on the rationale*

that many projects make up the total annual budget, so cost variations on one may be offset by another project. This approach often yields a recommended contingency value of less than 5%, or zero for a well-defined project (Clark, 2001). However, for very large or strategic projects, an 80% or 90% probability level is chosen for contingency; and at a preliminary stage of a project, 95% is usually required." (Baccarini, 2005).

- Yang (2008) study developed an algorithm that automatically performs distribution free MCS when correlations between random variables must be accounted for.
- Panthi et al., (2009) study combined MCS with Analytical Hierarchy Process (AHP) to combine the risk distributions of various Bill of quantities items in hydropower construction projects. This resulted in a risk adjusted cost from which the contingency was determined.
- Wang et al., (2010) applied the MCS method to life cycle cost analysis with the help of @RISK software on Private Finance Initiative (PFI) to estimate total cost. The study found that the traditional model underestimated total costs by 6%.
- Moghaddam (2015) combined hybrid MCS and goal programming to develop a method for supplier selection and order allocation in closed loop supply chain systems.
- Peleskei et al., (2015) study reaffirmed that MCS can be a helpful tool for risk managers and can be used for cost estimation in construction projects. The study also found that cost distributions are positively skewed and cost elements seem to have some interdependent relationships.

3.4.3 Limitations and Criticisms

The MCS method is well documented as a helpful tool for construction project management applications, however Kwak (2009) points out that the method is hardly used by project managers in real world situation. There are now a plethora of software and hardware such as @RISK and MATLAB that could perform MCS for projects, but this was not the case before. Williams (2003) mentioned that one of the main drawbacks of this method is the fact that in the past, the method required high use of computing power and time and resources used to complete the simulation activity. Furthermore, that there was a lack of easy-to-use software tools to run complex simulation. However, it seems like the main reason for the lack of adoption of this approach is due to project managers' irritation with statistical approaches, lack of thorough understanding of the method, and it being perceived as a burden rather than a benefit when it was implemented heavily (Kwak, 2009). Bodea and Purnus (2012) also mentions that there are many probabilistic methods that have been developed through software implementation. However most of them are rarely applied due to the complexity of the methods, the level of expertise involved with applying the method, and the difficulties in collecting historic data. Finding an industry partner to release historic data for this research was also difficult. Hence the reason for using the BCIS database.

Another drawback noted by Panthi et al., (2009) was that some of the Monte Carlo models require a detailed quantitative information, which is not normally available during the initial planning stage of the project. Furthermore, that the applicability of such models to real project risk analysis is limited, because project participant find it difficult making precise decisions. Thus, their study combined a subjective model (AHP) to Monte Carlo to allow for subjective evaluations.

3.4.4 The Reasons for Monte Carlo Simulation

Despite the criticisms of the Monte Carlo method, the perception is that the main drawback to this method, according to Kwak (2009), is the statistical nature which presents a dilemma that project managers are keen to avoid. If this is the case with the Monte Carlo method, it is the case with all the other non-traditional methods listed in the earlier sections of the thesis. One way of tackling this is through training programs that demonstrate this simulation technique, however, there is even more doubt that project managers would agree to attend these programs anyway.

Another possible way of dealing with this dilemma is to start small; if indeed it is the statistical aspects that frightens them, models should be simplified as much as possible. The bulk of other Monte Carlo studies simulated the individual project task schedules and cost components, investigating the correlations between the components to produce estimate. This research did consider going the same route but instead decided to estimate the probability distributions of final costs and durations by analysing the tenders received for contracts. The idea of this developed model was to provide project managers like those referred to in Kwak (2009) what they want, not statistics, but final outcomes in numbers that they can understand. Obviously, methods used to develop the model had to be explained in the thesis, and it was explained in the next chapter. But the main job of a project manager/client is not to learn how to develop models, it is the subsequent duty of the researcher to develop the model and present it in ways that will assist the project manager/client.

This research study involved seeing what the likely effect a contractor selection strategy: either lowest tender or best value, had on the outcome of a construction project. Therefore, the model is not trying to accurately predict or even predict the final cost or duration of the project. The model is a decision support tool that provide clients with all the possible cost and duration possible with a given strategy; in order to assist them in deciding on which strategy to select. Furthermore, by knowing all the possible cost and duration, it will allow clients allocate the necessary reserves that will enable them be agile enough to deal with unforeseen circumstances. This would not be possible with other estimating models, which insist on predicting a definite final cost.

Another reason for using the Monte Carlo method for this study was because it could be extended to other sectors in the construction industry and to other industries in general. It was mentioned earlier that Quality is a subjective term that means something different to different people. The idea was to develop a model that will be able to accommodate each business organisations' definition of quality on the assumption that it can be quantified.

3.5 SUMMARY

This chapter provided details of the research approach adopted in the thesis; including the reasons for adopting this approach. Then the simulation framework that structured the modelling aspect of the research was then detailed, followed by all the possible frameworks that could have been used to carry out the research. Finally, an overview of MCS method was then provided; this included some of its applications in construction research, the potential drawbacks of the method, and the reasons for conducting the study with this method.

Figure 3.2.1 outlined that the research study will adopt a quantitative approach using MCS to investigate the effect a strategy has on the outcomes (final cost and duration) of a construction project. However, as this research is not advocating for one strategy over another, it cannot be viewed as a purely positivist research. The research would investigate the probability distribution of possible outcomes involved with going for a strategy, not to predict the outcome. Therefore, whatever strategy the clients decide to adopt is up to them, meaning that the results cannot be considered law-like generalisations. Clients would likely interpret the findings differently.

Furthermore, this chapter mentioned the complexity in choosing quality as a parameter for project performance in this study. As there was no universal standard of quantifying quality, the quality parameter could not be used for this study.

In the subsequent chapter, the simulation framework design presented in this chapter was applied using 120 Educational facilities projects, all of which selected the lowest tender. Again, the main modelling techniques was MCS, which was conducted with MATLAB R2014b. Microsoft Excel was first used to analyse and extract the data needed from the 120 projects for the model. The simulation model was then developed to see the effects a contractor selection strategy has on the outcomes of a project and to assist clients in deciding on a strategy by providing all the possible cost and duration time. The next chapter, carefully went through the steps undertaken to build the model.

Chapter 4: PRESENTING THE MODEL

4.0 INTRODUCTION

The main aim of this research is to provide a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies. The purpose of this section is to present the simulation model, as well as the steps that went into developing the model. The research extracts information embedded in historical project data to build a model that can show a client the probability distribution of possible outcomes one can expect if it decides to go for a contractor selection strategy: lowest tender or best value strategy. The concept is not to determine what the "best" strategy is but to determine the probability distribution of possible outcomes that could arise from any strategy.

As already identified in earlier chapters, contractor selection is not the only reason to a successful project outcome; therefore, there were considerations to make when analysing historic projects for this study. This section also offers a brief description of the data that was used for this model.

This chapter begins by offering a brief introduction of the modelling philosophy adopted in this research. Then there is a description of the data used for the modelling, including the steps that were taken to take into consideration that a contractor selection strategy is not the only reason why a project would be successful. This also includes the data processing techniques that were used to calibrate and validate the model. The model is not advocating one strategy over the other, rather to show clients the probability distributions associated with them. The purpose here is to present a model that will aid the tender evaluation process; this is not a tool that should be used autonomously to evaluate a contractor. One of the strengths of this model is that in cases where the results are largely expected, it can show if or when a strategy goes wrong and the probability of it going wrong. The term 'probability' is used throughout in its correct statistical sense. Which is any number between 0 and 1. So in this case **M** is the number of successful events and **N** is the number of events. Therefore, the probability will be **M** over **N** to the infinity.

4.1 MODELLING PHILOSPOHY

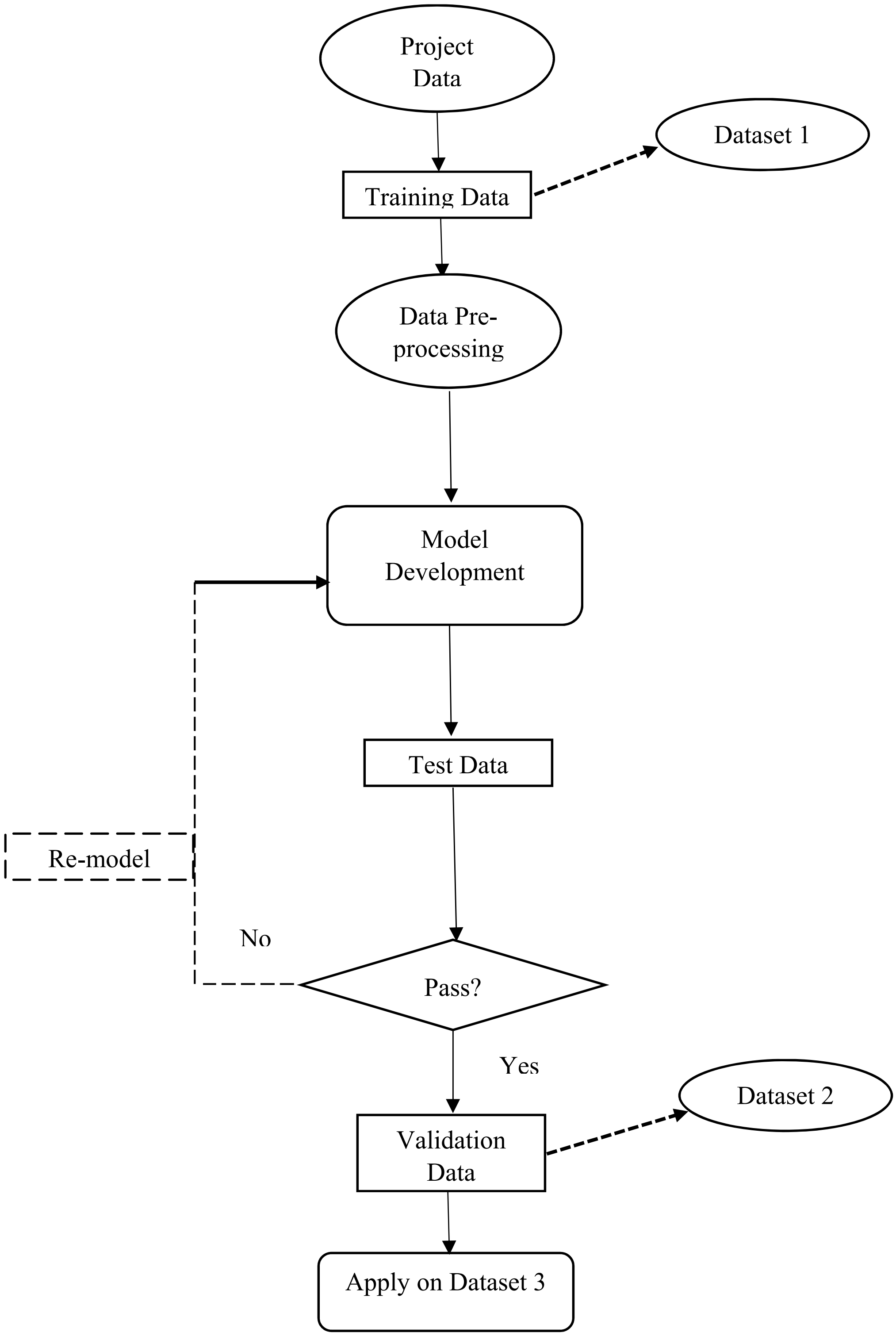
Williamson (2016) says that when a system resists direct study due to its complexity or the fact that it is hard to observe, modelling constitutes a key fall-back strategy. A model gives us an insight into the phenomena it models; in other words, they are reductions of reality. Models are generally presented in mathematical terms of different forms such as differential equations, statistical models, neural network and regression trees. When one model is replaced by another that captures more about how the phenomena work, science progresses (Williamson, 2016).

It has long been recognised that determining the probability density function for complex system is difficult to determine analytically. Simulation techniques have been developed to assist in this evaluation. This is particularly evident in water resources engineering. For example, when trying to evaluate the probability of failure of a complex water resources scheme, with direct supply reservoirs, river abstractions and complex ground water abstractions numerical models of the system are constructed and numerous simulations of different decision rules evaluated (see for example Korobova and Poizner, 1982). Simple simulations have been run using the historic record of rainfalls, river flows etc. but experience has shown that these often end up dealing with a single historic drought or flood event.

What is required are thousands of years of historic data that follows the patterns of hydrology seen today or forecast in the future. The area of Stochastic Hydrology was developed to supply this need (see Kottegoda 1980). The methods have been generalised over several years into the concept of MCS (see Oladeji and Elgy, 2012). Commercial companies like PanVera have developed the methods such as @RISK as add-ins to spreadsheets to make the tools more readily available to the practitioner. GoldSim is also another popular tool. There is also MATLAB, and Mathematica. Therefore, there were many software packages that could have been used for this study; all of which could have fairly carried out the study. The cost, flexibility and familiarity of use ultimately meant that MATLAB R2014b was used for the study.

The modelling in this research is carried out as structured in Figure 4.1.1. The developed model is summarised in Figure 4.2.4.1, in which further details will be provided later in the thesis. The MCS model for analysing the outcomes associated with a contractor selection strategy was developed from a dataset collected from the BCIS database (Dataset 1). The idea is to see how the lowest priced contractor would fare in projects that were awarded to the best value tender. Hence, the model developed from Dataset 1 was initially tested on recent projects that selected the lowest priced contractor (Dataset 2). Having achieved successful results, this model could then be applied on projects that selected the best value contractor (Dataset 3) to see how the lowest priced contractor would have fared. Each element of this dataset was created to calibrate, test, and validate the developed models. The aim of the modelling was to produce a model that could aid the tender evaluation process of a project; as well as show the probability distribution of outcomes expected by going with a strategy.

Figure 4.1.1: Modelling Procedure



4.2 THE DATA

The BCIS database harbours project data from different sectors in construction. These includes:

- Utilities, civil engineering facilities
- Industrial facilities
- Administrative, commercial, protective facilities
- Healthcare, welfare facilities
- Recreational facilities
- Religious facilities
- Educational facilities
- Residential facilities

It was important to select projects of the same nature to give a reliable representation of how projects usually fare in that sector. The reasons for choosing Educational facilities for this research are:

1. There is the increasing use of selective tendering generally; most of the projects collected from the BCIS database for this model used selective tendering, as well as the projects used to validate the model. Selective tendering involves having a preferred list of contractors and a client will usually select the one that offers the lowest price when a project comes up. In the process of searching for real project cases from industry players to validate the model, the best value strategy was hardly used. In most cases when it was used, the lowest tendered contractor turned out to be the best value contractor. Therefore, this research was important to this sector as a way of either validating common practice or as a nudge to reconsider strategies.

2. There were a few real recent project cases that could be used to validate the model, including few projects that selected on best value. A few of this project cases were yet to be completed by the time of developing the model.

It would have been preferable to have used a company's dataset to develop the model to be sure of project details such as the real reason why a project overran for example. In Chapter 2, it was mentioned that contractor selection is not the only reason for project success. In the BCIS database clients could name the reasons why the project overran, and sometimes this had nothing to do with the contractor. If the study was done using a company or multiple company data, the reasons could have been double checked. However, by working with the database, it could not. Therefore, this was mitigated by going with the reasons stated for overruns in the database. Projects with the following reasons for overruns were excluded from this research:

- Scope Added
- Design Changes
- Inflation/Relative Price Changes
- Exchange Rates

Again, the model was tested on recent double-checked projects to validate the model.

Dataset 1: 120 Educational facilities project cases, all of which selected the lowest tender, from the Building Construction Information Service database. These projects had a total contract value of over £270 million and completed between 2008 and 2015. A further 10 project cases from this database and from the same sector were used to initially test the model (see Figure 4.1.1).

Dataset 2: 20 recent Educational facilities projects, all of which selected the lowest tender from a consultant. 5 of these projects were still to be completed at the time of undertaken this study. These projects had a total contract value of over £68 million. The project outcomes were verified and was used to validate the model.

Dataset 3: 20 recent Educational facilities projects, all of which selected the best value tender, from two consultants and the BCIS database. These projects had a total contract value of over £74 million. This was used to apply the model and see how the lowest tenderer would have fared in these cases.

4.2.1 Data Pre-processing

Data pre-processing is an important step in the data process. Raw data is usually dirty; it is highly susceptible to noise, missing values, and inconsistency. The quality of the data influences results; a poor quality of data can produce misleading results. Pyle (1999) points out that raw data contains errors, outliers, wrong measurements or aggregate data. Therefore, to help improve the quality of the data, and subsequently of the results, raw data is pre-processed to improve the efficiency and ease of the process. Furthermore, this assures that the developed model is built right and is reliable (Pyle, 1999). The steps to this process can include cleaning the data or removing duplicate entries. It can also include transforming the data to suit the needs of the model. The data used in this research were pre-processed as follows:

4.2.1.1 Data Cleaning

Data cleaning is important as raw data can be incomplete, noisy, and inconsistent. This is usually the case when extracting data from a large, real-word database and data warehouses such as the BCIS database. The purpose of this study was to see how the lowest tendered contractor usually fared in its projects, therefore there was no room to take chances with incomplete data. For example, in the database there were cases where the lowest tender was said to be accepted, but the final cost of the project was missing. These kinds of projects were not used for this study to avoid bias. In dealing with inconsistency, majority of the projects in the Educational facilities sector was around £5 million; however, there were extreme cases of projects costing more than £20 million. Disregarding these cases however would fail to capture all the possible range of cases that may be encountered in practice. Therefore, the model's sensitivity to these extreme cases were tested on ten projects before deciding whether to include them in the final model. Noisy data, is usually human or computer errors occurring at data entry; for instance, in cases where there were decimal points in the wrong place. These were usually corrected and used in the model.

4.2.1.2 Data Transformation

The next step of data pre-processing used in this research was transforming the data into a specified range. The main issue here was that the clients' expected and actual duration were given vaguely; as months and weeks. So, assuming a project was completed in 8 months, was this exactly months? What if it was a few days shy of being 8 months? Therefore, the months and weeks were converted to working days using Excel; not to necessarily prove for example that it was exactly 8 months, rather to provide a consistent unit for the model. Furthermore, as it was unknown whether workers worked for a normal Monday to Friday shift, or during weekend; this was not provided in any of the data received. The assumption here was that workers worked Mondays to Fridays in each of the projects. The maximum working hours per week is 48 hours; which could of course be divided across 5 or 6 working days. Furthermore, workers can indeed choose to opt out of the 48 hours per week threshold. With educational facilities project, it is fair to assume that workers are likely to work Saturdays and even Sundays when students' disturbances are unlikely. However, the working days for this research is 5 (Monday to Friday) for the model as anything else would be an unjustified assumption given the nature of the data received. This was converted in excel and it was as follows:

$$\textbf{Working days in a week} = \mathbf{5}$$
$$\textbf{Weeks in a month} = \mathbf{4}$$

So, for example if duration is 5 months converting it to days in Excel is as follows:

$$\textbf{DAYS}(\textbf{end}_{\textbf{date}}, \textbf{start}_{\textbf{date}})$$

$$\textbf{DAYS}(31/\&5\&/2016{,}31/12/2015) = \textbf{152 days}$$

Now to convert this to working days, the assumption is that there are 8 days in a month where workers do not work.

$$\mathbf{152 - (8 * 5) = 112}\ \textbf{working days}$$

For projects given in weeks, a week contains 5 working days, therefore the number of weeks is multiplied by 5 to convert to working days. This allowed the model to capture a more detailed and realistic probability distribution of duration.

4.2.1.3 Data Reduction

To analyse a complex and huge amount of data takes time, and usually makes such analysis impractical and infeasible. Data reduction is not only helpful but necessary; this technique allows one to analyse a reduced representation of a dataset without compromising the integrity of the original data and at the same time furthering knowledge. This technique is basically reducing the volume of the data. The BCIS database carries projects that dates to the 1980s, analysing projects from that time may not have given an adequate picture of similar projects to date. For example, what inflation rate should be applied? Has technology changed? These are some of the questions one would have to consider. Therefore, this was shortened to projects between 2008 and 2015. Even so, this had to be reduced further, especially due to the data cleaning steps. It was reduced to 120 from 263, but as mentioned in the **4.2.1.1** Data Cleaning section, the model was tested on a further 10 projects from the dataset to know whether it captured the probability distribution of outcomes correctly. This would be expanded on in section **4.3**.

4.3 DEVELOPING THE MODEL

The outcome of any construction project consists of several components: The final outcome price, the quality of the finished product, any overrun on the project duration etc. All these are linked to the original tender price, the quality and reputation of the contractor and several random factors that can only be described in probabilistic terms such as bad weather, unforeseen ground conditions etc. Each of these components has a probability distribution associated with it and crucially correlated to the other components. As there is no universal way of judging quality, it was not used as a parameter for this research. However, for example there is the assumption that a high overrun cost is correlated with unduly low tender price (see Section 2.4; El-Abassy et al., 2013). This is not to say that every low tender will result in a higher cost and duration merely that it may be a tendency. The strength of the tendency is measured by the correlation between low tenders and the difference between the final cost of the project and the tender price (Diff). In simple terms, this can be expressed as the correlation coefficient, ρ. A simple equation will be used to generate a set of correlated random numbers

$(1)\ \mathbf{x} = \mathbf{A\eta}$

Where x is a vector of n correlated random numbers of mean zero and unit standard deviation, which will be rescaled later to produce tender prices, overrun costs and delay later. **A** is an $\mathbf{n*n}$ matrix of coefficients and $\boldsymbol{\eta}$ a vector of $\boldsymbol{\eta}$ independent random numbers to some distribution with zero mean and standard deviation of one.

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \cdots \\ x_n \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,3} & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & a_{2,3} & \cdots & a_{2,n} \\ a_{3,1} & a_{3,2} & a_{3,3} & \cdots & a_{3,n} \\ \cdots & \cdots & \cdots & \cdots & a_{1,1} \\ a_{n,1} & a_{n,2} & a_{n,3} & \cdots & a_{n,n} \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \\ \cdots \\ \eta_n \end{bmatrix}$$

The matrix **A** can be evaluated by taking moment and mathematical expectations as proposed by Matalas (1967).

Post multiply both sides of equation 1 by $\mathbf{x^t}$ gives

$$\mathbf{xx^t} = \mathbf{A\eta(A\eta)^t}$$

$(2)\ \mathbf{xx^t} = \mathbf{A\eta\eta^tA^t}$

If we take the expected values of these then the expected value of $\mathbf{xx^t}$ $\boldsymbol{E(xx^t) = E(A\eta\eta t\ A^t)}$.

$\mathbf{E(xx^t)}$ is the correlation matrix between all the values, **M**.

$$\mathbf{M} = \begin{bmatrix} \mathbf{1} & \boldsymbol{\rho}_{1,2} & \cdots & \boldsymbol{\rho}_{1,n} \\ \boldsymbol{\rho}_{2,1} & \mathbf{1} & \cdots & \boldsymbol{\rho}_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ \boldsymbol{\rho}_{n,1} & \boldsymbol{\rho}_{n,2} & \cdots & \mathbf{1} \end{bmatrix}$$

Since the η values are independent of one another their expected cross correlations are zero with the diagonal elements alters the variances of the elements, 1. This is the identity matrix I.

Any matrix pre-or-post multiplied by the identity matrix is unaltered therefore the expected values give.

$$(3)\mathbf{M} = \mathbf{AA^t}$$

Any matrix multiplied by its own transpose will give a symmetrical matrix and the correlation matrix is bound to be symmetrical. This means that there are effectively only $\mathbf{n(n+1)/2}$ independent variables in **A**. There are numerous ways to evaluate these independent variables, for example by assuming **A** is upper triangular or using the eigenvectors and eigenvalues of **M**. Since MATLAB has a function to do this this will be the function used.

It should be noted that if a negative eigenvalue is present in **M** the matrix **A** will not be entirely real but have an imaginary component. This is possible if there are inconsistent correlations in the matrix **M**. This happened with surprising probability when pair wise instead of case wise correlations was used to evaluate the correlations. The higher the n the more likely this inconsistency is likely to occur. The estimation of correlation coefficient between the components of the constructions projects proved tricky to estimate and some "tweaking" was required to ensure they were consistent. As Wall (1997, p248) rightly say:

"Establishing the strength of an empirical association between elemental rate variables is a relatively simple matter of using a statistical procedure from a computer program to calculate the correlation coefficient between the variables. It is much more difficult to determine whether the association found is generally reliable or whether it is a coincidence. The difficulties arise for at least three reasons. First, the variables are standardized and the standardization could introduce spurious correlations between elemental data; second, the data are imprecise) and the identified correlations could mean nothing; and third, the data show high variability and this could result in spurious correlations or the true correlations being distorted."

Table 4.3.1: Problem with correlation illustration example

Variable							
A	4		2	1	3	3	1
B	7	7	5			1	2
C		8	1	4	2		6

Table 4.3.1 presents an illustration of a problem that is usually common when dealing with multivariate statistics that has multiple variables; Table 4.3.1 would produce an inconsistent correlation as there are missing values in all 3 variables to be able produce a reliable dataset between A, B, and C. There were only 2 instances when a simultaneous data was received for all 3 variables at the same time. Fortunately, in datasets with many variables, groups of variables often move together. One reason for this is that more than one variable might be measuring the same driving principle governing the behaviour of the system.

In many systems, there are only a few such driving forces. But an abundance of instrumentation enables you to measure dozens of system variables. When this happens, you can take advantage of this redundancy of information. Principal Component Analysis (PCA) can reduce the dimensions of a data set. It reduces the data down to basic components, removing any unnecessary parts. This helps simplify the data and makes it easier to visualize. In this case one can simplify the problem by replacing a group of variables with a single new variable. In other words, the correlation was got to work by making minimum possible changes to the correlations to make them consistent. Consistent taken to mean, that all the eigenvalues of the correlation matrix are positive.

When there is a set of data points, the set can be deconstructed into eigenvectors and eigenvalues. Eigenvectors and eigenvalues exist in pairs: every eigenvector has a corresponding eigenvalue. An eigenvector is a vector whose direction remains unchanged when a linear transformation is applied to it. Therefore, if $\boldsymbol{T}$ is a linear transformation from a vector space $\boldsymbol{V}$ over a field $\boldsymbol{F}$ into itself and **v** is a vector in $\boldsymbol{V}$ that is not the zero vector, then **v** is an eigenvector of $\boldsymbol{T}$ if $\boldsymbol{T}$ **(v)** is a scalar multiple of **v**.

$$\boldsymbol{T}(\boldsymbol{v}) \ = \boldsymbol{\lambda v}$$

An eigenvalue is a number, telling you how much variance there is in the data in that direction where λ is a scalar in $\boldsymbol{F}$ associated with the eigenvector **v**.

If $\boldsymbol{V}$ is finite-dimensional, then $\boldsymbol{T}$ can be represented as a square matrix $\boldsymbol{A}$, and the vector **v** by a column vector. The above mapping will then be a matrix multiplication on the left-hand side and the scaling of the column vector on the right-hand side in the equation

$$\boldsymbol{A}(\boldsymbol{v}) \ = \boldsymbol{\lambda v}$$

See Aldrich (2006) for eigenvector and eigenvalue formula.

Nering (1970, p.38) points out that there is a correspondence between $\boldsymbol{n}$ by $\boldsymbol{n}$ square matrices and linear transformations from an $\boldsymbol{n}$-dimensional vector space to itself. Therefore, it is like define eigenvalues and eigenvectors using either the language of matrices or the language of linear transformation.

An eigenvector that corresponds to a real non-zero eigenvalue, points in a direction that is stretched by the transformation and the eigenvalue is the factor by which it is stretched. If the eigenvalue is negative, the direction is reversed (Burden and Faires, 1993, p.401). The eigenvector with the highest eigenvalue is therefore the principal component. See Jackson (1991) and Jollife (2002) for further information on PCA. Also see Herstein (1964) and Nering (1970) for further information on eigenvector and eigenvalues. Getting the correlation right was the first and most important step in developing the model, the next step was to determine the distribution.

Though no probability distributions were assumed for $\mathbf{x}$ or $\boldsymbol{\eta}$, Quenouille (1957) showed that the estimates were maximum likelihood estimates when $\mathbf{x}$ and $\boldsymbol{\eta}$ were normally distributed. It is possible to determine the distributions of $\mathbf{x}$ and $\boldsymbol{\eta}$ by fitting the model to the observed data and examining the resultant distributions. However due to the small sample size, distributions were difficult to determine. Due to the small number of samples, common distributions such as normal and lognormal (additive and multiplicative errors respect) make sensible choices with the parameters estimated from the sample data. Furthermore, this is supported by Graves (2001; mentioned in Section 3.2.2.3) who discussed different probability distributions that can be used for projects. Graves (2001) proposed using open-ended distributions, especially the lognormal distribution instead of a close-ended one such as the triangular distribution. The reason behind this is the fact that a close-ended distribution such as the triangular has a minimum and maximum limit; using this distribution in a construction project assumes that a project would never go beyond those limits. This is not a realistic assumption when it comes to real world projects, as there are unforeseen issues that were hardly expected which can cause problems in the project. Therefore, for this research the normal and lognormal distributions were the two considered; see Graves (2001) for further information on different types of probability distributions.
The Normal (or Gaussian) distribution is the most common distributed function. The notation $X \sim N(\mu_X, \sigma_X^2)$ denotes that X is a normal random variable with mean μ_X and standard deviation $\boldsymbol{\sigma_X^2}$. The standard normal random variable, Z, or "z-statistic", is distributed as $\boldsymbol{N(0, 1)}$.

The probability density function (PDF) of a standard normal variable has its symbol φ (z):

$$\boldsymbol{\varphi(z) = \frac{1}{\sqrt{2\pi}} e\left(-\frac{z^2}{2}\right)}$$

A normally distributed random variable can be characterised in terms of the standard normal random variable, through the change of variables

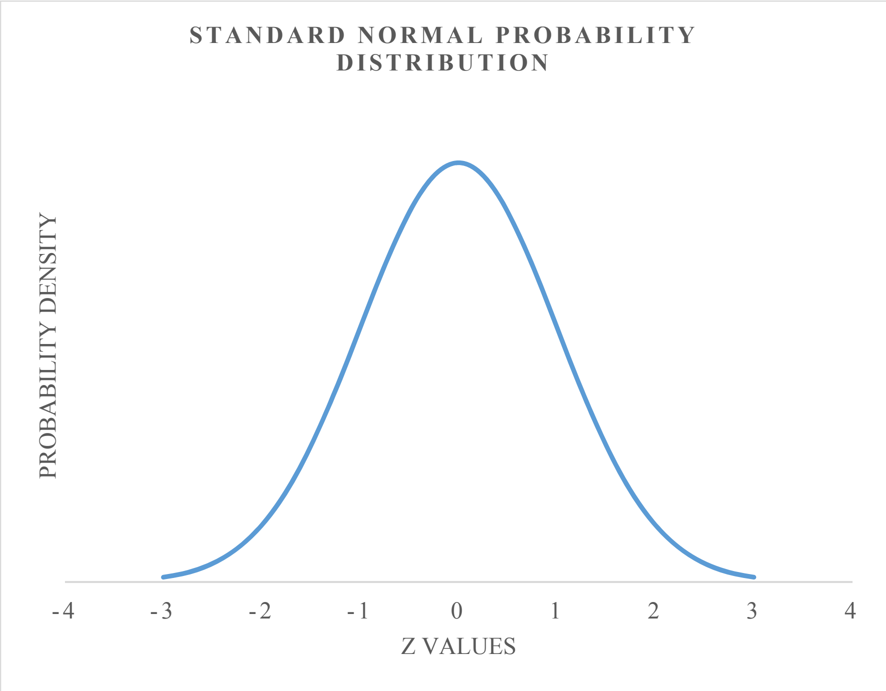
$$\boldsymbol{X = \mu_X + Z\sigma}.$$

If X is normally distributed, it has the PDF

$$\boldsymbol{f_x(x) = \varphi\left(\frac{x - \mu_X}{\sigma^2}\right) = \frac{1}{\sqrt{2\pi\sigma_X^2}} e\left(-\frac{(x - \mu_X)2}{2\sigma_X^2}\right)}$$

See Engineering Statistics Handbook (2013) for normally distributed formula.

Figure 4.3.1: An Illustration of a Normal Distribution



From Figure 4.3.1 we see that a normal distribution is symmetric and will produce both positive and negative values regardless of the value of the mean and standard deviation of a dataset. However, in construction projects, sometimes having a negative value makes no sense; therefore, using a distribution which admits only positive values will eliminate any possibility of unrealistic negative values. The lognormal distribution is appropriate for this. In this case: $In\ X \sim \boldsymbol{N}(\mu_{\boldsymbol{ln\ X}}, \boldsymbol{\sigma_{ln\ X}}$ then X is lognormal.

The PDF is:

$$\boldsymbol{f_x(x) = \frac{1}{x\sqrt{2\pi\sigma^2}} e^{-}\left(\frac{(ln\ x - \mu)^2}{2\sigma^2}\right)}$$

The mean and standard deviation of a lognormal X are related to the mean and standard deviation of $In\ X$ with mean being

$$\mu_{\boldsymbol{ln\ X}} = \boldsymbol{ln}\mu_X - \frac{\boldsymbol{1}}{\boldsymbol{2}}\boldsymbol{\sigma^2_{ln\ X}}$$

While the standard deviation being:

$$\sigma^2_{ln\,X} = ln + \left(1 + \ (\sigma_X/\mu_X)^2\right)$$

See Harvey et al. (2016) for further information on Probability Distributions. See Engineering Statistics Handbook (2013) for lognormally distributed formula.

Figure 4.3.2: An Illustration of a Lognormal Distribution

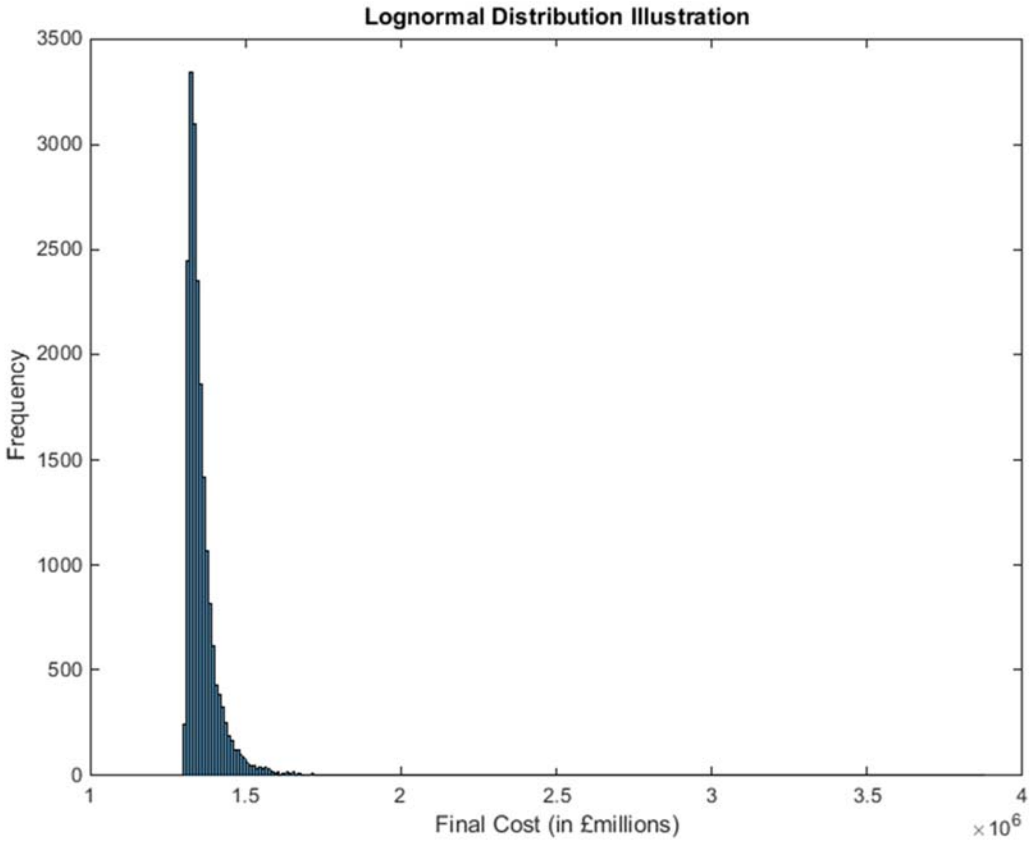


Figure 4.3.2 shows an example of a lognormal distribution positively skewed; the distribution can also be negatively skewed. The lognormal distribution represented the best possible distribution for the dataset used in the research study. In Section 4.3.2, Tables 4.3.3 and 4.3.4, and Figures 4.3.7 and 4.3.8 show that the outcomes of the projects analysed were positively skewed. Which means that the project outcomes were usually within the range of expected outcomes, however there were some outliers. Using a lognormal distribution for this model allows us to know when things can go wrong in a project and the probability of it happening. The next section would explain the code used to develop the model.

4.3.1 Implementation of the Model

This section will thoroughly explain the code used in the model. The aim of the research is to see how the lowest tender would fare in a project awarded to the best value tender whose price is not the lowest price. Project 4 of Dataset 2 (section 4.3.3) will first be used to explain the first phase of the model. Table 4.3.2 shows the number of contractors that tendered for the project and their tender prices. The last column shows the client's expected duration for the project. The model MATLAB code in its entirety will be displayed first. Then there will be a description of each part of the code.

Table 4.3.2: Project 4 Tender

	A	B	C	Expected Duration (days)
4	£984,633.15	£1,215,632	£1,425,365	89

```
%model to determine final costs and duration for lowest bid tenders
%The model produces 3 components for a tender quote: The price; related to
%the sample inputs, the difference between the final cost and the
%lowest bid index (diff), and the duration index
%as a normal standardised random variables.
%These indices will be converted to prices later.

%A final tender price is made up of the following components:
%Input variables are:
%Bid prices
%and a correlation matrix showing the correlations between price, the
difference between the final cost and the
%lowest bid index, and a duration index
%Output will be a matrix of final cost (FC), the difference between the final
cost and the 2nd
%lowest bid (diff), and a duration


%Now load the variables

%Now load the varibles
data= xlsread('P4.xlsx'); %load from excel document
bidpice = data(1:3);
lowest = data(1);
duration = data(6);
o=mean(data(1:3));
p=std(data(1:3));
y1= 0.036738;
y2=0.043266;
y3=o*y1;
y4=o*y2;
n1=0.023;
n2=0.0827;
```

```
n3=n1*duration;
n4=n2*duration;

%select the number of realisations

realisations = 20000;

%find mean and std for bidprice:

m=exp(1/2);
s=m*(exp(1)-1)^.5;

% rhoTQ - the correlation between tender and overrun prices
% rhoTO - the correlation between tender price and overrun time
% rhoQO - the correlation between Overrun price and Overrun time

rhoTQ = 0.57;
rhoTO = -0.02224;
rhoQO = 0.021491;



correl= [1,rhoTQ,rhoTO;rhoTQ,1,rhoQO;rhoTO,rhoQO,1];
% note - check that the correlation matrix is consistent before getting here


A=sqrtm(correl);% The key function correl=AA'

%for 7 different cases generate the likely values

for i=1:3
% for each different realisation generate the prices, diff, and duration.

    for j=1:realisations
        neta= (lognrnd(0,1,3)-m)/s;% 3 standard lognormal random numbers
required
        x=A*neta; %x are the standardised correlated lognormal value
        outputs(i,j,1)=x(1)+lowest;% fill up the outputs matrix. The first
one are prices
        outputs(i,j,2)=x(2)*y4+y3; %These are indices at the moment. Diff
        outputs(i,j,3)=x(3)*n4+n3;  %These are indices at the moment.
Duration
        outputs(i,j,4)=outputs(i,j,1)+outputs(i,j,2);
    end
end
 for j=1:realisations
%find the price of each tender as if it the sum of the components (FC)mean
     BP=outputs (i,j,1);
     FC(j)= outputs(i,j,4);
     Q(j)=outputs(i,j,2);
 end
 %put total prices into that matrix.
 for j=1:realisations
     BP(j)=outputs (i,j,1);
     FC(j)= outputs(i,j,4);
     delay(j)=outputs(i,j,3);
```

```
    actualduration(j)= duration + delay(j);
end
%ignore the others for a while
```

4.3.1.1 Model description

```
%model to determine final costs and duration for lowest bid tenders
%The model produces 3 components for a tender quote: The price; related to
%the sample inputs, the difference between the final cost and the
%lowest bid index (diff), and the duration index
%as a normal standardised random variables.
%These indices will be converted to prices later.

%A final tender price is made up of the following components:
%Input variables are:
%Bid prices
%and  a  correlation  matrix  showing  the  correlations  between  price,  the
difference between the final cost and the
%lowest bid index, and a duration index
%Output will be a matrix of final cost (FC), the difference between the final
cost and the 2nd
%lowest bid (diff), and a duration

%Now load the variables
```

The above is a description of what the model does.

```
data= xlsread('P4.xlsx') %load from excel document
bidpice = data(1:3);
lowest = data(1);
duration = data(4);
```

The first stage was to get the model to identify the tenders, the lowest tender, and the client's expected duration. Table 4.3.2 reminds us of Project 4's tender prices and client's expected duration, which selected Contractor A.

```
o=mean(data(1:3));
p=std(data(1:3));
```

Next, was to get the model to find the mean and standard deviation of the tender prices.

```
%Find mean and standard deviation of overrun cost and delay
y1=;
y2=;
n1=;
n2=;
```

The next step was to calculate the mean and standard deviation of the ratio between the initial tender price and final cost of all 120 projects; $\boldsymbol{y1}$ is the mean, while $\boldsymbol{y2}$ represents the standard deviation. The first step to this is to calculate the overrun cost in all the project. This is because all the projects are of different values, and this needs standardising.

$$\boldsymbol{Overrun\ Cost = Final\ Cost - Tender\ Bid}$$

Then we divide the $\boldsymbol{Final\ Cost}$ by the $\boldsymbol{Overrun\ Cost}$

$$\boldsymbol{Ratio = \frac{Overrun\ Cost}{Final\ Cost}}$$

Then the mean and standard deviation is calculated

$$\boldsymbol{y1 = \sum \frac{Ratio_{120}}{120}}$$

$$\boldsymbol{y2 = sqrt\left[\sum \frac{(Ratio_{120} - y1)^2}{120 - 1}\right]}$$

This same principle is then repeated to find the mean and standard deviation of Delay in all 120 projects; with $\boldsymbol{n1}$ representing the mean, while $\boldsymbol{n2}$ represents the standard deviation.

$$\boldsymbol{Delay = Actual\ Duration - Expected\ Duration}$$

Then we divide the $\boldsymbol{Actual\ Duration}$ by the $\boldsymbol{Delay}$

$$\boldsymbol{Ratio = \frac{Delay}{Actual\ Duration}}$$

Then the mean and standard deviation is calculated

$$\boldsymbol{n1 = \sum \frac{Ratio_{120}}{120}}$$

$$\boldsymbol{n2 = sqrt\left[\sum \frac{(Ratio_{120} - n1)^2}{120 - 1}\right]}$$

```
y3=o*y1;
y4=o*y2;
```

The next step was to scale the value of the tenders to the appropriate cost size. In doing so this will determine right the mean and standard deviation of overrun cost that Project 4 can expect to incur as it chooses the lowest tender. In this case $\boldsymbol{y3}$ represents the mean, while $\boldsymbol{y4}$ represents the standard deviation.

```
% rhoTQ - the correlation between tender and overrun prices
% rhoTO - the correlation between tender price and overrun time
% rhoQO - the correlation between Overrun price and Overrun time
```

```
rhoTQ = 0.57;
rhoTO = -0.02224;
rhoQO = 0.021491;

correl= [1,rhoTQ,rhoTO;rhoTQ,1,rhoQO;rhoTO,rhoQO,1];
% note - check that the correlation matrix is consistent before getting here
A=sqrtm(correl);% The key function correl=AA'
```

Then the correlation derived from the 120 projects are inputted into the model at this stage. The correlations were between three variables:

- Tender Price (which is always the lowest tender, T)
- Overrun Cost (Diff or Q)
- Delay (O)

```
for i=1:3
% for each different realisation generate the prices, diff, and duration.
 realisations = 20000
```

The model is then reproducing the tenders received for Project 4 20,000 times. It assumes that the project is being conducted 20,000 to get more stability and reproducibility in results. The model is simulating 20,000 realisations of the same tender as if they could occur now. This is to get a distribution of the likely outcomes and not a single realisation of the stochastic event.

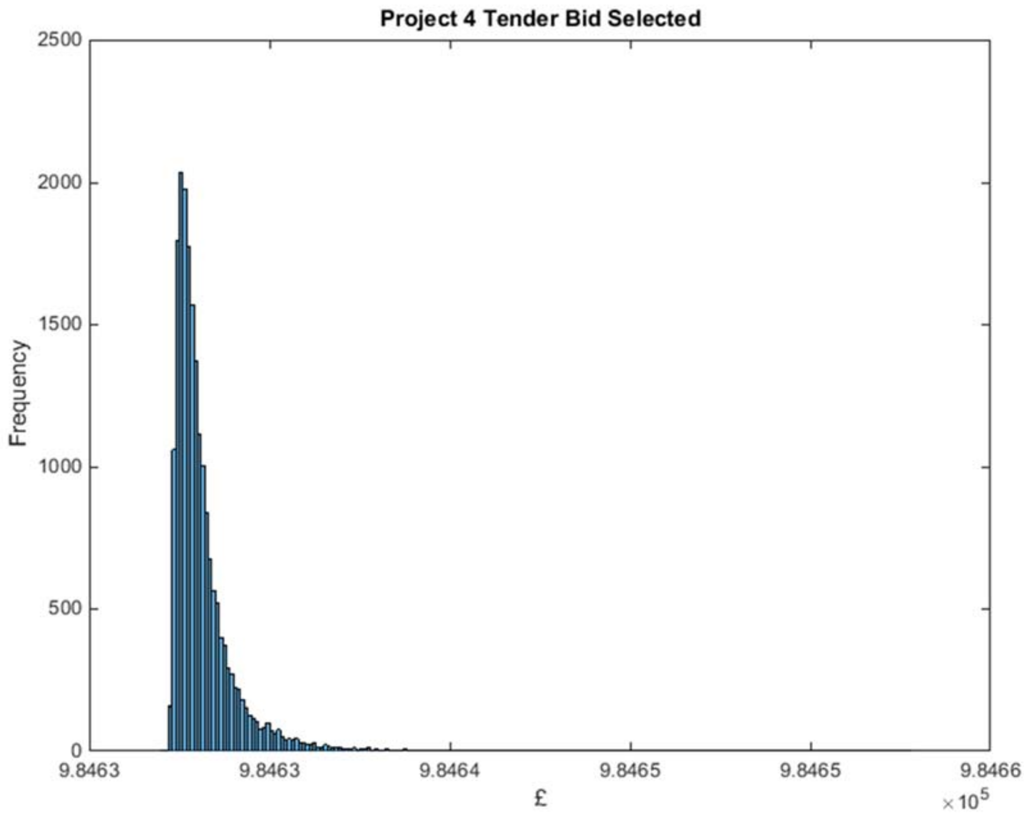
```
m=exp(1/2);
s=m*(exp(1)-1)^.5;

for j=1:realisations
        neta= (lognrnd(0,1,3)-m)/s;% 3 standard lognormal random numbers
required
        x=A*neta; %x are the standardised correlated lognormal vlaue
```

The model is then instructed to produce the distributions lognormally of all the three variables: Tender Price, Diff, and Delay.

```
outputs(i,j,1)=x(1)+lowest;% fill up the outputs matrix. The first one are
prices
```

The first variable coming through are the standardised indices tender prices. These are then correctly formatted by instructing the model to always pick the lowest tender for all 20,000 realisations; which has already been identified right at the beginning. Therefore, Contractor A tender of £984,633.15 is selected every time.

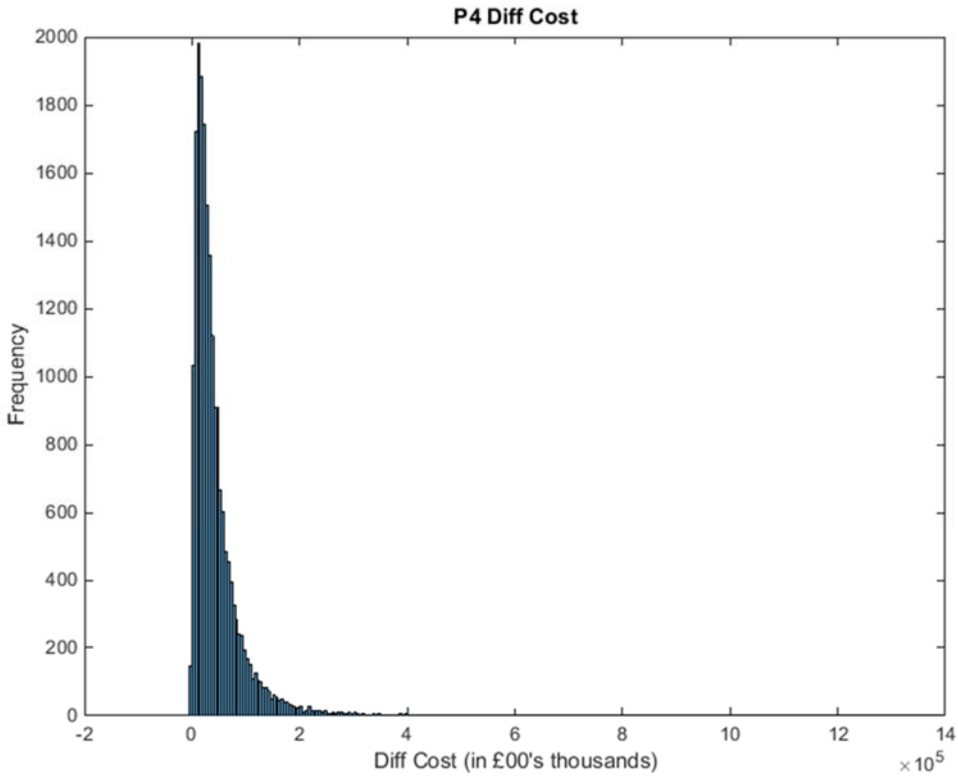
Figure 4.3.3: Project 4 Tender Bid Selected




```
outputs(i,j,2)=x(2)*y4+y3; %The 2nd are of Diff
```

The second variable are for diff; these are formatted by multiplying the indices by the standard deviation of overrun cost to expect for Project 4, $\boldsymbol{y4}$ and adding it to the mean overrun cost to expect for Project 4, $\boldsymbol{y3}$. The probability distribution of diff cost can also be viewed.

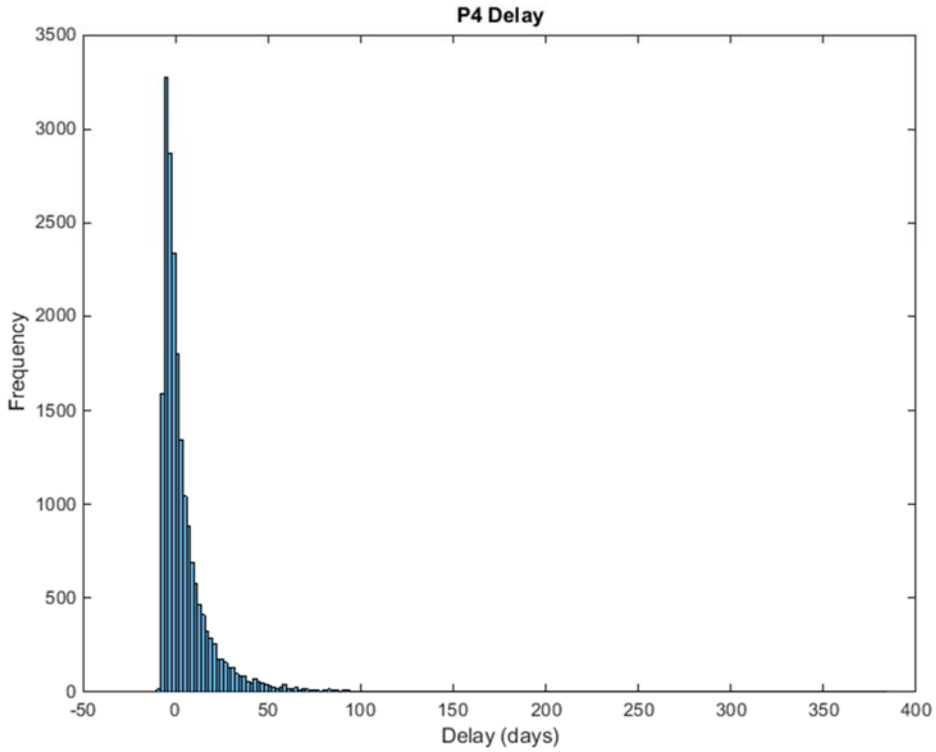
Figure 4.3.4: Project 4 Diff Cost




```
outputs(i,j,3)=x(3)*n4+n3; %The 3rd are of Delay
```

The third variable are for delay; these are formatted by multiplying the indices by the standard deviation of delay time to expect $\boldsymbol{n4}$ and adding it to the mean delay time to expect $\boldsymbol{n3}$ for Project 4. The probability distribution of delay can also be viewed.

Figure 4.3.5: Project 4 Delay

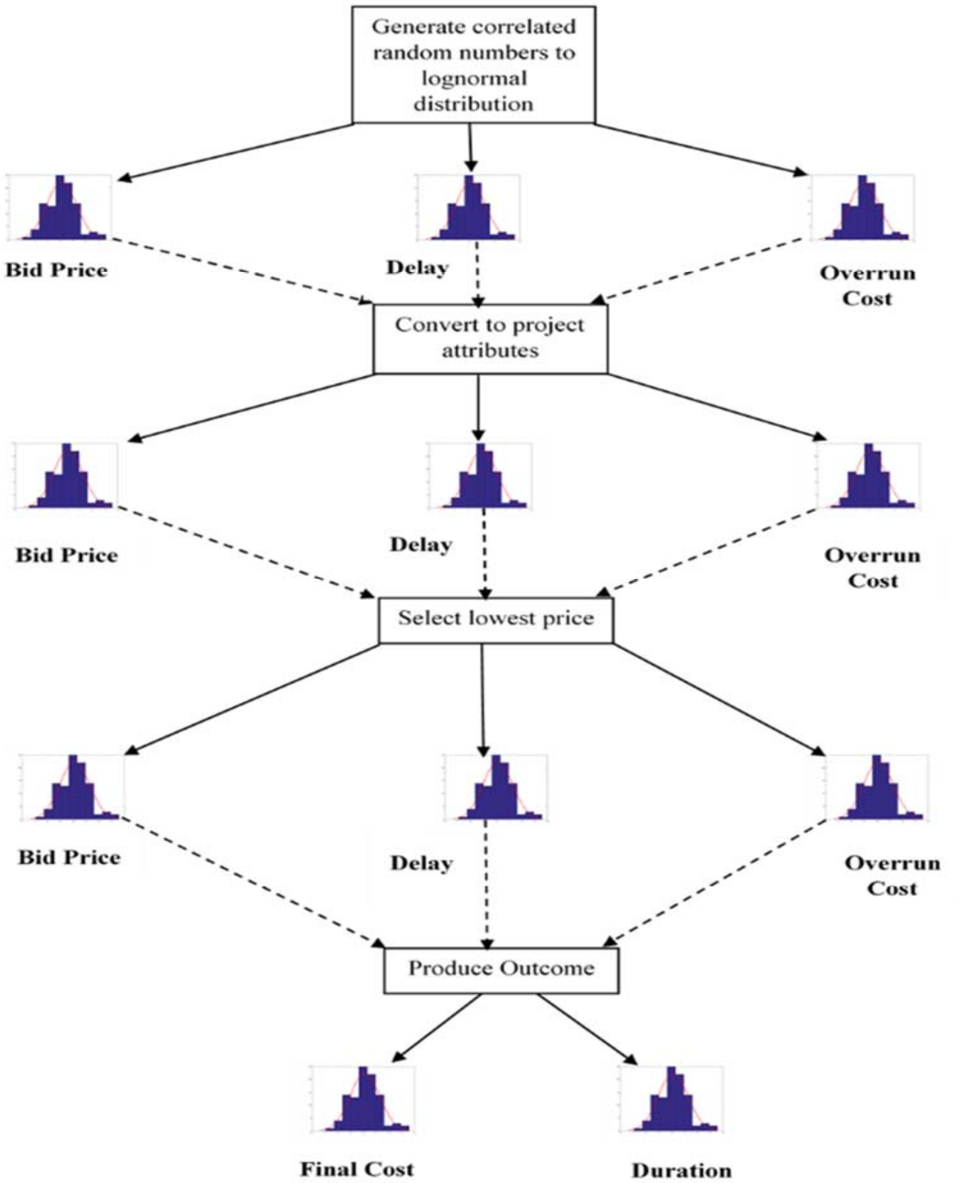



```
FC = outputs(i,j,1)+outputs(i,j,2);
Actualduration = duration + outputs(i,j,3)
    end
end
```

Finally, the model is instructed to find the final cost and actual durations to expect for Project 4. To find the final cost was to add the correctly rescaled 1st and 2nd variable; with the 1st variable being the lowest tender and 2nd being the overrun costs to expect. The same principle is then applied to find the actual durations to expect for this project by adding the client's expected duration which was already identified at the beginning of the model to the 3rd variable. The 3rd variable being the delay times to expect for the project.

As the model could capture the probability distribution of outcomes for the lowest tender selected contracts; first in the initial testing phase with Dataset 1 and then in the validation phase with Dataset 2, it could then be applied to Dataset 3. Dataset 3 again are projects that selected the best value contractor whose price is not the lowest price. This was done to see how the lowest tenderer would likely fare. Figure 4.3.6 depicts a visual summary of the developed model.

Figure 4.3.6: Summary of developed model



Note: *The histogram in* ***Figure 4.1.2*** *are illustrations generated randomly on MATLAB R2014b.*

4.3.2 Dataset 1

Dataset 1 was used to develop and test the MCS model. The Building Cost Information Service of RICS (BCIS) database was used to conduct this study. A total of 120 Educational facilities projects, all of which was awarded to the lowest tender, were analysed. Each project showed:

- Details of the contract awarded (the tendering method, tenders received from all the contractors that tendered for the project; companies were anonymous)
- Selection criteria; (lowest tender accepted)
- Project outcomes: initial tender price, final cost, the expected duration, and actual duration.

All 120 projects used the Traditional procurement method (see section 2.2.1), however the tendering methods (see section 2.2.2) were different:

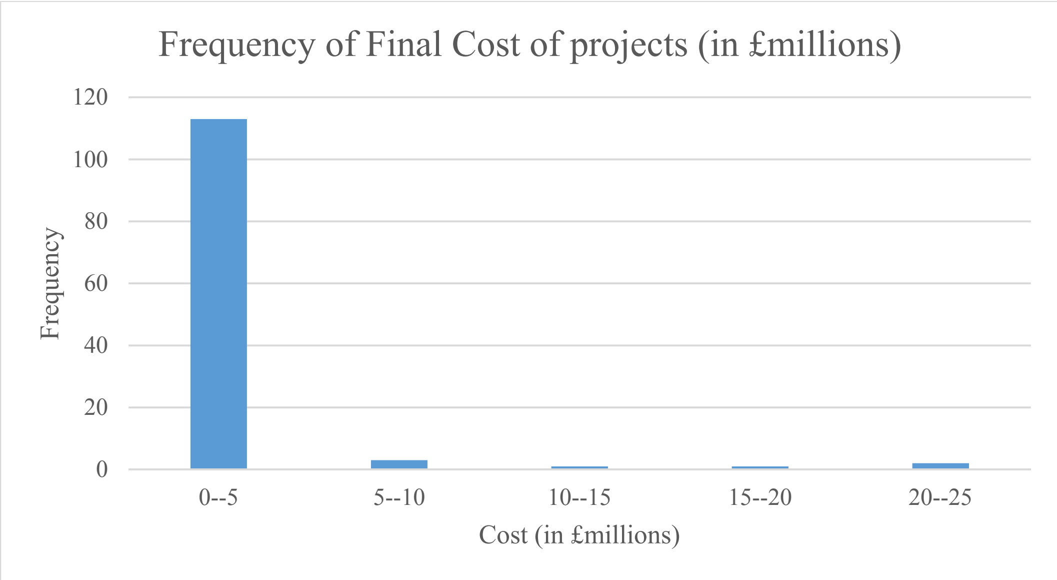
- **Single-stage Selective tendering**: 96 projects
- **Single-stage Open tendering:** 19 projects
- **Negotiating**: 5 projects

Therefore 120 projects were used for this model with most of the projects costing around £5 million. Table 4.3.3 and Figure 4.3.7 show the frequency of the final cost of projects.

Table 4.3.3: Final Cost Frequency (in £millions)

Final Cost (in £millions)	Frequency
0—5	113
5—10	3
10—15	1
15—20	1
20—25	2

Figure 4.3.7: Final Cost Frequency (in £millions)

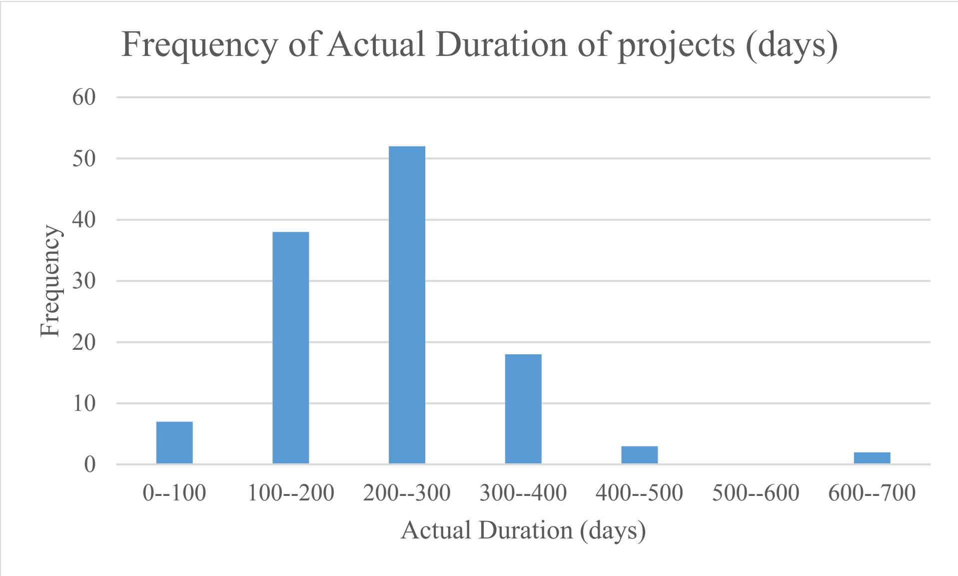


The duration of this projects varied, with the bulk of them completed within 400 working days. Table 4.3.4 and Figure 4.3.8 show the probability of the actual duration of projects.

Table 4.3.4: Actual Duration Frequency (in days)

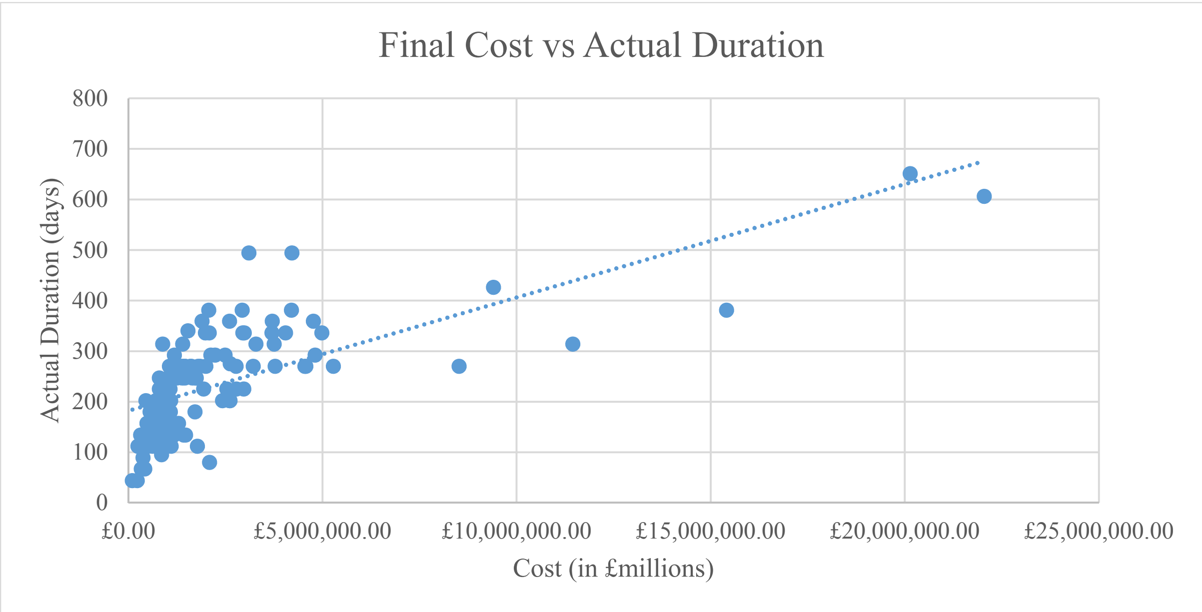
Actual Duration of projects (days)	Frequency
0—100	7
100—200	38
200—300	52
300—400	18
400—500	3
500—600	0
600—700	2

Figure 4.3.8: Actual Duration Frequency (in days)



One could assume that the higher the project cost the higher the duration, however a plot of actual duration versus final cost in Figure 4.3.9, does not appear to be show a linear relationship.

Figure 4.3.9: Actual Duration vs Final Cost



Furthermore **Figures 4.3.10** and **4.3.11** show a chart that plots the clients' expected outcomes against the actual outcomes.

Figure 4.3.10: Contract Value vs Final Cost

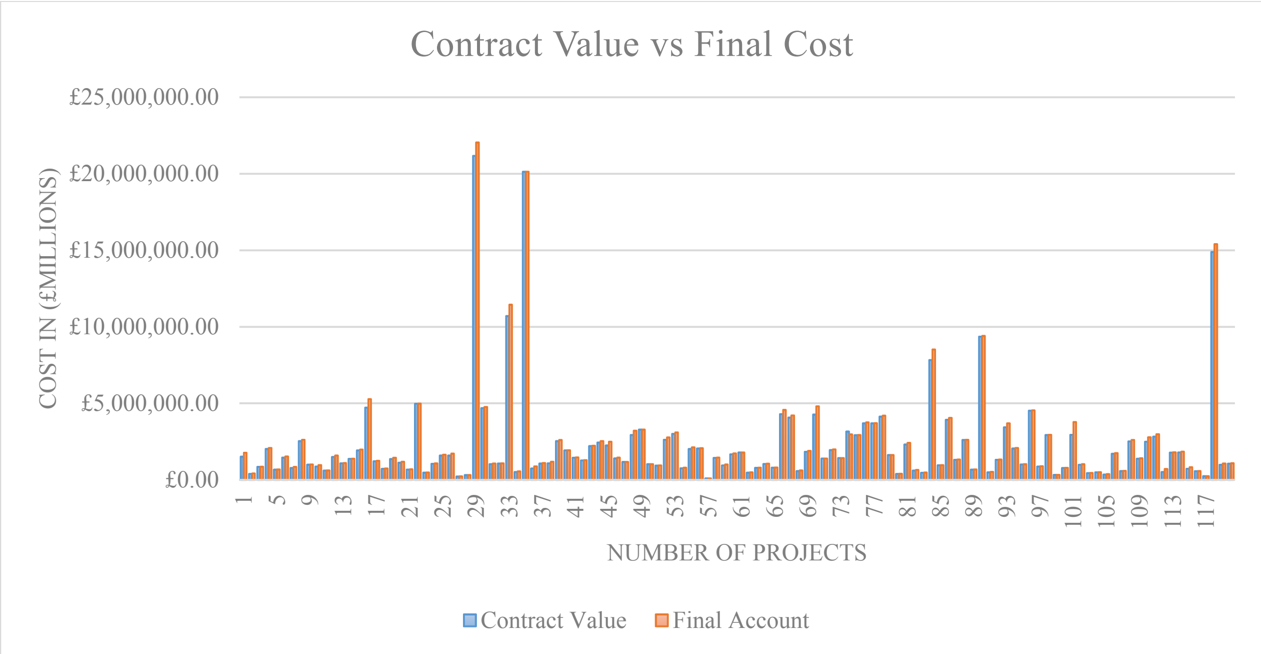
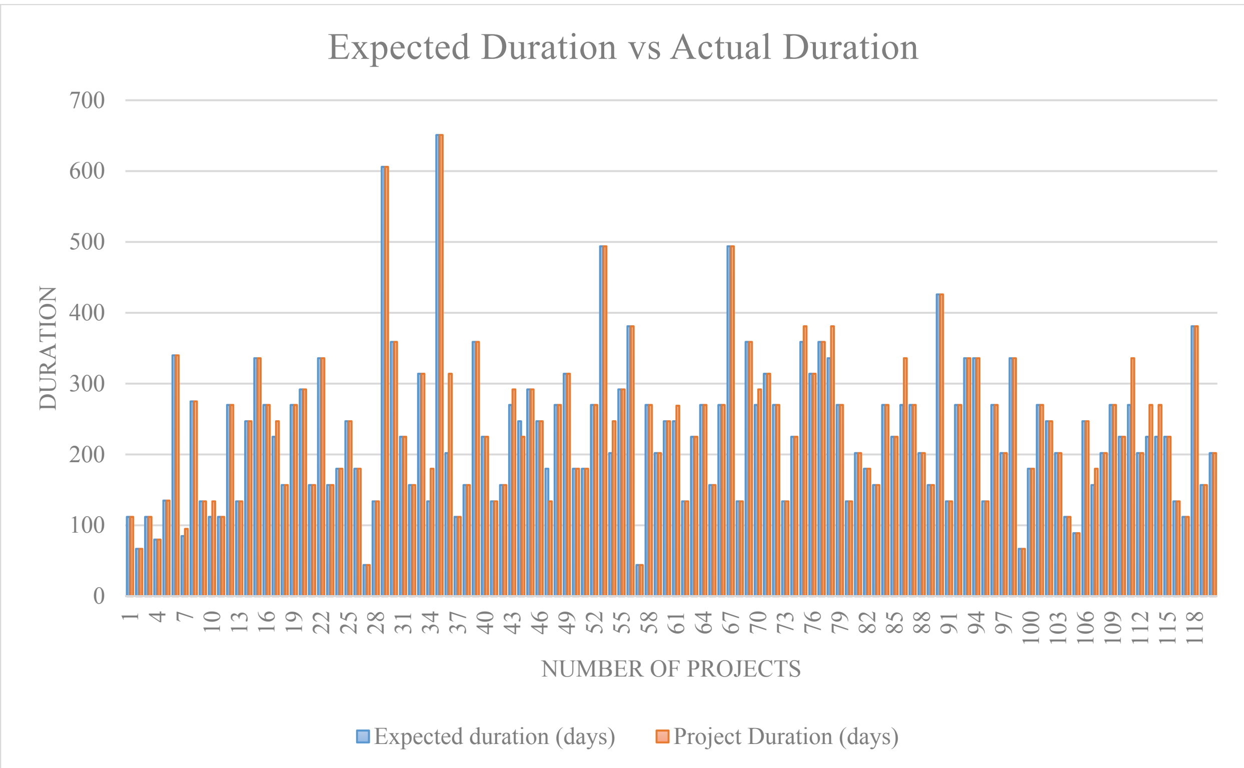


Figure 4.3.11: Expected Duration vs Actual Duration



From these Figures, the difference between clients' outcomes and project outcomes appears to be minimal. In other words, the lowest tenderer seems to have delivered quite in line with cost and time targets. The first step of the research was to use the findings in these projects to build the model. The next stage was then to test the model on 10 further Educational facilities project that selected the lowest tender from the database. The final outcomes of a project must be within the probability distribution of outcomes produced in the model to pass the training. Table 4.3.5 show the project cases that were used to initially test the model, with the tenders arranged in ascending order. While the Figures in Appendix 1, and Table 4.3.6 show the model and actual project results. The results in Appendix 1 will show that the final outcomes of these projects where within the probability distribution of outcomes produced from the model.

Table 4.3.5: Project cases for Model Testing.

	A	B	C	D	E	F	Expected Duration (days)
1	£1,309,236	£1,327,147	£1,330,990	£1,350,410	£1,397,686	£1,585,264	225
2	£954,426	£986,428	£1,065,237	£1,092,862	£1,154,428	£1,233,743	202
3	£607,107	£610,510	£611,573	£620,263	£622,677	£649,873	225
4	£810,000	£870,425	£875,785	£950,265			134
5	£407,255	£420,902	£450,178	£510,000	£512,000		67
6	£650,000	£667,000	£670,000	£685,000	£690,000		112
7	£204,000	£220,000	£224,635	£241,500	£252,500		44
8	£750,000	£777,500	£781,000	£835,532			112
9	£925,000	£978,736	£1,020,783	£1,200,000	£1,250,000		157
10	£1,725,357	£1,780,741	£1,827,148	£1,900,691	£2,225,221		247

Table 4.3.6: Actual Project Result

Project	Cost	Duration (days)
1	£1,331,236	247
2	£999,426	202
3	£638,271	225
4	£837,235	147
5	£422,125	75
6	£672,145	131
7	£211,000	44
8	£759,000	112
9	£936,000	157
10	£1,732,000	247

Again, the research is investigating how the lowest tenderer would fare in a contract awarded to the best value contractor with a higher price. Therefore, the model had to first be tested and validated with projects that awarded to the lowest tenderer. From the Model Results in Appendix 1 we see that the model captured the probability distribution of the final outcomes. The developed model is now ready to be validated with Dataset 2.

4.3.3 Dataset 2

As the model passed the test using Dataset 1, the model now had to be validated with Dataset 2. Dataset 2 is a set of 20 recent projects, all of which selected the lowest tender; with the tenders arranged in ascending order. The same principle used in selecting the projects to develop the model in section **4.3.2 Dataset 1**, was also applied in this dataset. Furthermore, as the data was from industry partners, the facts of the project could be double-checked. All 20 projects used the traditional procurement route, again the tendering methods differed.

Table 4.3.7: Tendering Methods for Dataset 2

Tendering Methods	Projects
Single-stage Selective	1,2,3,4,5,6,7,8,9,10 11,12,14,15,17,18,19, and 20
Single-stage Open	13 and 16

Table 4.3.8 show the project cases that were used to validate the model while the Figures in Appendix 2 and Table 4.3.9 show the model and actual results.

Table 4.3.8: Project cases for Model Validation

	A	B	C	D	E	Expected Duration (days)
1	£5,319,155.35	£5,613,917.77	£6,386,688			202
2	£2,085,239.76	£2,160,838.19	£2,290,031.02	£2,482,976.95	£2,564,364.13	89
3	£5,980,493.45	£6,065,465	£6,087,686	£6,190,328.30	£6,407,415	292
4	£984,633.15	£1,215,632	£1,425,365			89
5	£6,167,476	£6,544,768	£6,592,106.32	£6,679,425	£7,121,601	270
6	£1,519,214	1,699,619	£1,846,705.80			112
7	£953,572	£992,505.60	£1,302,560			180
8	£1,486,449.49	£1,500,060.74	£1,909,574.39			112
9	£2,787,622	£3,214,855	£3,364,044			270
10	£4,271,609.13	£4,399,151.17	£4,645,637.14	£5,416,261.42		225
11	£897,328.47	£929,598.99	£1,089,443			67
12	£396,162.86	£452,738.72	£467,824.25			67
13	£2,774,445.74	£3,029,624	£3,047,041			202
14	£1,900,000	£2,324,562	£2,752,842.17			112
15	£7,821,143.66	£8,718,245				292
16	£4,299,124	£4,414,468	£4,736,222	£4,795,316		134
17	£1,933,991	£1,938,227	£2,033,050	£2,037,620	£2,098,854	112
18	£2,747,847	£2,777,291	£2,914,958	£2,916,502		112
19	£855,182	£861,183	£862,143	£862,433	£869,138	89
20	£1,802,892	£1,835,219	£1,894,698	£1,918,792	£1,942,107	225

Table 4.3.9: Dataset 2 Actual Project Results

Project	Cost	Duration
1	£5,388,074	202
2	£2,162,406.45	89
3	£5,992,456	290
4	£1,002,408.14	89
5	£6,223,000	270
6	£1,561,325	112
7	£987,276.96	180
8	£1,521,456.78	134
9	£2,801,192	292
10	£4,271,609.13	247
11	£947,788.20	67
12	£424,278.97	89
13	£2,890,412.14	247
14	£1,929,352	112
15	£7,838,486	292
16	£4,418,642	178
17	£1,970,900	112
18	£2,813,591	134
19	£862,143	89
20	£1,814,892	225

The model captured the probability distribution of outcomes: both cost and duration of all 20 projects (see Appendix 2). Therefore, as the developed model was validated with a 100% mark, it could then be applied to Dataset 3; which is a set of project cases in Educational facilities that selected contractors on best value.

Dataset 2 was used to validate the model developed but the model was first tested in Dataset 1 to see whether it correctly predicted the probability distribution of outcomes of the lowest tenderer. Appendix 2 shows that the model captured the probability distribution of outcomes: both cost and duration of all 20 projects. These projects selected the lowest tender and from Table 4.3.7 we see that almost all of the projects in the dataset used single-stage selective tendering. Which can mean that there is a positive history between the client and contractor; a trust. Or, it can also mean that the contractor has undergone some pre-qualification and is seen by the client as suitable to execute the project. But just because a contractor is in a preferred list does not mean things will always go as planned. From Table 4.3.7 we see that 18 projects used the selective tendering method. In 5 out of the 18 projects that used the selective tendering method, the consultant cited the slow pace of construction and the scheduling of the construction programme as the reason for dispute. This ultimately led to cost and time overruns; these are Projects 8, 9, 12, and 18, Project 10 only incurred time overrun. 9 out of these 18 projects cited the quality of material as the reason for cost overruns (projects 1, 3, 4, 5, 6, 14, 15, 19, and 20). The lowest tenderers still managed to deliver on time in these projects. Finally, in the remaining 4 projects (2, 7, 11, and 17) the contractors claimed to have encountered an unexpected ground condition that resulted in cost overruns; while the consultant cited the contractor's lack of effective planning as the reason for cost overruns. Project 13 and 16 used the open tendering method, and it cited the slow pace of construction and scheduling of construction programme as the reason for cost and time overruns. Therefore, half of the selective tendering projects cited quality of materials as the reason for cost overruns, it meant that the old materials had to be replaced by tested ones. What this shows to clients and consultants with a preferred contractors' list, is that there must be regular assessment of contractors on those lists.

All the projects in Dataset 2 incurred cost and/or time overruns. On cost overruns, project 10's lowest tenderer delivered on cost but not on time. Furthermore in 12 out of the remaining 19 projects (1, 3, 4, 5, 6, 7, 9, 12, 13, 14, 15, and 20), though the lowest tenderer incurred cost overruns the final cost were still below that of the second lowest tender. 6 out of the 19 projects' final cost (2, 8, 11, 16, 17, and 18) were below the third lowest tender. While Project 19's final cost was exactly the third lowest tender. 77 out of 120 projects analysed in Dataset 1 delivered at a cost that was below the price of the second lowest tender. We are used to looking at cost overruns in percentages; analysis of Dataset 1 showed that the lowest tenderer in Educational facilities projects usually overran by 3%. In an ideal world, no client would want cost overruns. But we cannot really say how bad this 3% figure is. However, when we compare the projects' final cost to the other tenders received, we get a better idea of how bad the cost overrun is. **In Section 2.3**, Construction Excellence (2011) reported on how industry professionals wanted a reason for change i.e. selecting the best value contractor. Their argument was that what they are currently doing (selecting the lowest tender strategy) is working for them so there is little reason to change. Again, the research is not advocating one strategy over the other, but from the results of Dataset 2 it is difficult to argue for the use of best value strategy in terms of cost in Educational Facilities projects. Furthermore, it is more than likely that in most of these projects contractors would have undergone some sort of pre-qualification evaluation. Therefore, from validating the model on Dataset 2, 2 conclusions are drawn out:

1. **Selective tendering might imply that the client and contractor have a good history, or that the contractor has at least undergone some sort of pre-qualification that deem he/she qualified. However, regular assessment is needed.**
2. **Cost overruns are not always as bad as it seems especially when the cost is below the starting price of the next highest tender.**

4.3.4 Model on Best Value Contracts (whose price is not the lowest price, Dataset 3)

The model is now fit to be applied on projects that selected the best value contractor whose price is not the lowest price to see how the lowest tender would have likely fared if it was awarded the contract instead. There were difficulties in finding projects in these dataset, hence the reason why it was collected from multiple sources. These kinds of projects were rare; the 20 projects used from this dataset came from multiple sources which also included the BCIS database. The Design and Build procurement methods were used for these projects.

Table 4.3.10: Tendering Methods Dataset 3

Tendering Methods	Projects
Single-stage Selective	1,2,5,6,7,8,10,11,13,14,15,19, and 20
Single-stage Open	3, 9, 12, 16 and 17
Two-stage Open	4 and 18

The limitation in Dataset 3 is that contractors' quality scores were not given; the BCIS database do not include contractors' quality scores, and consultants that offered projects in this dataset did not reveal the scores due to its sensitivity. Another consultant that could provide 3 best value selected tender projects, all had the lowest tender as the best value tender and hence could not be used for the research. Therefore, it is possible for the lowest tender not to be suitable for the project in the first place, when a best value analysis is conducted; there might be a reason that may have disqualified the lowest tender. The assumption here is that all the lowest tenders in this dataset have at least passed the minimum threshold of clients' quality and can ultimately carry out the work respectably.

Table 4.3.11 show the tenders of projects who selected the best value tender whose price is not the lowest price; the highlighted (in red) column shows the tender selected in each project. Table 4.3.12 show the actual project results of best value tenderer and the most likely project results of the lowest tenderer. The Figures in Appendix 3 show the probability distribution of outcomes of how the lowest tenders in these projects are likely to fare and the actual project result of the best value tender.

Table 4.3.11: Best Value Project Cases

	A	B	C	D	E	F	Exp.(days)
1	£4,299,664	£4,343,931	£4,371,596	£4,447,081	£4,724,370	£5,017,168	292
2	£2,096,388	£2,108,776	£2,123,918	£2,206,340	£2,278,743		134
3	£261,778	£313,826	£328,959	£376,187			89
4	£3,837,781	£3,988,424	£4,700,177				200
5	£715,597	£743,247	£788,560				145
6	£665,844	£676,125	£678,799				130
7	£523,952	£543,113	£548,481	£589,857			130
8	£463,499	£465,301	£478,943	£484,459			120
9	£829,929	£838,961	£863,039	£864,821	£869,927		190
10	£738,177	£805,539	£811,132				100
11	£236,013	£248,254	£248,865	£262,251	£308,531	£318,290	65
12	£6,363,000	£6,483,183	£6,552,282	£6,736,394			270
13	£6,598,070	£6,808,821	£7,521,515				270
14	£264,184	£284,214	£298,129	£298,660	£307,877	£341,231	202
15	£864,810	£897,460	£912,145	£919,938	£938,706		247
16	£10,397,612	£10,582,000	£10,767,458	£10,805,894	£11,188,459	£12,144,742	343
17	£873,326	£969,078	£974,671	£989,102			95
18	£1,284,658	£1,360,450	£1,393,099	£1,447,250	£1,695,274	£1,912,660	134
19	£559,180	£569,171	£570,515	£584,380	£648,297		200
20	£314,525	£315,529	£316,430	£381,420	£404,050		112

Table 4.3.12: Actual Project Results

Project	Actual Final Cost of Best Value Tenderer	Duration of Best Value Tenderer	Average Final Cost of Lowest Tenderer (from model)	Average Duration of Lowest Tenderer (from model)
1	£4,371,596	292	£4,467,600.00	299
2	£2,123,918	134	£2,175,500.00	137
3	£343,200	89	£273,500.00	91
4	£3,965,134	200	£3,991,500.00	204
5	£743,247	145	£742,970.00	148
6	£678,799	130	£690,630.00	133
7	£543,113	130	£544,180.00	133
8	£465,301	120	£480,820.00	123
9	£842,156	190	£861,700.00	194
10	£805,539	100	£766,950.00	102
11	£248,254	65	£245,980.00	66
12	£6,613,683	270	£6,603,700.00	276
13	£6,808,821	270	£6,858,900.00	276
14	£298,129	202	£275,260.00	207
15	£919,938	247	£898,040.00	253
16	£10,779,400	343	£10,803,000.00	351
17	£989,102	95	£907,790.00	97
18	£1,353,478	134	£1,340,600.00	137
19	£569,171	200	£580,810.00	204
20	£316,430	112	£327,270.00	115

13 out of the 20 projects of Dataset 3 used single-stage selective tendering, the best value tenderer delivered the project at the exact amount that was initially tendered, and in the clients' expected duration. The results of the model also show that in these projects (1, 2, 5, 6, 7, 8, 10, 11, 13, 14, 15, 19, and 20), the actual project results were well within the range of outcomes of how the lowest tenderer would have fared if he/she was awarded the contract instead.

Project 4 and 18 of this dataset used two-stage open tendering, and the best value tender delivered the project below the initial tender. Again, this was well within the 95% interval of the expected final cost of the lowest tender. In Projects 3, 9, 12, 16, and 17 (single-stage open tendering) the best value tender incurred cost overruns. Apart from 3 and 17, the costs were well within the 95% interval of the expected final cost of the lowest tender. In projects 3 and 17, we find that the costs are outside this interval, however, the results were within the range of outcomes that the model predicted. The consultant cited the fact the best value contractor had to alter its approach mid-way into the project. The strength of this model is its ability to also show when things can go wrong; in real-world projects where there are unforeseen issues that can cause problems in the project. This also justifies the reason for using an open-ended distribution like the lognormal to carry out the research.

In Dataset 3, the best value tenderers' average final costs of all 20 projects were just over 1% more than the final cost of the lowest tenderer; with a standard deviation of 5.5%. This means that on average the lowest tenderer incurs less than the starting price of the best value tender whose price is not the lowest price. In 9 out of 20 projects in Dataset 3, the model is predicting that the lowest tenderer final cost will likely be below the starting price of the best value tender (Projects 3, 5, 10, 11, 12, 14, 15, 17, 18 see Table 4.3.12). It is important to remember that the model is not aiming to predict the exact final cost, the mean average cost here is the likely final cost. Furthermore, this is only being stated to see how the lowest tenderer would on average fare in a project that is being awarded to the best value tender whose price is not the lowest price.

Regarding the duration, the best value tender met the clients' expected duration, however there is a higher likelihood of delaying the project in going for the lowest tender. The initial analysis of lowest tender projects (Dataset 1) found that the lowest tenderer would on average incur a 2.23% increase on the expected duration, with a standard deviation of 8.27%. Furthermore in 7 projects from Dataset 2 the client cited the slow pace of construction and the scheduling of construction programmes as the reasons for disputes and overruns. Thus, it comes down to how risk averse the client selecting is; will the client risk delaying the project at a lower cost? These are the kind of decisions that they will have to make.

The correlation between Tender Price, Overrun cost (Diff), and Delay in Dataset 1 were found to be miniscule; the initial analysis of lowest tender projects that were used to develop the model, found that the lowest tenderer usually overran by just over 3%; with a standard deviation of just over 4%. Therefore, depending on how high the next lowest tender or best value tender is, the lowest tender was likely to still deliver the project below the next highest tender or best value tender.

From applying the developed model on the Educational facilities sector, 2 conclusions are drawn out:

1. **The lowest tenderer would likely overrun in cost but this will be below the price of the best value tenderer.**
    - In Dataset 2, 12 out of 20 projects overran in costs but the final cost was below the starting price of the second lowest tender. In Dataset 3, the model recorded on average that the lowest tenderer will incur more than the best value tender if it was awarded the contract instead. However, in 9 out of the 20 projects the final costs of the lowest tenderer were below the starting price of the best value tender. The results are influenced by the standard deviation of the tender prices in each project. A higher standard deviation of tender prices would likely mean that the lowest tenderers' final cost would likely be below that of the best value tenderer despite an overrun. The next section (4.3.5) would investigate this further.
2. **There is a higher probability that the lowest tender will exceed the clients' expected duration.**
    - Why? This could relate to the criteria that are used to evaluate contractors in this sector and the weights applied to them. The model is limited as there is not a healthy dataset of tenders where the criteria used to select contractors is provided. In Section 4.3.6 a consultant provided 3 projects that used the same criteria to select the best value contractor in the Educational facilities sector. Although it is only 3 projects, it gives an idea of which criteria clients prioritise and whether completion time is amongst the highly prioritised criteria. It may be that clients do not consider it at all, or that they just stipulate when they would like the project to be completed. Nevertheless, the conclusion is supported by Assaf and Al-Hejji (2006) and Olaniran (2015) study that found that the most frequent nature of performance problems caused by awarding to the lowest tender is project delay (see **Section 2.1.3**).

Appendix 4 shows the model's flow diagram, stating the steps undertaken to develop the model for Dataset 1, 2, and 3. The next stage of the research is to conduct a sensitivity analysis to know how often the lowest tender would turn out to be the best overall tender as the correlations between Tender Price (lowest tender), Diff, and Delay changed. These correlations are vital to the whole concept and it proved difficult to evaluate them. As the correlations were found to be miniscule and has subsequently been validated in the results, there is a chance that these correlations are not universal. Indeed, other clients may find a higher correlation between these variables, thus the sensitivity analysis will show whether a change in these correlations have an effect on the amount of times the lowest tender turns out to be the best tender.

4.3.5 Sensitivity Analysis

The sensitivity analysis of the model required minimal changes to the model which will be explained in this section. Projects 8 and 13 of Dataset 3 will be used to demonstrate this analysis. This analysis would look at how many times the lowest tender turns out to be the best tender as the correlation and variance changes. Best tender in this context is taken to mean that if for example the lowest tender overruns but still delivered the project below the tendered price of the next highest tender, then it will be considered the best tender in terms of cost. The same will also be conducted for duration, although in all these projects contractors did not list their duration time. Therefore, the assumption is that every contractor meets the clients' expected duration time. The model MATLAB code in its entirety will be displayed first. Then there will be a description of each part of the code.

Table 4.3.13: Project 13 Tender

A	B	C	Expected Duration (days)
£6,598,070	£6,808,821	£7,521,515	270

```
%model to determine costs for tenders
%The model produces 3 components for a tender quote: The price, related to
%the sample inputs, a quality cost based on existing tender to final cost
figures
%and a overrun index (not used at the moment)

%Input variables are:
% TPmean - the mean of the tender prices
% TPstd - the standard deviation of the tender prices
% QPmean - the mean of the overrun price, which is calculated from historic
% outcome prices
% QPstd - the standard deviation of the overrun price
% ORmean - the mean overrun in days
% ORstd - the standard deviation of overrun
% rhoTQ - the correlation between tender and overrun prices
% rhoTO - the correlation between tender price and overrun time
% rhoQO - the correlation between overrun price and Overrun time
% numTenders is the number of tenders considered for each project - we could
% vary it to see what effect it has on the final price

%Output will be a matrix of tender prices (fp, 1), quality prices (ex, 2),
%and overrun (or,3) indices. The matrix is called outputs. The array itself
%is 3 dimensional. The first dimension is the realisation number
(1:realisations), the
%second the tender (1:numTenders) and the third the actual value(1 refers to
%tender price, 2 to overrun price, 3 to overrun days and 4 for the final
%price)
```

```
%Now load the variables
data= xlsread('P13.xlsx'); %load from excel document
bidpice = data(1:3);
lowest = data(1);
duration = data(7);
o=1.048226*7000000;
p=0.103617*7000000;
y1= 0.036738;
y2=0.043266;
y3=o*y1;
y4=o*y2;
n1=0.023;
n2=0.0827;
n3=n1*duration;
n4=n2*duration;
%Now set the variables - please set them or devise a way to input them from
%a file

 %select the number of realisations

        realisations = 5000;

TPmean = o;
TPstd = p;
QPmean = y3;
QPstd = 1000; % not used now, but overwritten
ORmean = n3; % that is on average no overrun
ORstd = 1; % OK only a single day
rhoTQ =-.9;
rhoTO = 0;
rhoQO = 0;
numTenders = 3;

% At this point I am setting up the loops to determine the count surface
% Take 30 different QPstd going from 10,000 to 300,000 in steps of 10,000

QPSfirst = 10000;
QPSnum = 30;
QPSstep = 10000;



for QI = 1:QPSnum %  These will be the indices of the output array
    QPstd = QPSfirst+QPSstep*(QI-1);

    % now vary the correlation between tender price and quality
    % Take 20 different values between -0.8 and +0.8 in steps of .05

    rhofirst = -.8;
    rhonum = 33;
    rhostep = .05;

    for CJ = 1: rhonum % These will be the indices for the output array
        rhoTQ= rhofirst+rhostep*(CJ-1);
```

```
        correl= [1,rhoTQ,rhoTO;rhoTQ,1,rhoQO;rhoTO,rhoQO,1];

        % note - check that the correlation matrix is consistent before
getting here

        A=sqrtm(correl);% The key function correl=AA'

        %for 3 different cases generate the likely values


        % for each different realisation generate the prices, diff etc.
        lncount=0; % how many times does the selected tender turn out to
have the least overall cost

        for j=1:realisations
            for i=1:numTenders %for each realisation generate a number of
tenders
                neta= lognrnd(0,1,3);% 3 standard log normal random numbers
required
                x=A*neta; %x are the standardised correlated lognormal vlaue
(just check they are chiquared test required
                outputs(j,i,1)=x(1)*TPstd+TPmean;% These are the tender
prices
                outputs(j,i,2)=x(2)*QPstd+QPmean; %These are the quality
prices
                outputs(j,i,3)=x(3); %overrun days
                outputs(j,i,4)=outputs(j,i,1)+outputs(j,i,2);

            end

            % find the tender to accept based on lowest tender price
            %this really should be the min function on the second dimension
            lnaccepted_bid(j) = outputs(j,1,1);
            lnbest_bid(j)=1; %this just keeps a record of what was the best
bid
            for i= 2:numTenders
                if outputs(j,i,1)<lnaccepted_bid(j)
                    lnaccepted_bid(j)=outputs(j,i,1);
                    lnbest_bid(j)=i;
                end
            end

            %now find the lowest overall final price
            lnbest_price(j) = outputs(j,1,4);
            lnbest_outcome(j)=1; %this just keeps a record of what was the
best final price
            for i= 2:numTenders
                if outputs(j,i,4)<lnbest_price(j)
                    lnbest_price(j)=outputs(j,i,4);
                    lnbest_outcome(j)=i;
                end
```

```
            end

            %keep track of how many times the best tender turns out not to
have the
            %lowest final price
            if lnbest_bid(j) == lnbest_outcome(j)
                lncount=lncount+1;
            end
        end
        lncountarray(QI,CJ) = lncount;
        Qualval(QI)=QPstd;
        Corrval(CJ)=rhoTQ;

    end
    end
```

4.3.5.1 Model description

```
%model to determine costs for tenders
%The model produces 3 components for a tender quote: The price, related to
%the sample inputs, a diff cost based on existing tender to final cost figures
%and a delay index (not used at the moment)

%Input varables are:
% TPmean - the mean of the tender prices
% TPstd - the standard deviation of the tender prices
% QPmean - the mean of the overrun price, which is calculated from historic
% outcome prices
% QPstd - the standard deviation of the overrun price
% ORmean - the mean overrun in days
% ORstd - the standard deviation of overrun
% rhoTQ - the correlation between tender and overrun prices
% rhoTO - the correlation between tender price and overrun time
% rhoQO - the correlation between overrun price and Overrun time
% numTenders is the number of tenders considered for each project - we could
% vary it to see what effect it has on the final price

%Output will be a matrix of tender prices (fp, 1), quality prices (ex, 2),
%and overrun (or,3) indices. The matrix is called outputs. The array itself
%is 3 dimensional. The first dimension is the realisation number
(1:realisations), the
%second the tender (1:numTenders) and the third the actual value(1 refers to
%tender price, 2 to overrun price, 3 to overrun days and 4 for the final
%price)
```

The above is a description of what the model does.

```
%Now load the varibles
data= xlsread('P13.xlsx'); %load from excel document
bidpice = data(1:3);
lowest = data(1);
duration = data(7);
```

The first stage was to get the model to identify the tender prices, the lowest tender, and the client's expected duration. Table 4.3.13 reminds us of Project 13's tender prices and client's expected duration, which selected Contractor B.

```
o=1.048226*7000000;
p=0.103617*7000000;
```

Next was to find the mean and the standard deviation of the tender prices. However, the whole idea of the sensitivity analysis is not just to analyse the tenders that a client has in front of them, but a set of likely tenders from the same multivariate probability distribution. The client can rightly assume that it can get a different set of tenders from different contractors for the same project. Therefore, instead of limiting the mean and standard deviation of the tender prices to expect to the one already in front of the client (Table 4.3.13), the model aims to get an overall picture. To execute this, in the initial analysis of the lowest tenders used to develop the model we get the ratio between every contractor tender received for a project to the final cost of that project.

$$\boldsymbol{Ratio} = \frac{\boldsymbol{Tender\ Price_i}}{\boldsymbol{Final\ Cost}}$$

Then the mean and standard deviation is calculated, with $\boldsymbol{o}$ representing the mean, and $\boldsymbol{p}$ representing the standard deviation.

$$\boldsymbol{o} = \frac{\boldsymbol{Ratio_{120}}}{\boldsymbol{120}}$$

$$\boldsymbol{p} = \boldsymbol{sqrt}\left[\sum \frac{(\boldsymbol{Ratio_{120}} - \boldsymbol{o})^2}{\boldsymbol{120 - 1}}\right]$$

Then the worth of the project, in other words the clients' budget for the project is multiplied by the mean and standard deviation, to give an overall picture of the mean and standard deviation a client can expect for the project.

```
y1= 0.036738;
y2=0.043266;
y3=o*y1;
y4=o*y2
```

The next step was to scale the value of the tenders to the appropriate cost size. In doing so this will determine right the mean and standard deviation of overrun cost that Project 4 can expect to incur as it chooses the lowest tender. In this case $\boldsymbol{y3}$ represents the mean, while $\boldsymbol{y4}$ represents the standard deviation; with $\boldsymbol{y1}$ and $\boldsymbol{y2}$ staying the same; remember that they represent the percentage of mean and standard deviation of overrun cost to expect from the analysis done on 120 projects in Dataset 1.

```
TPmean = o;
TPstd = p;
QPmean = y3;
QPstd = 1000; % not used now, but overwritten
rhoTQ =-.9;
numTenders = 3;

% At this point I am setting up the loops to determine the count surface
% Take 30 different QPstd going from 10,000 to 300,000 in steps of 10,000

QPSfirst = 10000;
QPSnum = 30;
QPSstep = 10000;

for QI = 1:QPSnum %  These will be the indices of the output array
    QPstd = QPSfirst+QPSstep*(QI-1);

    % now vary the correlation between tender price and quality
    % Take 33 different values between -.8 and .8 in steps of .05

    rhofirst = -.8;
    rhonum = 33;
    rhostep = .05;


for CJ = 1: rhonum % These will be the indices for the output array
        rhoTQ= rhofirst+rhostep*(CJ-1);

        correl= [1,rhoTQ,rhoTO;rhoTQ,1,rhoQO;rhoTO,rhoQO,1];

        % note - check that the correlation matrix is consistent before
getting here

        A=sqrtm(correl);% The key function correl=AA'

        %for 3 different cases generate the likely values
```

At this stage of the model, it recognises the mean and standard deviation to expect for tender prices, $\boldsymbol{TPmean}$ and $\boldsymbol{TPstd}$. It also then recognises the mean overrun cost to expect for Project 13 $\boldsymbol{QPmean}$. The standard deviation, $\boldsymbol{QPstd}$ of overrun cost is then overwritten at this stage; when $\boldsymbol{y4}$ is calculated manually for Project 13, the standard deviation of overrun cost to expect is around £300,000. Therefore $\boldsymbol{QPstd}$ is now taken to be any amount between: £10,000 and £300,000. Then the correlation between tender price and overrun cost is overwritten; so instead of giving it a fixed correlation like the model for Dataset 1, 2, and 3 the model allows it to deviate from -0.8 to 0.8. A correlation of -0.8 means that the lower the tender price, the higher the overrun cost. While 0.8 means the higher the tender price, the higher the overrun cost. The range from -0.8 to 0.8 removes the extremities of +-1 and +-0.9.

```
realisations = 5000;
% for each different realisation generate the prices, diff etc.
```

```
        lncount=0; % how many times does the selected tender turn out to
have the least overall cost

        for j=1:realisations
            for  i=1:numTenders %for each realisation generate a number of
tenders
                neta= lognrnd(0,1,3);% 3 standard log normal random numbers
required
                x=A*neta; %x are the standardised correlated lognormal value
(just check they are chiquared test required
                outputs(j,i,1)=x(1)*TPstd+TPmean;%  These  are  the  tender
prices
                outputs(j,i,2)=x(2)*QPstd+QPmean; %These are the diff prices
                outputs(j,i,3)=x(3); %overrun days
                FC=outputs(j,i,1)+outputs(j,i,2);

            end
```

The model is then instructed to reproduce results 5,000 times; this is a decrease of the 20,000 it was instructed to do in the model for Dataset 1, 2, and 3. The reason is down to the greater number of different values mean and standard deviation being considered which would have resulted in a longer running time to get the results had it been asked to reproduce 20,000 results.

The model is then instructed to produce the distributions lognormally of all the three variables: Tender Price, Diff, and Delay. The first variable coming through are the standardised indices tender prices. These are then correctly formatted by instructing the model to produce 5,000 possible sets of tender prices that Project 13 can receive, by multiplying it to the standard deviation of tender prices to expect $\boldsymbol{TPstd}$ and adding it to the mean of tender prices to expect $\boldsymbol{TPmean}$. The second variable are that of diff; these are formatted by multiplying the indices by the standard deviation of overrun cost to expect for Project 13, $\boldsymbol{QPstd}$ and adding it to the mean overrun cost to expect for Project 13, $\boldsymbol{QPmean}$.

Finally, the model is instructed to find the final cost to expect for Project 13. To find the final cost was to add the correctly formatted 1st and 2nd variable; with the 1st variable being the tender prices and 2nd being the overrun costs to expect.

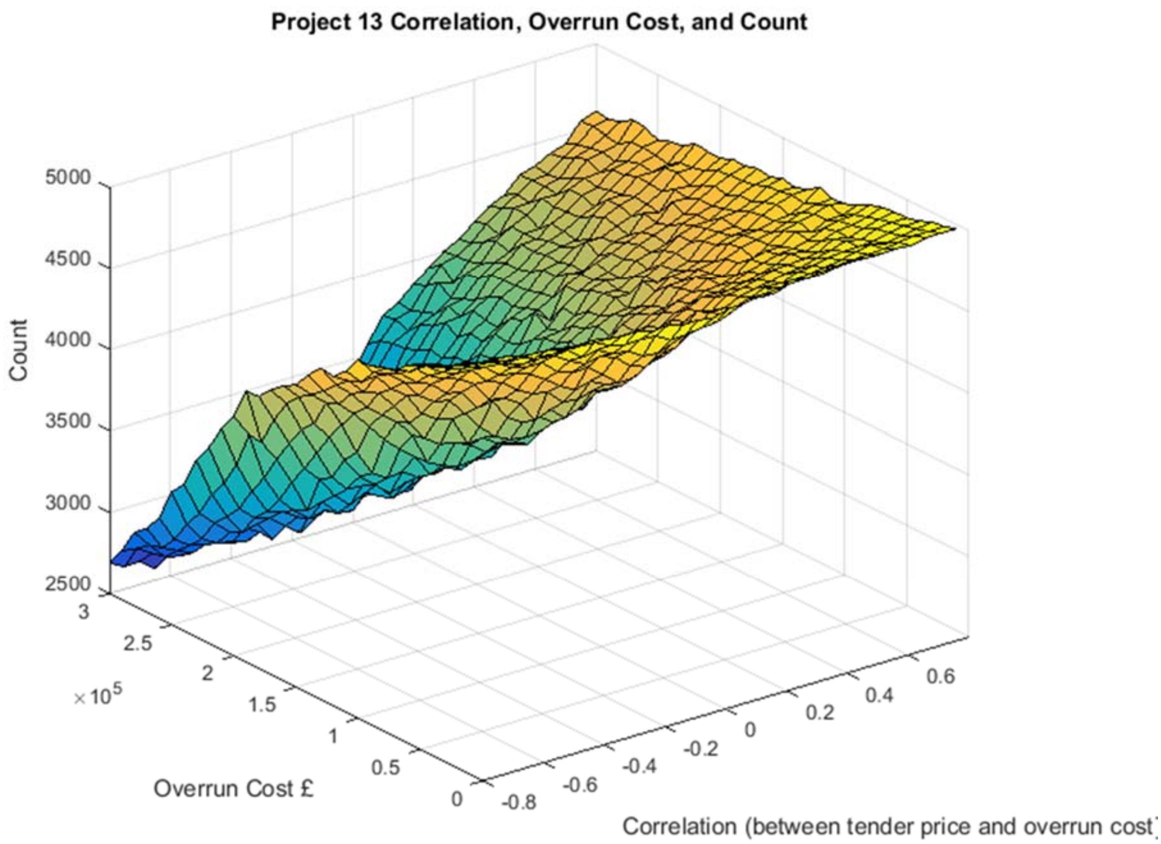
```
   % find the tender to accept based on lowest tender price
            %this really should be the min function on the second dimension
            lnaccepted_bid(j) = outputs(j,1,1);
            lnbest_bid(j)=1; %this just keeps a record of what was the best
bid
            for i= 2:numTenders
                if outputs(j,i,1)<lnaccepted_bid(j)
                    lnaccepted_bid(j)=outputs(j,i,1);
                    lnbest_bid(j)=i;
                end
            end
```

Up until this stage of the model, it has not yet been instructed to select the lowest tender from all the possible set of tender prices that the model generates. The code here instructs it to do just that, and to keep a record of it.

```
  %now find the lowest overall final price
            lnbest_price(j) = outputs(j,1,4);
            lnbest_outcome(j)=1; %this just keeps a record of what was the
best final price
            for i= 2:numTenders
                if outputs(j,i,4)<lnbest_price(j)
                    lnbest_price(j)=outputs(j,i,4);
                    lnbest_outcome(j)=i;
                end

            end

            %keep track of how many times the best tender turns out not to
have the
            %lowest final price
            if lnbest_bid(j) == lnbest_outcome(j)
                lncount=lncount+1;
            end
        end
        lncountarray(QI,CJ) = lncount;
        Qualval(QI)=QPstd;
        Corrval(CJ)=rhoTQ;

    end
    end
```

The model at this stage, then finds out whether the lowest tender selected turned out to be the overall best tender. It first keeps a record of the contractor who had the best after the lowest tender has completed the project, and subsequently counts the amount of time the lowest tender comes out as the best tender. **Figure 4.3.12** displays the relationship between the correlation of tender price and overrun cost, the overrun cost, and the amount of time that the lowest tender turns out to be the best tender in terms of the final cost.

Figure 4.3.12: Project 13 Correlation, Overrun Cost, and Count



- The X-axis is the correlations that ranges from -0.8 to 0.8 (removing the extremities of +-1 and +-0.9), with a step of 0.05; this is then given a range from 0 to 33.
- The Y-axis is the standard deviation of Diff that ranges from £10000 to £300,000; this is then given a range from 0 to 30.
- The Z-axis counts the number of times that the lowest tender did turn out as the best overall tender; in other words, if the amount of time that the lowest tender's outcome cost, turns out to still be lower than the next highest price.
- The model was given 5000 realisations.

4.3.5.1.1 *Now for Duration*

The same principle is then used to find how many times the lowest tender turns out to be the best tender for duration.

```
TPmean = o;
TPstd = p;
ORmean = n3;
ORstd = 1; % not used now, but overwritten
rhoTO = -.9;
numTenders = 3;

% At this point I am setting up the loops to determine the count surface
% Take 40 different QPstd going from 1 to 40 in steps of 1


Dfirst = 1;
Dnum = 40;
Dstep = 1;

 for ORI = 1:Dnum; % These will be the indices of the output array
        ORstd = Dfirst + Dstep*(ORI-1);

    % now vary the correlation between tender price and quality
    % Take 20 different values between -.8 and .8 in steps of .05

    rhofirst = -.8;
    rhonum = 33;
    rhostep = .05;

    for CJ = 1: rhonum % These will be the indices for the output array
        rhoTO= rhofirst+rhostep*(CJ-1);

        correl= [1,rhoTQ,rhoTO;rhoTQ,1,rhoQO;rhoTO,rhoQO,1];

        % note - check that the correlation matrix is consistent before
getting here

        A=sqrtm(correl);% The key function correl=AA'

        %for 3 different cases generate the likely values
```

At this stage of the model, it recognises the mean and standard deviation to expect for tender prices, $\boldsymbol{TPmean}$ and $\boldsymbol{TPstd}$. It also then recognises the mean delay time to expect for Project 13 $\boldsymbol{ORmean}$. The standard deviation, $\boldsymbol{ORstd}$ of delay time is then overwritten at this stage; remember that the mean and standard deviation of delay time was 2.3% and 8.27% respectively in the initial analysis for lowest tender projects used to develop the model. Therefore $\boldsymbol{ORstd}$ is now taken to be anything between: a day and 23 days; as 8.27% of Project 13's duration which is 22.326 days. In the model, however this increased to 40 days to dig deeper into the relationship between the correlation of tender price and delay time, the delay, and the amount of time that the lowest tender turns out to be the best tender in terms of meeting the clients' expected duration. Then the correlation between tender price and delay is overwritten; so instead of giving it a fixed correlation like the previous model, the model allows it to deviate from -0.8 to 0.8.

```
realisations = 5000;
% for each different realisation generate the prices, qulaity etc.
        lncount=0; % how many times does the selected tender turn out to
have the least overall cost

        for j=1:realisations
            for i=1:numTenders %for each realisation generate a number of
tenders
                neta= lognrnd(0,1,3);% 3 standard log normal random numbers
required
                x=A*neta; %x are the standardised correlated lognormal vlaue
(just check they are chiquared test required
                outputs(j,i,1)=x(1)*TPstd+TPmean;% These are the tender
prices
                outputs(j,i,2)=x(2); %These are the diff prices
                outputs(j,i,3)=x(3)*ORstd+ORmean; %overrun days
                actualduration=outputs(j,i,3)+duration;
            end
```

The model is then instructed to produce the distributions lognormally of all the three variables: Tender Price, Diff, and Delay. The first variable coming through are the standardised indices tender prices. These are then correctly formatted by instructing the model to produce 5,000 possible sets of tender prices that Project 13 can receive, by multiplying it to the standard deviation of tender prices to expect $\boldsymbol{TPstd}$ and adding it to the mean of tender prices to expect $\boldsymbol{TPmean}$. The third variable are that of diff; these are formatted by multiplying the indices by the standard deviation of delay to expect for Project 13, $\boldsymbol{ORstd}$ and adding it to the mean delay time to expect for Project 13, $\boldsymbol{ORmean}$.

Finally, the model is instructed to find the actual duration to expect for Project 13. To find the actual duration was to add the correctly formatted 3rd variable to the clients' expected duration for Project 13; with the 3rd variable being the delay time to expect.

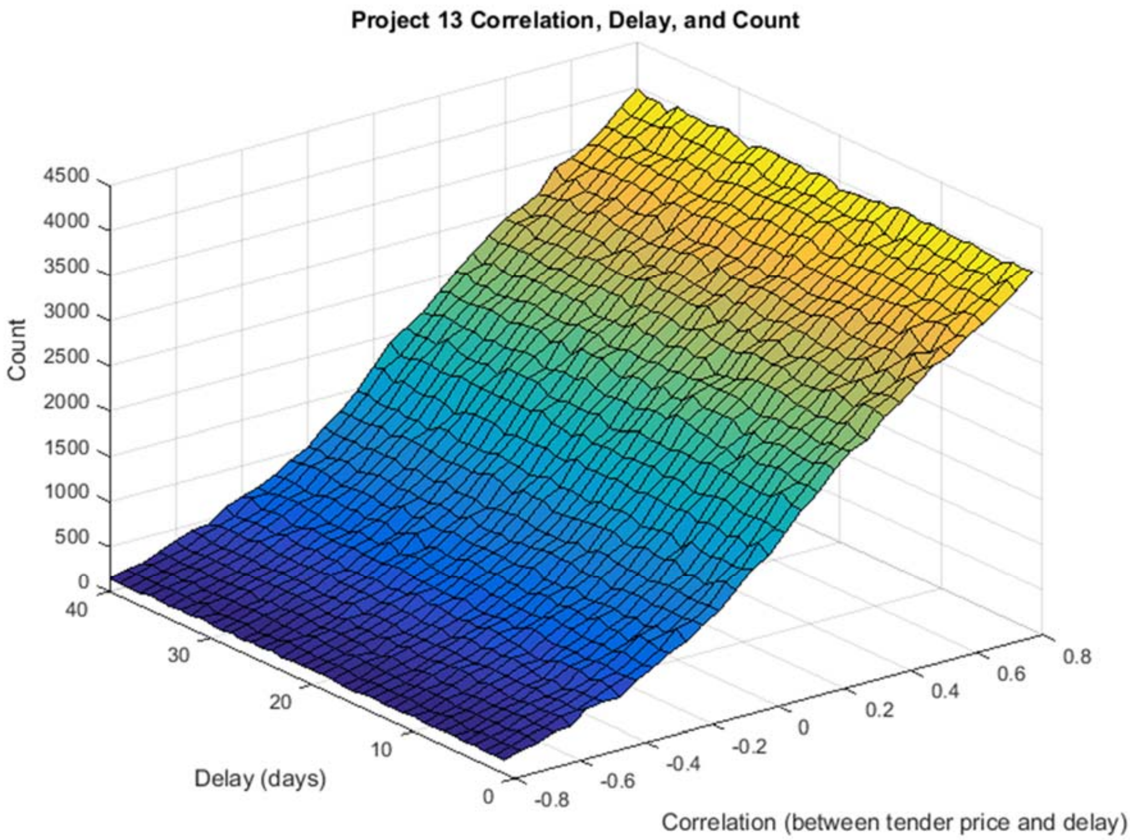
```
   % find the tender to accept based on lowest tender price
            %this really should be the min function on the second dimension
            lnaccepted_bid(j) = outputs(j,1,1);
            lnbest_bid(j)=1; %this just keeps a record of what was the best
bid
            for i= 2:numTenders
                if outputs(j,i,1)<lnaccepted_bid(j)
                    lnaccepted_bid(j)=outputs(j,i,1);
                    lnbest_bid(j)=i;
                end
            end
```

Again, up until this stage of the model, it has not yet been instructed to select the lowest tender from all the possible set of tenders that the model generates. The code here instructs it to do just that, and to keep a record of it.

```
  %now find the lowest overall final price
            lnbest_price(j) = outputs(j,1,4);
            lnbest_outcome(j)=1; %this just keeps a record of what was the
best final price
            for i= 2:numTenders
                if outputs(j,i,4)<lnbest_price(j)
                    lnbest_price(j)=outputs(j,i,4);
                    lnbest_outcome(j)=i;
                end

            end

            %keep track of how many times the best tender turns out not to
have the
            %lowest final price
            if lnbest_bid(j) == lnbest_outcome(j)
                lncount=lncount+1;
            end
        end
        lncountarray(ORI,CJ) = lncount;
        ORval(ORI)= ORstd;
        Corrval(CJ)=rhoTO;
    end
    end
```

The model at this stage, then finds out whether the lowest tender selected turned out to be the overall best tender in terms of duration. It first keeps a record of the contractor who had the best after the lowest tender has completed the project, and subsequently counts the amount of time the lowest tender comes out as the best tender in terms of duration. **Figure 4.3.13** the relationship between the correlation of tender price and delay time, the delay, and the amount of time that the lowest tender turns out to be the best tender in terms of meeting the clients' expected duration.

Figure 4.3.13: Project 13 Correlation, Delay, and Count



- The X-axis is the correlations that ranges from -0.8 to 0.8 (removing the extremities of +-1 and +-0.9), with a step of 0.05; this is then given a range from 0 to 33.
- The Y-axis is the standard deviation of Delay that ranges from 1 to 40; this is then given a range from 0 to 40.
- The Z-axis counts the number of times that the lowest tender did turn out as the best overall tender in terms of duration.
- The model was given 5000 realisations.

Looking at the sensitivity analysis for duration, **Figure 4.3.13**, we see a close to perfect linear relationship. When the correlation between the tender price and delay time is highly negative i.e. the lower the tender price the higher the delay, then the lowest tender price is hardly ever the best tender in terms of duration, regardless of the amount of delay time incurred. The more positive the correlation becomes; that is the lower the tender the lower the delay or vice versa, the more the lowest tender becomes the best tender in terms of duration. This is to be expected given that it is assumed that all the other contractors that tendered will meet the clients' expected duration. Remember that in this project, the contractors did not state how long they will take to deliver the project, so it was safe to assume that they all can meet the clients' expected duration.

The sensitivity analysis for final cost, **Figure 4.3.12**, depicts a more complicated relationship between the correlation of tender price and overrun cost, the overrun cost, and the amount of time that the lowest tender turns out to be the best tender in terms of the final cost. When the correlation is highly negative; the lower the price the higher the overrun cost, and the lowest tender incurs its highest overrun cost of £300,000, the lowest tender is the best tender 50% of the time. When the correlation is still highly negative, but the overrun cost decreases, we find that the chances of the lowest tender being the best tender in terms of final cost increases. The more positive the correlation, the better chance that the lowest tender turns out to be the best tender in terms of cost. Therefore, at its worst, which is a highly negative correlation, and an overrun cost of £300,000, there is still a 50% chance that the lowest tender becomes the best tender in terms of final cost when it completes the project. The main reason for this is due to the standard deviation of the tender prices one can expect for Project 13. In Table 4.3.3.1 we see that the lowest tender is £6,598,070 and the best value tender is £6,808,821 that is already over £200,000. Then take into consideration that the thirst highest tender is almost a £million higher than the lowest tender at £7,521,515, which further increases the standard deviation of the tender prices. Therefore, for a standard deviation of overrun cost for £300,000, there will be a better chance that the lowest tender remains the best tender in terms of final cost. To illustrate this point further, let us take a project with a much lower standard deviation between tender prices like Project 8 of Dataset 3.

Table 4.3.14: Project 8 Tender

A	B	C	D	Expected Duration (days)
£463,499	£465,301	£478,943	£484,459	120

The sensitivity analysis for duration for Project 8 would be like that of Project 13. **Figure 4.3.14** also show a close to perfect linear relationship between the correlations of tender price and delay, the delay time, and the amount of time the lowest tender is the best tender in terms of duration.

Figure 4.3.14: Project 8 Correlation, Delay, and Count

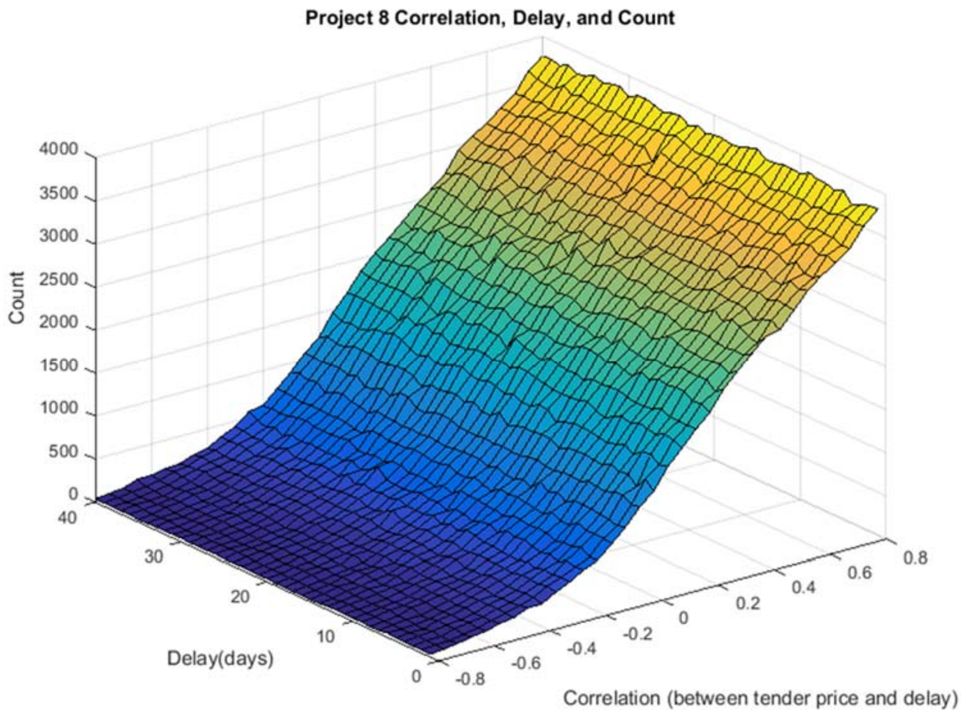


Figure 4.3.15: Project 8 Correlation, Overrun Cost, and Count

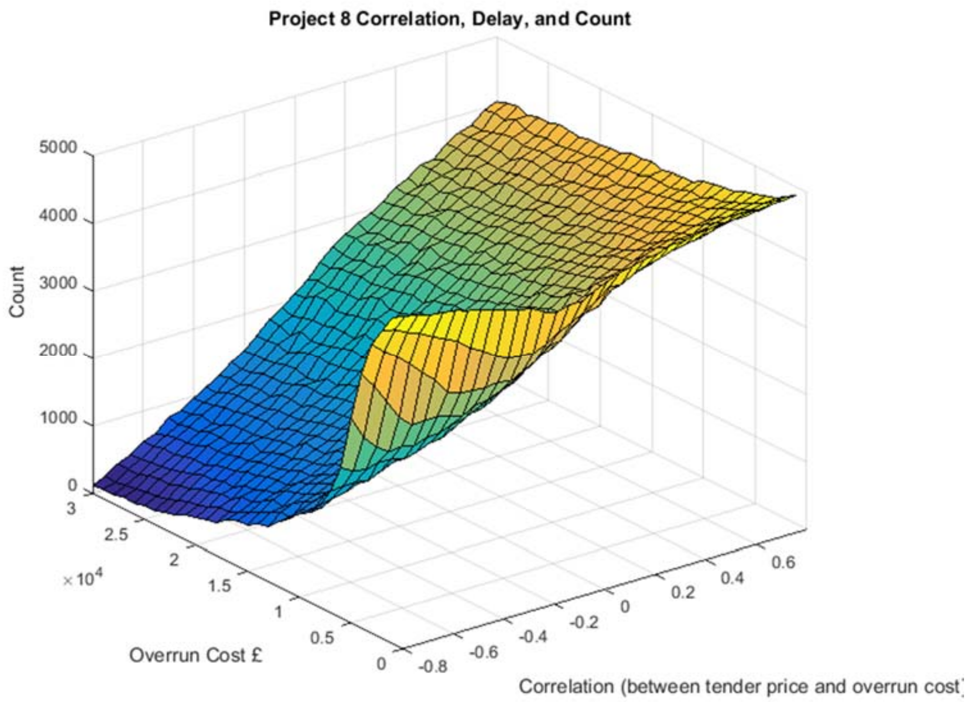


Figure 4.3.15, shows that there is no chance of the lowest tender being the best tender when it incurs the highest possible overrun cost for the project, and correlation is highly negative. Due to the size of Project 8, the highest possible overrun cost is £30,000. But in the worst-case scenario when the correlation is highly negative and the lowest tender incurs the highest overrun cost possible, Project 13's lowest tender still had a 50% chance of being the best tender. In Project 8, however, there is no chance; the difference between the lowest tender and the best value tender is just over £2,000. The difference between the lowest tender and the highest tender is just over £20,000; the standard deviation here would not be as high as that of Project 13. Nevertheless, as the overrun cost decreases and the more positive the correlation becomes, the better the chance that the lowest tender in Project 8 turns out to be the best tender in terms of final cost. Having said that, what best value is for one client can be different to another client. It may be that the clients' idea of best value is not incurring a delay on the project. If that is the case, then the client is better off selecting the best value tender seeing that they delivered the projects on time. Figures 4.3.12 to 4.3.15 illustrate the impact that correlation has on results. In Figures 4.3.13 and 4.3.14 we see for example that regardless of what the standard deviation of delay is, the number of times the lowest tender is the overall best tender in terms of duration remains even. The number of times the lowest tender is the overall best tender in terms of duration only increases as the correlation alters. Therefore, the standard deviation has less of an impact than the correlations. This supports Wall (1997) finding (given in Section 3.4.2) which highlighted the importance of correlations. It pointed out how excluding correlations has a more profound effect than the effect of choosing which probability distributions to represent a data set. Appendix 5 shows the model's flow diagram stating the steps undertaken to develop the model for the correlation's Sensitivity Analysis.

4.3.5.2 Applying model to different sector

It will be misleading to apply this model on another project that is not in the Educational facilities sector. The research demonstrates this notion by applying the developed model of Dataset 1 on two of Dataset 5 projects (Projects 1 and 2) which are Industrial facilities projects collected from two consultants that selected the lowest tender.

Table 4.3.15: Dataset 5 Project Cases

Tendering Methods	**Projects**
Single-stage Selective	3, 11, 12, and 16
Single-stage Open	1,2,4,5,6,7,8,9,10,13,14,15,17

Table 4.3.16: Dataset 5 Project Cases

	A	B	C	D	E	Expected Duration (days)
1	£2,081,375.86.	£2,125,741.85	£2,275,640	£2,465,789	2,589,650	89
2	£6,544,768	£6,592,106.32	£6,679,425	£7,121,601		292
3	£1,519,214	£1,699,619	£1,846,705.80			112
4	£2,776,622	£3,214,855	£3,364,044			202
5	£778,369	£810,930	£863,829	£897,594	£917,290	85
6	£2,498,520	£3,649,071	£3,694,031			225
7	£3,439,605	£3,482,230	£3,951,477			336
8	£1,086,416	£1,129,329	£1,152,634	£1,197,777	£1,286,196	157
9	£514,246	£605,988	£606,892	£704,540		134
10	£10,707,137	£10,762,455	£11,099,516	£11,107,000	£11,123,458	314
11	£1,367,725	£1,385,448	£1,493,281	£1,603,808		270
12	£1,084,930	£1,115,852	£1,122,143			247
13	£1,692,593	£1,710,654	£1,790,321	£1,850,000	£1,902,125.32	157
14	£984,633.15	£996,777	£1,050,452			157
15	£1,486,449.49	£1,500,060.74	£1,909,574.39			292
16	£3,029,624	£3,067,327.11	£3,150,214	£3,321,154		180
17	£927,194	£1,116,930	£2,667,040			180

Table 4.3.17: Dataset 5

Project	Cost	Duration
1	£2,462,406	102
2	£7,741,025	340
3	£1,778,000	134
4	£3,503,154	202
5	£1,055,485	95
6	£3,006,682	225
7	£4,280,000	336
8	£1,384,193	157
9	£608,746	180
10	£11,450,000	314
11	£1,453,295	270
12	£1,220,393	247
13	£2,013,447	157
14	£1,202,408.14	157
15	£2,043,048	314
16	£3,966,000	225
17	£1,243,588	180

Figure 4.3.16: Project 1 Final Cost

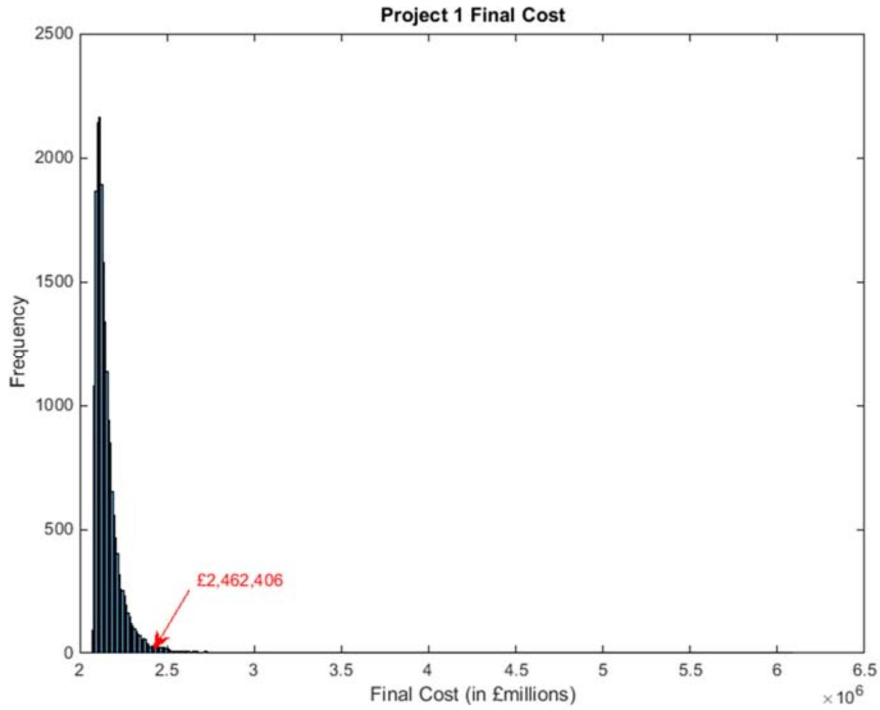


Figure 4.3.17: Project 1 Duration

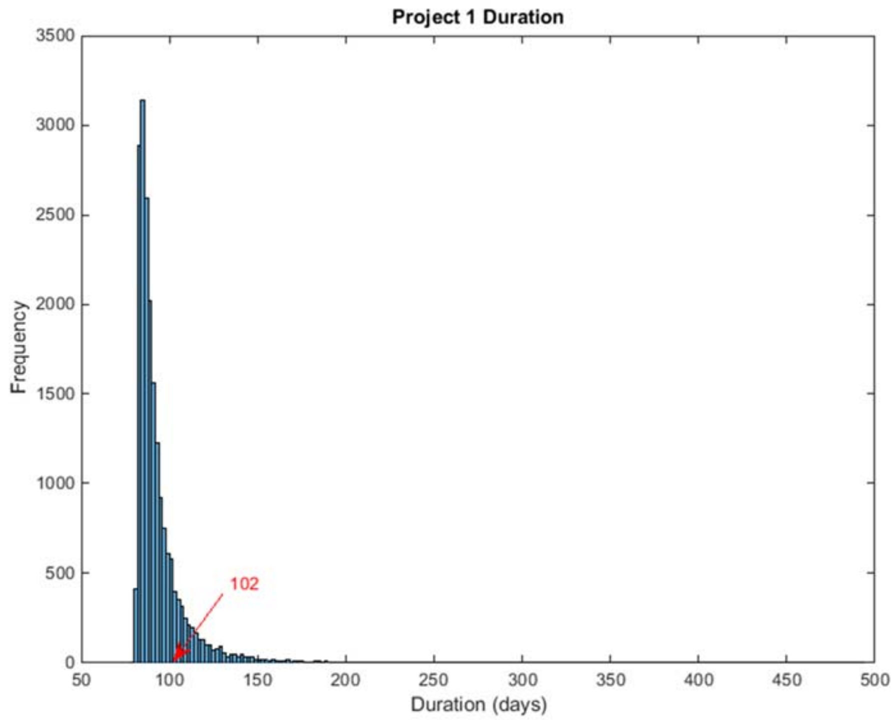


Figure 4.3.18: Project 2 Final Cost

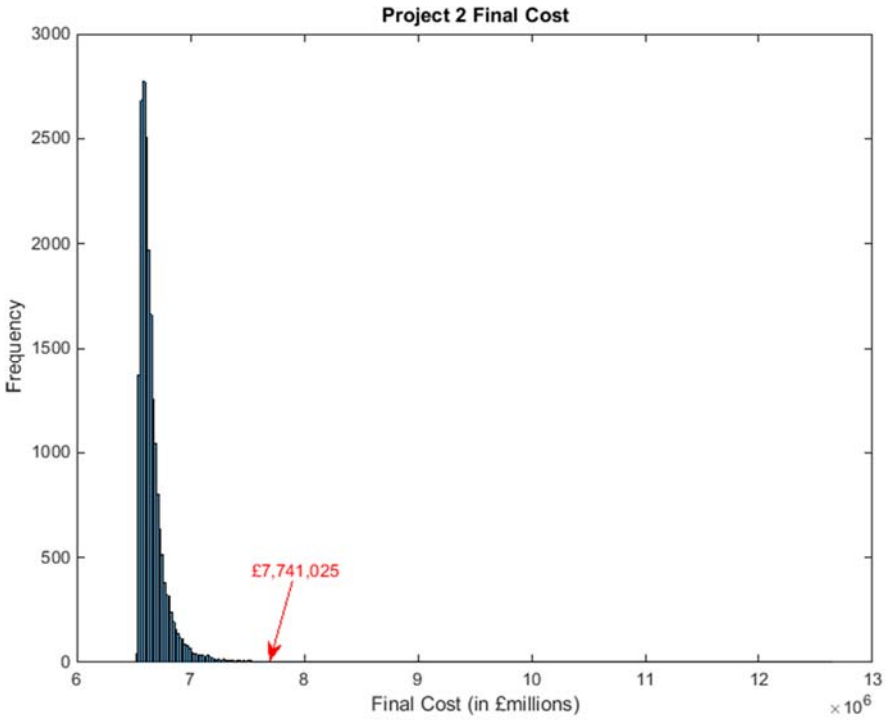
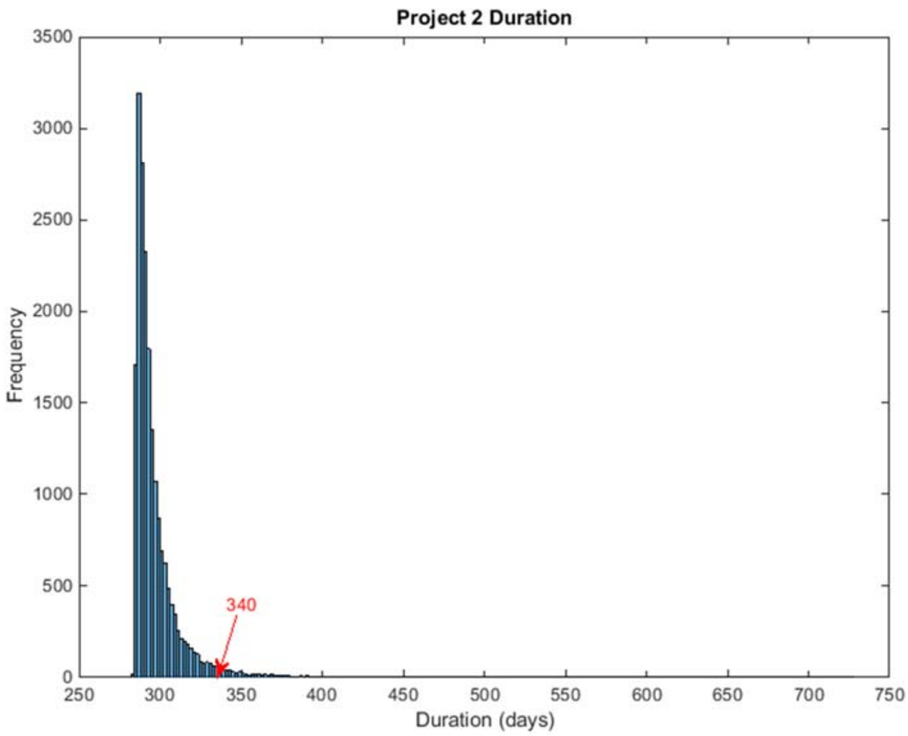


Figure 4.3.19: Project 2 Duration



From **Figures 4.3.16** to **4.3.19** we see that the completion time of these projects were usually well within the captured probability distribution generated from the model. However, even though the model captured the final cost of these projects, they were usually outside the 95% interval predicted thus, presenting these results would mislead clients. The right thing to do is to analyse historic data on industrial projects that have selected the lowest tender, to see how the lowest tenderers have fared. Therefore, a further 120 Industrial projects that selected the lowest tender was extracted from the BCIS database to get the appropriate mean and standard deviation of outcomes to expect in this sector. The same data processing method applied in Dataset 1 was also applied in Dataset 4. The developed model will subsequently be tested on Dataset 5.

Out of the 120 projects in Dataset 4, 87 projects used the Traditional procurement method, however the tendering methods were different:

- **Single-stage Selective tendering**: 28 projects
- **Single-stage Open tendering:** 59 projects

33 projects used the Design and Build procurement methods; however, the tendering methods were different:

- **Single-stage Selective tendering:** 26 projects
- **Single-stage Open tendering:** 7 projects

The Figures in Appendix 4 above show a healthier capturing of results, in that the actual results were well within the probability distribution of outcomes predicted by the model. For educational facilities projects the lowest tenderer usually overran by 3% with a standard deviation of 4% while from the industrial facilities projects analysed the lowest tenderer overran by 17% with a standard deviation of 6%. The lowest tenderer on average incurred a 2.23% increase on the expected duration, with a standard deviation of 8.27% in Dataset 1, but for Dataset 4 this was 9.23% with a standard deviation of 8.88%. The shortcomings of applying a model developed in Dataset 1 to Dataset 5 is clear. The developed model for Dataset 4 even failed to capture the actual final cost of projects 10 and 11 in Dataset 5 (see Appendix 4), as the lowest tenderer performed better than expected (cost overrun of 7%). The contractor cited an unexpected ground condition encountered midway through the project as the reason for cost overruns. While the client cited the contractor's lack of effective planning and coordination between the contractor and its suppliers and subcontractors as the reasons for cost overruns.

In Dataset 5 only 1 out of 17 projects incurred cost overruns that were below the price of the second lowest tender. 9 out of 17 (2, 5, 7, 8, 12, 13, 14, 15, and 16) projects incurred cost overruns that were higher than the price of all the tenders received. The consultants cited the unsuitability of the contractor and the subsequent changing of contractor midway through the project as the reasons for the overruns. Project 12 and 16 are particularly interesting as they both used the single-stage selective tendering method. The contractor in project 12 had a dispute with its workforce that led to workforce shortages. While the contractor in project 16 went bankrupt, and this had nothing to do with payment schedules. This supports the conclusion derived from Dataset 2; the regular assessment of contractors in a preferred contractors' list is needed. 12 out of 17 (1, 2, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, and 17) projects used the single-stage open tendering method, meaning that the client had little to no experience of working with the contractor. Again, the consultants cited the unsuitability of the contractor as the reasons for overruns. This supports Griffith et al. (2003) and ICE (2016) criticism of the open tendering method (**Section 2.2.2**), of attracting unsuitable contractors/suppliers that may lead to wasting time, effort, and money. Although this does justify the increase in the use of selective tendering, what selective tendering does is it limits the client to the set of tender prices it receives. There is a chance that a different set of contractor tender better prices than the one received for the same project. With the open tendering method, not only does it offer an equal opportunity to any organisation to submit a tender, it offers a better view of the market. The Sensitivity Analysis section (**4.3.5**) offers a solution to this problem, as the model is able to generate 20,000 different sets of tenders given a project size. This is in other to gauge the minimum and maximum or the spread of tenders to expect for a project. Having said that, if a client chooses to use the open tendering method, then the client should do their homework on the contractor. The likelihood is that this will be their first time working together, so the award criterion should be more than just price. Therefore, from these findings 3 conclusions are drawn (2 new, no.1 repeated):

1. **Selective tendering might imply that the client and contractor have a good history, or that the contractor has at least undergone some sort of pre-qualification that deem he/she qualified. However, regular assessment is needed.**
2. **The Sensitivity Analysis (Section 4.3.5) offers a good solution to the limited number of tenders usually received in selective tendering, in that the model is able to generate thousands of different sets of tenders to give client a better view of the market.**
3. **If a client is using the open-tendering method, then select the best value contractor, or at least do some homework on the contractor. A client in this case should incorporate other aspects in their tender analyses to determine the suitability of the contractor rather than just relying on solely price as there is lack of familiarity between the two parties.**

The lowest tenderers seemed to fare better in Educational facilities projects than in Industrial facilities projects. This supports Yu and Wang (2012) research that developed a mathematical model which measures the heterogeneity of the market to determine when a best value contractor should be favoured against a price only contractor. Though no mathematical model was used in the testing of the different sector, developing a model that can predict the likely outcomes (cost and duration) of the lowest tenderer in two different sectors offer a more practical contribution to Yu and Wang (2012) research. The perfect scenario would have been to equally have several projects that selected the best value contractor, including the quality scores of all the contractors that tendered. There were only 3 projects that were gathered that offered this information, all in Education facilities, and all where the best value tender was the lowest tender. The next section would demonstrate how the project would have accounted for quality had more quality scores been provided.

4.3.6 Quality Demonstration

Cost, time, and quality are typically used in planning and assessing project performance in the construction industry.

- **Cost:** This is the final cost of the project not the tender price.
- **Time:** The actual duration of the project
- **Quality:** Reliability of the contractor/project.

The research accounted for final cost and time, but not quality due to the fact the quality/reliability scores of the contractor were not given. This section of the thesis will demonstrate how the model would have incorporated the quality score of the contractor had there been a healthy dataset. This section will use 3 projects from a consultant that selected the best value tender (of which the best value tender was also the lowest tender) in educational facilities projects to illustrate.

All three projects used the same criteria to evaluate contractors using a weight distribution of 30% Price and 70% Quality. The Quality criteria are:

- Approach 10%: A qualitative assessment of the intended approach and it's feasibility
- Health and Safety 10%: A qualitative assessment based upon interaction with company and H&S criteria.
- Experience 30%: A qualitative assessment based upon demonstrated experience.
- Resources 10%: A qualitative assessment of company and supply chain fortitude.
- Programme 10%: A qualitative assessment based upon the deliverability and speed of the programme

*The weights and quality criteria used for this demonstration were provided/used by the consultant on these 3 projects below. Also included are the contractors' scores in these criteria.

Table 4.3.18: Project A Tender Information

Budget = £900,000	A	B	C
Price	£548,309.00	£781,538.00	£574,737.00
Approach	95%	75%	90%
H&S	95%	70%	70%
Experience	80%	70%	80%
Resources	50%	70%	90%
Programme	60%	90%	60%
BV Score (points)	103.24	86.05	101.98

Table 4.3.19: Project B Tender Information

Budget = £5,000,000	A	B	C	D
Price	£4,444,607.30	£4,502,940.42	£4,531,075.07	£5,111,851.66
Approach	90%	47%	67%	80%
H&S	85%	65%	85%	90%
Experience	90%	37%	77%	70%
Resources	55%	53%	90%	90%
Programme	55%	60%	70%	54%
BV Score (points)	89.25	66.91	87.40	81.74

Table 4.3.20: Project C Tender Information

Budget = £1,200,000	A	B	C	D	E
Price	£830,000.00	£911,150.00	£967,150.00	£1,100,000.00	£1,105,000.00
Approach	85%	55%	90%	72%	90%
H&S	80%	74%	90%	80%	90%
Experience	95%	70%	80%	70%	65%
Resources	47%	55%	90%	80%	90%
Programme	50%	60%	95%	75%	90%
BV Score (points)	98.07	84.91	97.72	84.43	88.08

The client first transformed the tender prices to percentage by dividing the budget cost by the contractor's submitted tender price. For example, in Project C, Contractor A's percentage will be (£1,200,000/830,000) *100 = 146%.

The client then calculated the contractors' best value score as the sum of multiplying the weight of each criteria by the score of the contractor in that criteria. From the tender information of these 3 projects, correlation will be derived between the 6 criteria to form the model. Remember that the main aim of the thesis is to provide a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies: lowest price or best value. It is possible for the lowest tenderer to still be the best value tender. However, in situations when it is not the model developed for the thesis has been able to show how the lowest tenderer would have fared if he/she was awarded the contract instead. Therefore, the model that is described in this section would be able to show:

- **The lowest cost tender**
- **Its best value score**
- **Its final cost**
- **Its overrun costs**
- **Its overrun time**
- **The best value tender**
- **Its best value score**
- **Its final cost**
- **Its overrun costs**

- **Its overrun time**

Furthermore, the model would be able to spot how often the lowest tenderer turns out to be the best value tender. In cases where the lowest tenderer is not the best value tenderer, the model would show how the lowest tenderer fared compared to the best value tender selected whose price was not the lowest price. The model MATLAB code in its entirety will be displayed first. Then there will be a description of each part of the code.

```
%Script to calculate the weights for selecting a best value project
%The weights are uniformly distributed 1 to 100 and correlated to each
%other
% Price is log normally distributed with mean of mu and a standard
% deviation of sigms.
% The decision criteria are to be added at the end
% row 1 = price
% row 2 = approach
% row 3 = health and safety
% row 4 = experience
% row 5 = resources
% row 6 = programme
% row 7 = overrun cost
% row 8 = delay

% Set some constants up
num_tenders=3; %How many companies submit a tender
num_sim=5000;
sigma=127711.17; %Standard deviation of price
mu=634861.33;%Mean of price
num_crit=8; % the 8 rows above
W_price= -0.3; %weight given to price. the minus sign is to minimise cost so
find the highest weighted score
W_approach= 0.1; %weight given to approach
W_HS= 0.1; %weight given to H&S
W_experience= 0.30; %weight given to experience
W_resouces= 0.1; %weight given to resources
W_programme= 0.1; %weight given to programme
sigma_overrun_cost= 32090.25; % obvious
mu_overrun_cost=6327; % a bit high
mu_overrun_time=1;
sigma_overrun_time=10; %some projects finish early

tender_score(1:num_sim,1:num_tenders,1:num_crit)= 0; %set up the matrix - it
is faster this way 1st dim = simulation number, 2nd = tender number, 3rd =
criteria
results(1:num_sim,1:11)=0; %set up the results matrix

corr(1:8,1:8)=1; % easy to set leading diagonals
corr(1,2) = -0.44; % price and approach
corr(1,3) = -0.02; % price and H&S
corr(1,4) = -0.56; % price and experience
corr(1,5) = 0.04; % price and resources
corr(1,6) = -0.37; % price and programme
corr(1,7) = -0.58; % price and overrun costs
corr(1,8) = -0.026; % price and delay
```

```
corr(2,3) = 0.48; % approach and H&S
corr(2,4) = 0.66; % approach and experience
corr(2,5) = 0.62; % approach and resources
corr(2,6) = 0.49; % approach and programme
corr(2,7) = 0.0; % approach and Overrun costs
corr(2,8) = 0.0; % approach and delay

corr(3,4) = 0.46; % H&S and experience
corr(3,5) = 0.19; % H&S and resources
corr(3,6) = 0.09; % H&S and programme
corr(3,7) = 0.0; % H&S and overrun costs
corr(3,8) = 0.0; % H&S and delay

corr(4,5) = 0.42; % experience and resources
corr(4,6) = 0.22; % experience and programme
corr(4,7) = 0.0; % experience and overrun costs
corr(4,8) = 0.0; % experience and delay

corr(5,6) = 0.54; % resources and programme
corr(5,7) = 0.0; % resources and overrun costs
corr(5,8) = 0.0; % resources and delay

corr(6,7) = 0.0; % programme and overrun costs
corr(6,8) = 0.0; % programme and delay

corr(7,8) = 0.33; % overrun cost and delay

%flip the matrix to make it symmetrical
for i =2:num_crit
    for j=1:i-1
        corr(i,j)=corr(j,i);
    end
end
[V,D]=eig(corr); % find the eigen values and vectors
%alter the diagonal elements to get rid of negative values - note this will
increase
%the overall variance of the model, but it has to be done to make the
%correaltions consistent.
for i = 1:num_crit
    if D(i,i)< 0
        D(i,i) =0.001;
    end
end
newcorr=V*D*inv(V); % reconstitute the covariance matrix
A=sqrtm(newcorr); %This matlab function finds A such that C=AA'
%The main simulation
for i=1:num_sim

    for tender=1:num_tenders %for each realisation of tenders

        for j=1:num_crit
            neta(j)=normrnd(0,1); %generate normal random numbers
        end
        correlated_normal=A*transpose(neta); % a vector of correlated normal
numbers. We need neta as a column vector
```

```
        % Now get the price as a log normal distribution with mean mu and
standard
        % deviation sigma. This is the first element of the output score


        for j=1:num_crit-2

tender_score(i,tender,j)=(cdf('Normal',correlated_normal(j),0,1)*0.6+0.4);
%the cdf function converts the normal random numbers into uniform 0.4,1
numbers
        end
        tender_score(i,tender,num_crit+1)=(correlated_normal(1)*sigma+mu);
%costs are normally distributed the last column is the tender price
        tender_score(i,tender,num_crit-1)=(correlated_normal(num_crit-
1)*sigma_overrun_cost+mu_overrun_cost); % These are the overrun costs

tender_score(i,tender,num_crit)=(correlated_normal(num_crit)*sigma_overrun_
time+mu_overrun_time); %These are the overrun days
    end
    % now we make our selections The results matrix contains the following
    % columns:
    % 1 the lowest cost tender
    % 2 its best value score
    % 3 Its cost
    % 4 its overrun costs
    % 5 its overrun time
    % 7 the best value tender
    % 8 its best value score
    % 9 its cost
    % 10 Its overrun costs
    % 11 its overrun time

    % The standard way of find a minimum and where it is
    results(i,1)=1; % thes first tender so far is the best
    best_price=tender_score(i,1,num_crit+1); % The cost of first tender

best_score=tender_score(i,1,1)*W_price+tender_score(i,1,2)*W_approach+tende
r_score(i,1,3)*W_HS+tender_score(i,1,4)*W_experience+tender_score(i,1,5)*W_
resouces+tender_score(i,1,6)*W_programme;% The weighted scores
    results(i,7)=1;
    results(i,2)=best_score;
    results(i,3)=best_price;
    results(i,4)=tender_score(i,1,num_crit-1);
    results(i,5)=tender_score(i,1,num_crit);
    results(i,7)=1;
    results(i,8)=best_score;
    results(i,9)=best_price;
    results(i,10)=tender_score(i,1,num_crit-1);
    results(i,11)=tender_score(i,1,num_crit);

    % now go through the rest of the tenders

    for tender=2:num_tenders %  best price
        if tender_score(i,tender,num_crit+1)<best_price
            results(i,1)=tender;
            best_price=tender_score(i,tender,num_crit+1);
```

```
results(i,2)=tender_score(i,tender,1)*W_price+tender_score(i,tender,2)*W_ap
proach+tender_score(i,tender,3)*W_HS+tender_score(i,tender,4)*W_experience+
tender_score(i,tender,5)*W_resouces+tender_score(i,tender,6)*W_programme;
            results(i,3)=best_price;
            results(i,4)=tender_score(i,tender,num_crit-1);
            results(i,5)=tender_score(i,tender,num_crit);
        end

score_test=tender_score(i,tender,1)*W_price+tender_score(i,tender,2)*W_appr
oach+tender_score(i,tender,3)*W_HS+tender_score(i,tender,4)*W_experience+te
nder_score(i,tender,5)*W_resouces+tender_score(i,tender,6)*W_programme;%
The weighted scores

        if score_test > best_score %  best score
            results(i,7)=tender;
            best_score=score_test;
            results(i,8)=best_score;
            results(i,9)=tender_score(i,tender,num_crit+1); %final cost
            results(i,10)=tender_score(i,tender,num_crit-1); % overrun cost
            results(i,11)=tender_score(i,tender,num_crit); % overrun delay
        end
        % warning flag if any criteria less than 50% for the best selected
        % tender then put a flag in column 6

        for crit_number= 1:num_crit-2
            if    abs(tender_score(i,results(i,7),crit_number))    <    0.5
%results(i,7,) is the number of the best tender and we are flagging i the
absolute value is less than 0.5
                results(i,6) = 1;
            end
        end


    end
end
```

4.3.6.1 Model description

```
%Script to calculate the weights for selecting a best value project
%The weights are uniformly distributed 1 to 100 and correlated to each
%other
% Price is normally distributed with mean of mu and a standard
% deviation of sigms.
% The decision criteria are to be added at the end
% row 1 = price
% row 2 = approach
% row 3 = health and safety
% row 4 = experience
% row 5 = resources
% row 6 = programme
% row 7 = overrun cost
% row 8 = delay
```

Above is a description of what the model does.

```
% Set some constants up
num_tenders=3; %How many companies submit a tender
num_sim=5000;
sigma=127711.17; %Standard deviation of price
mu=634861.33;%Mean of price
num_crit=8; % the 8 rows above
W_price= -0.3; %weight given to price. the minus sign is to minimise cost so
find the highest weighted score
W_approach= 0.1; %weight given to approach
W_HS= 0.1; %weight given to H&S
W_experience= 0.30; %weight given to experience
W_resouces= 0.1; %weight given to resources
W_programme= 0.1; %weight given to programme
sigma_overrun_cost= 32090.25; % obvious
mu_overrun_cost=6327; % a bit high
mu_overrun_time=1;
sigma_overrun_time=10; %some projects finish early
```

The first part of the model is to introduce the criteria and its weights. Project A, B, and C had 3, 4 and 5 contractors that tendered for the project respectively. The model will also check to see how the results are affected when the number of tenders increases. The model begins with 3: `num_tenders=3; %How many companies submit a tender`

The model is given 5000 realisations: `num_sim=5000;`

The next stage is to put in the mean and standard deviation of tender prices. For the demonstration, Project A's tender were used:

```
sigma=127711.17; %Standard deviation of price
```

```
mu=634861.33;%Mean of price
```

Next, the criteria and its weights are assigned:

```
W_price= -0.3; %weight given to price. the minus sign is to minimise cost so
find the highest weighted score
W_approach= 0.1; %weight given to approach
W_HS= 0.1; %weight given to H&S
W_experience= 0.30; %weight given to experience
W_resouces= 0.1; %weight given to resources
W_programme= 0.1; %weight given to programme
```

The idea of the model is to be able to respond to clients' needs; these are the same weights the client used in evaluating the contractors for Project A, B, and C. However in the model the price weight is intentionally given as -0.3: `W_price= -0.3; %weight given to price. The minus sign is to minimise cost so find the highest weighted score.`

This is because had the weight been given as a positive, the model would assume that that the higher the price, the higher the best value score. When in reality, it is the lower the price, the higher the best value score. Therefore, having the price weight as a negative would enable the model identify the lowest tender price as the highest best value score in the Price criteria. After the total best value score for each contractor is calculated, the model then adds a +0.3 to the scores to get the actual best value score of each of the contractors.

The next stage is to put in the mean and standard deviation of overrun costs and delay to expect for the best value tenderer. Remember that in the first model the mean and standard deviation of overrun costs (Diff) and delay for the lowest tenderer was put instead. The first model had a reliable dataset of 120 educational facilities project to work with. For this demonstration, the mean and standard deviation of overrun costs and delay was derived from the 20 best value tender projects (Dataset 3) used earlier:

```
sigma_overrun_cost= 32090.25; % std obvious
mu_overrun_cost=6327; % mean a bit high
mu_overrun_time=1;
sigma_overrun_time=10; %some projects finish early
```

The next stage is to put in the correlation between the 8 (the 6 used to evaluate contractors, and the overrun costs and delay time) criteria. In the first part of the model (under Section 4.3) it was explained that missing information leads to an inconsistent correlation matrix. In this demonstration, the main problem was the lack of a healthy dataset of best value selected projects and tender information with contractors' quality scores to work with.

```
tender_score(1:num_sim,1:num_tenders,1:num_crit)= 0; %set up the matrix - it is faster this way 1st dim = simulation number, 2nd = tender number, 3rd = criteria
results(1:num_sim,1:11)=0; %set up the results matrix

corr(1:8,1:8)=1; % easy to set leading diagonals
corr(1,2) = -0.44; % price and approach
corr(1,3) = -0.02; % price and H&S
corr(1,4) = -0.56; % price and experience
corr(1,5) = 0.04; % price and resources
corr(1,6) = -0.37; % price and programme
corr(1,7) = -0.58; % price and overrun costs
corr(1,8) = -0.026; % price and delay

corr(2,3) = 0.48; % approach and H&S
corr(2,4) = 0.66; % approach and experience
corr(2,5) = 0.62; % approach and resources
corr(2,6) = 0.49; % approach and programme
corr(2,7) = 0.0; % approach and Overrun costs
corr(2,8) = 0.0; % approach and delay

corr(3,4) = 0.46; % H&S and experience
corr(3,5) = 0.19; % H&S and resources
corr(3,6) = 0.09; % H&S and programme
corr(3,7) = 0.0; % H&S and overrun costs
corr(3,8) = 0.0; % H&S and delay

corr(4,5) = 0.42; % experience and resources
corr(4,6) = 0.22; % experience and programme
corr(4,7) = 0.0; % experience and overrun costs
corr(4,8) = 0.0; % experience and delay

corr(5,6) = 0.54; % resources and programme
corr(5,7) = 0.0; % resources and overrun costs
corr(5,8) = 0.0; % resources and delay

corr(6,7) = 0.0; % programme and overrun costs
corr(6,8) = 0.0; % programme and delay

corr(7,8) = 0.33; % overrun cost and delay

%flip the matrix to make it symmetrical
for i =2:num_crit
    for j=1:i-1
        corr(i,j)=corr(j,i);
    end
end
[V,D]=eig(corr); % find the eigen values and vectors
%alter the diagonal elements to get rid of negative values - note this will increase
%the overall variance of the model, but it has to be done to make the
%correaltions consistent.
for i = 1:num_crit
    if D(i,i)< 0
        D(i,i) =0.001;
    end
```

```
end
newcorr=V*D*inv(V); % reconstitute the covariance matrix
A=sqrtm(newcorr); %This matlab function finds A such that C=AA'
%The main simulation
for i=1:num_sim

    for tender=1:num_tenders %for each realisation of tenders

        for j=1:num_crit
            neta(j)=normrnd(0,1); %generate normal random numbers
        end
        correlated_normal=A*transpose(neta); % a vector of correlated normal
numbers. We need neta as a column vector
```

Table 4.3.21: Correlation between the criteria

	Price	Approach	H&S	Exp.	Res.	Prog.	OC	Delay
Price	1	-0.44	-0.02	-0.56	0.04	-0.37	-0.58	-0.026
Approach	-0.44	1	0.48	0.66	0.62	0.49	0.0	0.0
H&S	-0.02	0.48	1	0.46	0.19	0.09	0.0	0.0
Exp.	-0.56	0.66	0.46	1	0.42	0.22	0.0	0.0
Res.	0.04	0.62	0.19	0.42	1	0.54	0.0	0.0
Prog.	-0.37	0.49	0.09	0.22	0.54	1	0.0	0.0
OC	-0.58	0.0	0.0	0.0	0.0	0.0	1	0.33
Delay	-0.026	0.0	0.0	0.0	0.0	0.0	0.33	1

Table 4.3.21 shows the correlation between the contractor scores in the criteria used to evaluate them, the Overrun Cost and Delay. However, the Overrun Cost and Delay criteria is not in the equation when evaluating a winning contractor. This is because the overrun cost and delay are only known after a project is completed. The correlation between Price (the best value selected Price), Overrun Cost, and Delay was derived from the 20 Projects in Dataset 3. Though this may not be enough when doing an actual comparison between lowest tender and best value tender, it is enough for this demonstration of how the model would have accounted for the quality scores of the contractor. Furthermore, we see that the correlation between overrun cost and delay and all the other criteria are given as 0, which means that in the model they have no relationship. However, this is often not the case; remember that the Programme criteria evaluates contractors based on the deliverability and speed of their programme. Therefore, we would assume that there will be a negative correlation between the Programme criteria and Delay; the higher the Programme score the lower the Delay time. However, the Delay and Overrun

cost do not factor into the initial criteria of evaluating contractors, simply because they are known after a project has been completed and only for the contractor selected.

When the correlations in Table 4.3.21 was inputted into the model, it initially produced an inconsistent matrix in Table 4.3.22.

Table 4.3.22: Inconsistent matrix

	Price	Approach	H&S	Exp.	Res.	Prog.	OC	Delay
Price	1	-0.44	-0.02	-0.56	0.04			
	0.37	0.58	0.26					
Approach	-0.44	1	0.48	0.66	0.62	0.49	0.0	0.0
H&S	-0.02	0.48	1	0.46	0.19	0.09	0.0	0.0
Exp.	-0.56	0.66	0.46	1	0.42	0.22	0.0	0.0
Res.	0.04	0.62	0.19	0.42	1	0.54	0.0	0.0
Prog.	-0.37	0.49	0.09	0.22	0.54	1	0.0	0.0
OC	-0.58	0.0	0.0	0.0	0.0	0.0	1	0.33
Delay	-0.026	0.0	0.0	0.0	0.0	0.0	0.33	1

Instead of randomly altering values to create a consistent matrix the following method was invented. Using the mathematics of PCA we calculate the eigenvectors of the correlation matrix. The eigenvalues ($\mathbf{l}$) correspond to the variance of principal components in the rotated space and the eigenvectors ($\mathbf{v}$) the direction of this rotation. The equation is:

$$\mathbf{Cv} = \mathbf{lv}$$

Below is the eigenvalue for this matrix

Table 4.3.23: Diagonal elements of D

0.001	0	0	0	0	0	0	0
0	0.251165	0	0	0	0	0	0
0	0	0.519385	0	0	0	0	0
0	0	0	0.581528	0	0	0	0
0	0	0	0	1.019434	0	0	0
0	0	0	0	0	1.085098	0	0
0	0	0	0	0	0	1.625707	0
0	0	0	0	0	0	0	2.962585

Traditionally we make the values a diagonal matrix and the vectors correspond to a square matrix. In multivariate statistics, PCA says that the variance in some transformed dimensions so small that it could be considered zero. In this case because of the inconsistent correlation matrix we have a negative variance. Clearly this is not possible in the real world and it has only happened because we have been doing pairwise correlations or due to the small sample size used in this demonstration. The following rule for making the minimum possible alteration to a correlation matrix to make it consistent was devised.

1. Calculate the eigenvectors and eigenvalues of the correlation matrix $\boldsymbol{C}$. In MATLAB, these form a diagonal matrix $\boldsymbol{L}$ of eigenvalues and a square matrix **V** of eigenvectors.
2. Replace any negative eigenvalues with zero $\boldsymbol{L1}$.
3. Reconstitute the correlation matrix with $\mathbf{C}=\mathbf{VLV}^{-1}$

It is important to note that since the mathematics is derived for covariance, the leading diagonal terms are no longer exactly 1.0. This does not matter. The following consistent matrix is then produced, which is close to the original correlations (Table 4.3.21) inputted into the model. Table 4.3.23 shows the diagonal elements of **D** and Table 4.3.24 shows the consistent matrix.

Table 4.3.24: Consistent matrix

	Price	Approach	H&S	Exp.	Res.	Prog.	OC	Delay
Price	1.02	-0.43	-0.03	-0.55	0.03	-0.36	-0.57	-0.03
Approach	-0.43	1.00	0.48	0.66	0.62	0.49	0.00	0.00
H&S	-0.03	0.48	1.00	0.46	0.19	0.09	0.00	0.00
Exp.	-0.55	0.66	0.46	1.01	0.41	0.22	0.01	0.00
Res.	0.03	0.62	0.19	0.41	1.01	0.54	-0.01	0.00
Prog.	-0.36	0.49	0.09	0.22	0.54	1.00	0.00	0.00
OC	-0.57	0.00	0.00	0.01	-0.01	0.00	1.01	0.33
Delay	-0.03	0.00	0.00	0.00	0.00	0.00	0.33	1.00

The next stage was to instruct the model to reproduce 5000 realisations of tender information given the correlation inputted.

```
        % Now get the price as a log normal distribution with mean mu and
standard
        % deviation sigma. This is the first element of the output score
```

```
        for j=1:num_crit-2

tender_score(i,tender,j)=(cdf('Normal',correlated_normal(j),0,1)*0.6+0.4);
%the cdf function converts the normal random numbers into uniform 0.4,1
numbers
        end
        tender_score(i,tender,num_crit+1)=(correlated_normal(1)*sigma+mu);
%costs are normally distributed the last column is the tender price
        tender_score(i,tender,num_crit-1)=(correlated_normal(num_crit-
1)*sigma_overrun_cost+mu_overrun_cost); % These are the overrun costs

tender_score(i,tender,num_crit)=(correlated_normal(num_crit)*sigma_overrun_
time+mu_overrun_time); %These are the overrun days
    end
```

The model is specifically instructed to initially expect contractors' quality score for individual criterion to be between 0.4 and 1; meaning 40% to 100%:

```
 tender_score(i,tender,j)=(cdf('Normal',correlated_normal(j),0,1)*0.6+0.4);
%the cdf function converts the normal random numbers into uniform 0.4,1
numbers
```

The reason for this is because the client that provided the 3 projects used for this demonstration, stated that a contractor with a score below 50% (from 40% to 49%) for one of its criterion is treated with caution. Although this does not necessarily mean that the client cannot work with the contractor. By looking at the weights assigned to the criteria, we see that Price and Experience carries the most weight with 30% each; the other 40% is shared equally between the other 4 criteria. This means that a contractor would likely get away with having a low score in any criteria other than Price and Experience.

As the model moves along, it produces standardised indices of price (tender prices), overrun costs and delay time. These are correctly formatted by multiplying the indices by the mean and standard deviation of price, overrun costs and delay that has been given to it:

```
    tender_score(i,tender,num_crit+1)=(correlated_normal(1)*sigma+mu);
%costs are normally distributed the last column is the tender price
        tender_score(i,tender,num_crit-1)=(correlated_normal(num_crit-
1)*sigma_overrun_cost+mu_overrun_cost); % These are the overrun costs

tender_score(i,tender,num_crit)=(correlated_normal(num_crit)*sigma_overrun_
time+mu_overrun_time); %These are the overrun days
    end
```

The next stage is then to apply the weights to the standardised indices of all the criteria used to evaluate contractors generated by the model. By this time in the model the tender prices have been formatted to produce different sets of contractor tenders. All the other criteria will produce scores between 0.4 to 1 or 40% to 100% for each contractor that submits a tender price.

```
% now we make our selections The results matrix contains the following
    % columns:
    % 1 the lowest cost tender
    % 2 its best value score
    % 3 Its cost
    % 4 its overrun costs
    % 5 its overrun time
    % 7 the best value tender
    % 8 its best value score
    % 9 its cost
    % 10 Its overrun costs
    % 11 its overrun time

    % The standard way of find a minimum and where it is
    results(i,1)=1; % the first tender so far is the best
    best_price=tender_score(i,1,num_crit+1); % The cost of first tender

best_score=tender_score(i,1,1)*W_price+tender_score(i,1,2)*W_approach+tende
r_score(i,1,3)*W_HS+tender_score(i,1,4)*W_experience+tender_score(i,1,5)*W_
resouces+tender_score(i,1,6)*W_programme;% The weighted scores
    results(i,7)=1;
    results(i,2)=best_score;
    results(i,3)=best_price;
    results(i,4)=tender_score(i,1,num_crit-1);
    results(i,5)=tender_score(i,1,num_crit);
    results(i,7)=1;
    results(i,8)=best_score;
    results(i,9)=best_price;
    results(i,10)=tender_score(i,1,num_crit-1);
    results(i,11)=tender_score(i,1,num_crit);
```

The code above shows that the model is instructed to identify the contractor with the lowest tender price first. Then multiply the lowest tenderers' score by the weights assigned to each of the criteria to get the lowest tenderers' overall best value score.

```
for tender=2:num_tenders %  best price
        if tender_score(i,tender,num_crit+1)<best_price
            results(i,1)=tender;
            best_price=tender_score(i,tender,num_crit+1);

results(i,2)=tender_score(i,tender,1)*W_price+tender_score(i,tender,2)*W_ap
proach+tender_score(i,tender,3)*W_HS+tender_score(i,tender,4)*W_experience+
tender_score(i,tender,5)*W_resouces+tender_score(i,tender,6)*W_programme;
            results(i,3)=best_price;
            results(i,4)=tender_score(i,tender,num_crit-1);
            results(i,5)=tender_score(i,tender,num_crit);
        end

score_test=tender_score(i,tender,1)*W_price+tender_score(i,tender,2)*W_appr
oach+tender_score(i,tender,3)*W_HS+tender_score(i,tender,4)*W_experience+te
nder_score(i,tender,5)*W_resouces+tender_score(i,tender,6)*W_programme;%
The weighted scores

        if score_test > best_score %  best score
```

```
            results(i,7)=tender;
            best_score=score_test;
            results(i,8)=best_score;
            results(i,9)=tender_score(i,tender,num_crit+1); %final cost
            results(i,10)=tender_score(i,tender,num_crit-1); % overrun cost
            results(i,11)=tender_score(i,tender,num_crit); % overrun delay
        end
        % warning flag if any criteria less than 50% for the best selected
        % tender then put a flag in column 6
```

The model is then instructed to go through the rest of the contractors that submitted a tender and find its best value score. By doing so we can then find who the lowest tenderer is, and who the best value tenderer is (or if the lowest tenderer is the best value tender) for each realisation.

```
for crit_number= 1:num_crit-2
            if    abs(tender_score(i,results(i,7),crit_number))    <    0.5
%results(i,7,) is the number of the best tender and we are flagging i the
absolute value is less than 0.5
                results(i,6) = 1;
            end
        end


    end
end
```

Finally, the model is instructed to signal a warning if the winning contractor scores less than 50% in any of the criteria. However, the client that provided the tender information stated that a less than 50% score in any criteria does not necessarily result in an automatic disqualification of the contractor in question. Therefore, the last part of the model would help clients know how likely a less than 50% score in any criteria is for the winning contractor.

It is important to note that the results generated from the model are from only 3 projects where the tender prices and quality scores of all the contractors were provided. As well as the projects in Dataset 3 (20) to get the mean and standard deviation of overrun cost and delay of the best value selected tenderer.

In the 3 projects provided, each had a different number of submitted tenders (3, 4, and 5). One thing to investigate is what happens when there is a change to the number of tenderers, and of course to the weights. So, let us begin with looking at the results for 3 contractors; with the initial weight ratio of 30% Price and 70% Quality:

- The percentage of Warning (a criterion score of less than 50%) of all selected tenders: **56%.**
- The percentage of time the lowest tender turns out to be the best tender: **68%.**

- The percentage of Warning (a criterion score of less than 50%) when the Best Value tender selected is not the lowest tender: **39%.**
- The average best value score of the best value contractor who is also the lowest tenderer: **70%.**
- The average best value score of the lowest tendered contractor who is not the best value contractor: **58%.**
- The average best value score of the best value contractor who is not the lowest tenderer: **66%.**

The tender information provided in Table 4.3.20 shows that the lowest tenderer still ended up being the best value tender despite it having a less than 50% score in one of its criteria. As the sample size is just 3 projects, this increases the probability of having the winning contractor score less than 50% in one of its criteria in the model (56%). Although this decreases to 39% when the best value tenderer is not the contractor with the lowest price. Furthermore, the probability of the lowest tenderer being the best value contractor is high at 68%. This is attributed to the weights given to the criteria. The two criteria that seem to work in the lowest tenderers' favour are Price and Experience. From the tender information given from Table 4.3.18 to Table 4.3.20, the lowest tender seems to have the most experience (or at least an adequate score of 80%). This results in a negative correlation between the 2 criteria of -0.55; meaning the lower the price, the higher the experience. From the tender information provided it seems that the lowest tender does well in Experience due to its history of winning more projects. The model shows that the lowest tenderer would have to average an overall best value score of 58%, while another contractor must average an overall score of 66% to win the project off of the lowest tenderer. Now let us see what happens when the number of contractors is increased to 4:

- The percentage of Warning (a criterion score of less than 50%) of all selected tenders: **62%.**
- The percentage of time the lowest tender turns out to be the best tender: **61%.**
- The percentage of Warning (a criterion score of less than 50%) when the Best Value tender selected is not the lowest tender: **45%.**
- The average best value score of the best value contractor who is also the lowest tenderer: **73%.**
- The average best value score of the lowest tendered contractor who is not the best value contractor: **61%.**
- The average best value score of the best value contractor who is not the lowest tenderer: **69%.**

The probability of getting a red flag (a criterion score of less than 50%) from all selected tenders increases slightly. This is simply because there are more tenders to consider. We also find a slight increase in the probability of getting a red flag when the Best Value tender selected is not the lowest tender. While the probability that the lowest tender turns out to be the best value contractor decreases. The remaining results each yielded a 3% increase when the number of tenderers increased to 4. Now let us see what happens when the number of contractors is increased to 5:

- The percentage of Warning (a criterion score of less than 50%) of all selected tenders: **66%.**
- The percentage of time the lowest tender turns out to be the best tender: **56%.**
- The percentage of Warning (a criterion score of less than 50%) when the Best Value tender selected is not the lowest tender: **51%.**
- The average best value score of the best value contractor who is also the lowest tenderer: **74%.**
- The average best value score of the lowest tendered contractor who is not the best value contractor: **63%.**
- The average best value score of the best value contractor who is not the lowest tenderer: **71%.**

The model shows a similar pattern; the probability of getting a red flag (a criterion score of less than 50%) from all selected tenders increases slightly. We also find a slight increase in the probability of getting a red flag when the Best Value tender selected is not the lowest tender. While the probability that the lowest tender turns out to be the best value contractor decreases. We also see a slight increase in the remaining results when the number of tenderers increases from 4 to 5. Therefore, with a weight of 30% for Price, 30% for Experience, and 10% each for the remaining 4 criteria. The lowest tender has a more than 50% chance of being the best value winning contractor when there is a total of 5 contractors in contention. This probability increases as the number of tenderers reduces from 5 to 4 to 3. Another thing to investigate is how this probability is affected when the price weight is increased to 50%. To do this we add 20% to the price and subtract 4% from the other 5 criteria, given us a weight of:

- Price 50%
- Approach 6%
- Health & Safety 6%
- Experience 26%
- Resources 6%
- Programme 6%

This resulted in a higher probability of the lowest tenderer turning out to be the best value winning contractor. When there are 3 tenders the probability stands at **79%**; 4, **74%**, and 5, **71%**. Therefore, the weight criteria were then reduced to 20%, given us a weight of:

- Price 20%
- Approach 12%
- Health & Safety 12%
- Experience 32%
- Resources 12%
- Programme 12%

This resulted in there being a better than average chance of the lowest tenderer turning out to be the best value winning contractor. When there are 3 tenders the probability stands at **61%**; 4, **55%**, and 5, **51%**. Therefore, Price would have to be reduced to below 20%, for the lowest tender not to have a more than 50% chance of winning the contractor. The other results followed the same pattern, so from the model we draw the following conclusions from the demonstration:

- **The higher the number of tenderers the higher the percentage of Warning (a criterion score of less than 50%) of all selected tenders.**
- **The higher the number of tenderers the lower the percentage of time the lowest tender turns out to be the best tender.**
- **The higher the number of tenderers the higher the percentage of Warning (a criterion score of less than 50%) when the Best Value tender selected is not the lowest tender.**
- **The higher the number of tenderers the higher the average best value score of the best value contractor who is also the lowest tenderer.**
- **The higher the number of tenderers the higher the average best value score of the lowest tendered contractor who is not the best value contractor.**
- **The higher the number of tenderers the higher the average best value score of the best value contractor who is not the lowest tenderer.**
- **Given the weight distribution, the weight of Price would have to be less than 20% for the lowest tenderer not to have a more than 50% chance of being the best value winning contractor.**

Table 4.3.25 shows the percentage of time the lowest tender turns out to be the best value tender per weight of Price

Table4.3.25: The percentage of time the lowest tender turns out to be the best value tender per weight of Price

Weight given to price %	No. of Tenders %		
	3	4	5
20	61%	55%	51%
30	68%	61%	56%
50	79%	74%	71%

Still after drawing these conclusions, the main question of the research has not yet been answered. Which is, how will the lowest tenderer fare in a project that has awarded the contract to the best value tender whose price is not the lowest price? The above results allow us to also look at the quality score of the contractor, as well as the final costs and time of the project. The model results for this demonstration shows that the lowest tendered contractor would on average incur a lesser cost of **£80,867.28** to deliver the project with a standard deviation of **£66,552.04** had it been awarded the contract instead; this equates to a 12.5% decrease in final cost. Furthermore, the lowest tenderer would likely complete the project marginally slower (average of **less than a day** with a standard deviation of just under **15 days**) than the best value contractor with a higher price; which equates to a less than 1% increase.

Figure 4.3.20: Lowest Tenderers' Overrun Cost

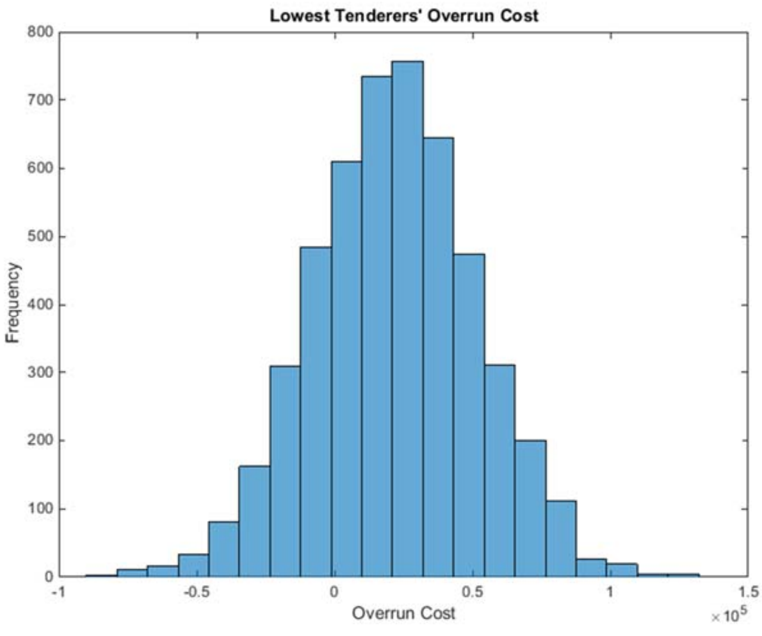
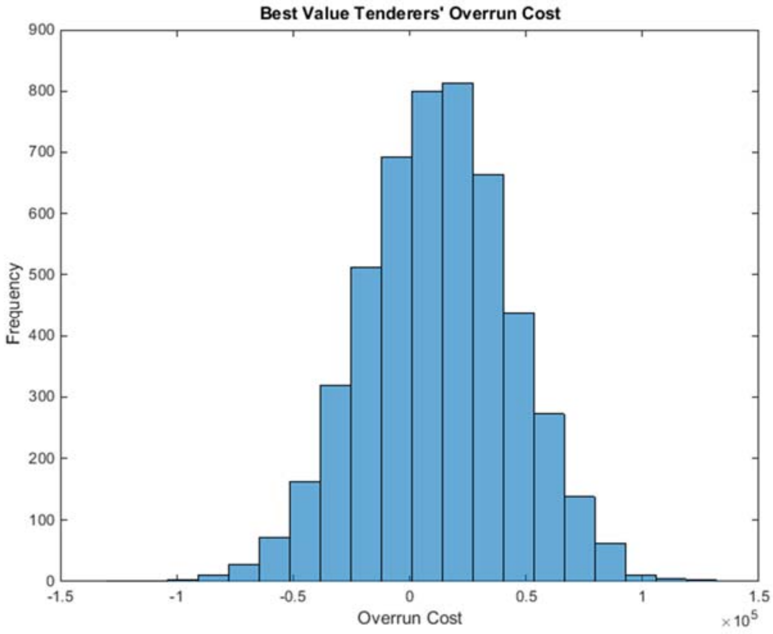


Figure 4.3.21: Best Value Tenderers' Overrun Cost



From the 3 projects used to demonstrate in this section, we find that the lowest tenderer usually had an average score in the programme criteria. The programme criteria evaluate the contractor based on their speed and deliverability of its programme. However, this criterion had a weight 10% compared to Price and Experience that was 30%. Therefore, this signifies that the client will accept the project finishing slightly later than anticipated if it is completed with know-how and low cost.

Figure 4.3.22: Lowest Tenderers' Delay

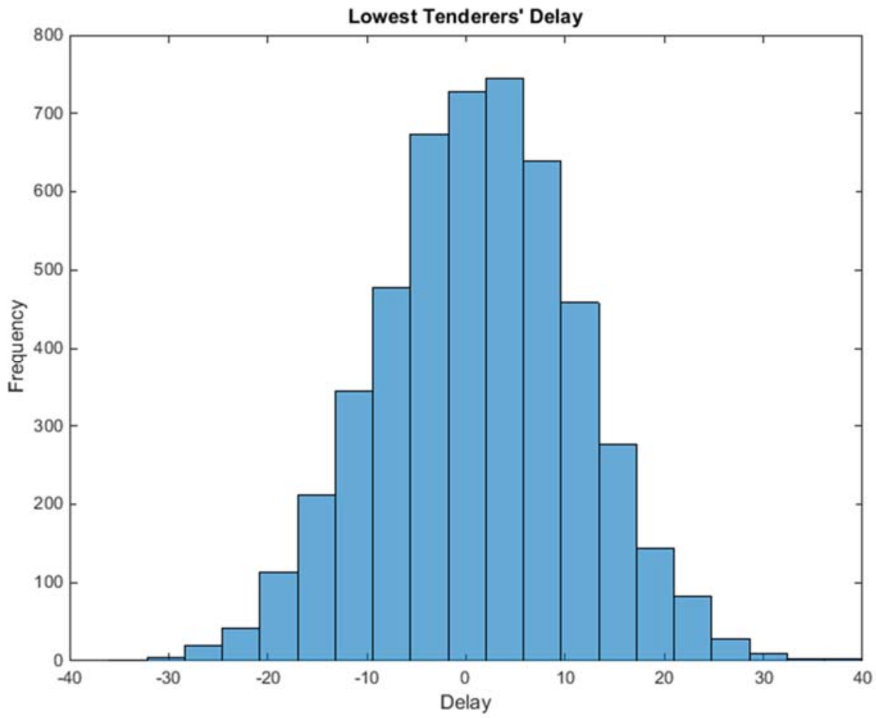
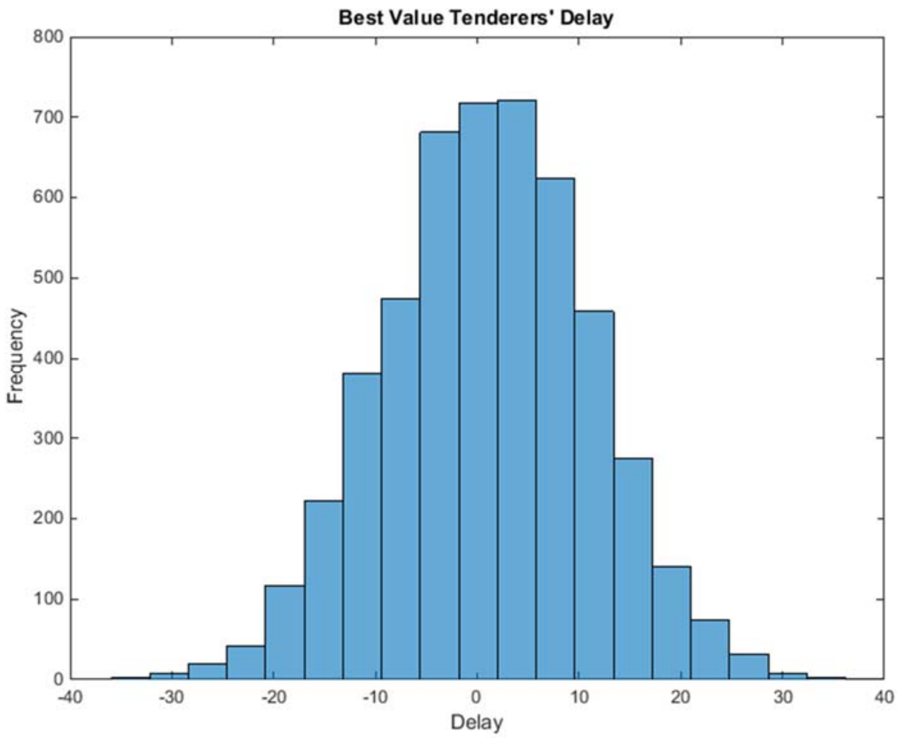


Figure 4.3.23: Best Value Tenderers' Delay



Finally, when the lowest tender is not the best value winning contractor, the lowest tenders' quality averages between 52% and 65%. While the best value contractor whose price is not the lowest price has an average score between 58% an 75%. Again, the purpose of the research is not to help select the best value contractor; rather to provide quantifiable information to help clients select a strategy to with. For example, the model recorded that lowest tendered contractor would on average incur a higher overrun cost of **£27,985.02** than the best value contractor if it was given the contract instead. The tender information in Table 4.3.18 shows us that if the overrun cost was **£27,985.02,** then this is just over the price of the second lowest tender (by **£1,557.02**). If the second highest tender is the best value contractor, the client could risk going with the lowest tender if it does not mind losing £1,557.02 more of what it could have paid the best value contractor for the project. It ultimately boils down to how risk averse the clients are. If for example this mean of **£27,985.02** was applied to the 2 other projects that were used for this demonstration the client could easily have selected the lowest tender despite it not being the best value tender. This is because even if it had incurred the whole **£27,985.02**, it would still below what it was going to pay the second lowest tender, if the second lowest tender is the best value tender. Furthermore, the model shows that there is a 68% chance that the lowest tender would be the best value tender. So, in Dataset 2 that awarded every project to the lowest tenderer, 12 out of the 20 projects would still be awarded to the lowest tender if the client decided to use the best value strategy. The likelihood of Contractor B or C (in Table 4.3.18) being selected as the best value tender is small compared to Contractor A.

Therefore, the demonstration section has shown the model would have incorporated contractors' quality scores had they been provided using 3 projects of the same client. The dataset used for this demonstration is far from adequate to extract meaningful results. However, the aim of this section was to use the dataset to produce the type of results shown in this section. Having said that, when we look at the tender information provided for this demonstration it is easy to see why the lowest tenderer often end up winning contracts in Educational facilities projects in the UK. And why it was difficult to find a healthy dataset of projects that awarded to the best value contractor whose price is not the lowest price. If this is the standard weighting of criteria in these sector, then the lowest tenderer would usually be the best value tender unless the weights of price falls to below 20%. Yu and Wang (2012) mentions how the market should dictate whether to adopt the best value or the lowest tender strategy. The model done on Educational facilities projects in the UK points to the fact that, the lowest tenderer fares well in this sector; especially when they are in their clients' preferred contractors' lists. Appendix 7 shows the model's flow diagram stating the steps undertaken to develop the model for the Quality Demonstration.

4.4 SUMMARY

Project outcomes (cost and duration) information are usually generated on any construction project. When information is extracted in a meaningful and clear way for a number projects, this ultimately results to a valuable database. Using data processing techniques, the database can be converted into an important decision support system that could help industry practitioners make better decision at the early stage of the project; in this case, on what strategy to select.

The research began by examining the sources of overruns on construction projects; mainly to gauge the effect a contractor has on the outcome of a project. It was found that there were many reasons as to why a project may incur an overrun that is not limited to the contractor. However, a contractor still has an important role to play in a successful completion of a project. One reason for overruns given in the literature is strategic misrepresentation or the underestimation of project works; which can be done by a contractor to win a project. This has led to more recommendation of the best value strategy in selecting contractors.

Picking the lowest tender is a clear and straightforward strategy, picking the best value strategy is not. Therefore, the research examined the existing studies that have developed models to aid in picking contractors on best value. The aim of the research was to subsequently provide a method of seeing the effect that the strategies had on the outcomes of the project: Final Cost and Duration.

This was executed by developing a Monte-Carlo simulation model using 120 completed educational facilities projects in the UK, all of which selected the lowest tender. The model went through an initial testing phase, where it was tested on a further 10 projects that selected the lowest tender from the same database. Before, it was validated on a further 20 projects provided by a consultant that selected the lowest tender where facts could be double checked. As the model could capture the probability distribution of outcomes in both the testing and validation phase, it was then fit to be applied in projects that selected the best value tender whose price is not the lowest price. This were done to see the probability distribution of outcomes on how the lowest tender would likely fare in a similar project that selects the best value contractor with a higher price.

It is acknowledged that in the best value projects (Dataset 3), contractors' quality scores were not provided, thus in some cases this could have meant that the lowest tender was not even fit enough to carry out the works. However, the basis of the research is to show that the method is capable of investigating the effect of a contractor selection strategy on the outcomes of a project. Thus, moving forward with more reliable information, the model will produce more reliable results. The model was developed using the BCIS database, however the model can also be tailored to an individual client's database.

Therefore, the model will particularly be useful in helping a client decide on what strategy to select: lowest or best value tender. The idea of the model is not to advocate a strategy, rather to see the effect the strategy has on outcomes. The method and approach adopted to develop the models can be extended to incorporate clients' needs as long as relevant data can be acquired.

Chapter 5: CONCLUSION

5.0 INTRODUCTION

This chapter would therefore make sense of the key findings and results by linking the arguments and the results in the body of the thesis to the main aim, objectives and research questions set out in the introductory chapter. Finally, suggestions will be put forward for further research.

5.1 REVIEW OF MAIN AIM AND OBJECTIVES

Aim: *To provide a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies.*

This was achieved by developing a model that shows how the lowest tenderer would have likely fared in a project that has been awarded to the best value tenderer whose price is not the lowest price. Below are the key points that describe the model:

1. **It considered the strategy used to select a contractor. Therefore, it did not analyse past projects alone, it considered the contractor selection strategy used in a project.**
2. **It is not aiming to predict the final cost of a project, rather to predict the probability distribution of final outcomes (final cost and final duration when the quality criteria and scores of contractors are not given) given a contractor selection strategy.**
3. **When quality criteria, weights of criteria and contractors scores are provided; the model would be able to show:**
   - **The lowest price tender**
   - **Its best value score**
   - **Its final cost**
   - **Its overrun costs**
   - **Its overrun time**
   - **The best value tender**
   - **Its best value score**
   - **Its final cost**
   - **Its overrun costs**
   - **Its overrun time**
4. **By providing (3), the model would also be able identify when the lowest tenderer is the best value tender and how often that is the case.**

The objectives represent the steps taken to develop the model.

Objective a): Identify and collect a reliable dataset of past projects.

The dataset used to develop the model was from the BCIS database. In this database, data from 120 UK educational facilities projects were extracted to develop the model; all of which selected the lowest tender. Data processing techniques were then utilised to clean the data derived from projects. See Section 4.2. The BCIS database is the leading provider of cost and price information to the construction industry. Section 3.3 mentioned how the BCIS database is considered a traditional method of estimating costs; and it is used by clients, contractors, and consultants. Their historic data goes back 50 years. Furthermore, it has also been used to conduct research; "*Wall (1997) collected 216 office building from the BCIS database of RICS to outline the issues that should be recognised when using Monte Carlo methods (Section 3.4.2.1).*"

Objective b): Investigate the probability distribution of final costs and duration for construction projects: by modelling the tenders to determine the total outcome cost and duration arising from selecting contractors on the lowest tender strategy

After the model was developed in **Objective a)**, a further 10 similar projects from the BCIS database that selected the lowest tender was then used to test the model. In Appendix 1 we see that the model actual project results were within the probability distribution of outcomes that the model predicted.

Objective c): Validate the model on recent project cases.

The model was developed with Dataset 1, and after it was tested in **Objective b)**, a further 20 projects that selected the lowest tender (Dataset 2) were used to validate the model. The projects were received from industry partners, and the outcomes were verified and double checked to subsequently validate the model. Appendix 2 shows that the model captures the actual results of this project in its probability distribution of outcomes. Cost overruns are usually presented in percentages, for example, Project A overran by 20%. However, the findings show that even though the lowest tenderer will likely overrun in cost, the final cost is usually below the starting price of the second or third lowest tender. On the other hand, the discussion in Section 4.3.4 suggests that even though clients select contractors from a preferred list, regular assessment is needed.

Objective d): Apply the model on best value selected tender projects

The model was now fit enough to be applied on projects that selected the best value tender with a higher price. Appendix 3 and the Sensitivity Analysis conducted in Section 4.3.5 showed that in terms of final cost, the likelihood of the lowest tender resulting in the overall best tender, even if they incur cost overruns is good. However, there is more risk of project delay, though this had no obvious effect on the final cost. So, what does the client value the most? Delivering projects cheaper or on time? Assaf and Al-Heij (2006) study of projects in Saudi Arabia attributed project delay to clients using the lowest tender strategy. Olaniran (2015) also listed project delay as the most important problem triggered by using the lowest tender strategy. Cost overrun was listed as the fourth ranked performance problem; behind non-compliance with construction standards, and reduced quality. The findings from using educational facilities projects show that clients should be more concerned with project delays than cost when awarding to the lowest tender. In Chapter 1, it was mentioned that only 56% of project delivered on cost estimates in 2015, and only 48% delivered on time estimates. But the Glenigan Report (2016) reported that that percentage of clients that scored their projects 8/10 or better in 2015 for product, service, and value for money were over 70%. On one hand, this can be interpreted that cost and duration are not key performance indicators. Section 3.2.2.4 has however shown that in the literature this is not the case. On the other hand, this can also be interpreted as even though only 56% and 48% of projects met cost and time estimates, the final outcomes (especially in regards to cost) were still acceptable. The conventional way of presenting cost and time overruns in percentages is fine, but it may not tell the full story.

5.2 ANSWERING THE RESEARCH QUESTIONS THAT WILL GUIDE THE RESEARCH IN ACHIEVING ITS AIM

As the aim and objectives of the research was achieved, a response is now provided for the research questions formulated in the introductory chapter. The objectives stated above where the steps taken to achieve the aim of the research. The research questions however are questions that needs to be answered to establish the basis of carrying out the main aim of the research in the first place. The main aim of the research is to provide a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies. Therefore, the research is looking at the impact of a contractor selection strategy on the outcome of a construction projects. The first step was to know the sources that can affect the outcome of a project. Once it was established that contractor selection strategy was one of the factors that affected the outcome of a project, the basis of investigating the relationship between them were established. However, in construction, the term procurement is to do with the structure by which a project will be delivered and not just the selecting of contractors/supplier. The contractor selection strategy is part of a structure; therefore, it was important to know what these procurement and tendering methods are and to what extent it influenced the strategy used to select a contractor. Once this was established, it was important to know whether MCS was a suitable tool to develop a model able to investigate the relationship between contractor selection strategy and project outcome.

1. *What are the sources of overruns stated in the existing literature?*

In Section 2.2 we see a plethora of reasons as to why a project may incur cost overruns or delay in project duration. The reasons include wrong contractor selection, strategic misrepresentation (deception), optimism bias (delusion), scope/design changes, changes in the exchange rate, force majeure, etc. (see Crantelli et al., 2010 and Flyvbjerg, 2008). Strategic misrepresentation for one, is directly linked to wrong contractor selection. This is when a contractor would deliberately underestimate estimates to win the project. Optimism bias is another which goes hand-in-hand with strategic misrepresentation. This refers to clients that are overly optimistic about the implementation of projects. Thus, they would usually select the lowest tenderer believing that the lowest tenderer would deliver the project at their stated price.

2. *Is there a relationship between contractor selection strategy and project outcomes?*

Yes, there is, the answer is directly linked to that of Question 1. Furthermore, the answer to **Objective d)**, and Section 2.3.1 have pointed out various other research that have attributed project performance problems such as reduced quality and project delays to awarding to lowest tender. However, from the answer to the previous question it is clear that contractor selection is not the only reason to a successful project. There are other reasons, sometimes unforeseen that can have a negative impact on project outcomes, such as design changes and force majeure.

3. *What are the current procurement and tendering methods in the UK construction industry?*

Section 2.3 give us the different procurement and tendering methods in the UK construction industry. The Traditional Method is still the most used method and in these methods the lowest tender is usually selected. There is an increase in the use of selective tendering, whereby a client has a list of preferred contractors and subsequently pick the contractor that offers the lowest price when there is a project.

4. *To what extent do these methods affect the contractor selection strategy?*

This is answered in Research Question 3; the procurement and tendering method dictates the strategy that will be used. A project using the Traditional Procurement method will usually award to the lowest tender. If it is a selective tendering method, it makes little sense to select anything other than the lowest tendered contractor, especially when there is a good working history between the client and the contractors. The question now becomes, how often do clients evaluate contractors on those lists? This should be done regularly to ensure that contractors are able to deliver on future projects. In Section 2.3 we see that more procurement methods have been introduced recently that aim to encourage clients not just to award contract to the lowest tender.

5. *Is Monte Carlo simulation the appropriate method of investigating the relationship between contractor selection and project outcomes?*

The results achieved at the development phase of the research (Chapter 4) demonstrate that a MCS model can appropriately predict the probability distributions of outcomes given the selection criteria. Section 3.4 show us that the concept of MCS is not new, that it has indeed been applied in construction before. The advantage of the model is that it does not aim to predict an outcome, but rather to show the probability distribution of outcomes. Furthermore, its ease of use, power, and the ability to handle complex information, made it an appropriate tool for this research.

5.3 RESEARCH CONTRIBUTION

The aim and objectives of the research has been achieved; the research question has also been answered. It is now important to place the research within the wider context of construction management research and practice; in other words, stating what difference the research makes.

5.3.1 Theoretical Contribution

- **Providing a new understanding of construction cost overruns.**

In Section 1.4 one of the research's main contribution stated was a new way of understanding cost overruns. Chapter 1 cited several research that found projects overrunning their initial estimates. Love et al. (2014) in their research of Australian projects found that construction projects overran by up to 70% more than their initial estimates. The Glenigan UK Industry Performance Report (2016) show that only 56% construction project met or bettered the cost figure agreed at the start of the phase in 2015. Furthermore, only 48% of construction projects in 2015 met or bettered the length of time agreed at the start of the phase. These figures at face value are unimpressive; however, the model developed in this thesis compared the contractors' cost overrun to the price of the next highest tender. This gives us a better picture of how bad the cost overrun really is. In the projects used to validate the model in Section 4.3.2 it is shown that even though the lowest tenderer will likely exceed cost estimates, the final cost will likely be below the price of the next highest tender. In a perfect circumstance, a client would want a contractor to deliver on the agreed estimates. However, a cost overrun that is below the starting price of the next highest tender should be acceptable. Furthermore, the model results show that the there are situations where the market shows that selecting the best value tender is not necessary. This supports Yu and Wang (2012) study which states that clients should use the market to dictate what strategy to select. In the educational facilities sector, the results show that it is okay to select the lowest tender as they can deliver projects in terms of final costs. This is because even though the lowest tenderer may overrun, the cost is usually less than what the client would have paid the best value tenderer whose price is not the lowest price. However, on the other hand the lowest tenderer would take longer to deliver the project. So, if a client is looking to execute the project on a strict deadline, awarding to the best value tender is advised.

- **A novel model of determining the probability distributions of cost and time involved with the different contractor selection strategies.**

The key theoretical contribution however is that the research has provided a novel model of determining the probability distributions of cost and time arising from the different contractor selection strategies (lowest tender or best value tender) by focussing on educational facilities projects. The research examined the existing studies that developed models to aid in selecting the best value tender seeing that selecting the lowest tender is relatively straightforward. There are many models that have been developed, however there are hardly any that aim to empirically show the effect that the strategy has on project outcomes. This research contributes to existing knowledge on modelling approaches, by not just aiming to predict final cost or final duration, but to rather show the probability distribution possible. It demonstrates the use of MCS by seeing how the lowest tender would have fared in a project awarded to the best value tender whose price is not the lowest price.

5.3.2 Practical Contribution

Appendix 4, 5, and 7, highlight the steps taken to build the model developed in this research. The developed model for this research will benefit client bodies or organisations, or an institution that regularly procure goods or services either from a vast pool of contractors/suppliers or from a selected pool of contractors/suppliers. Basically, any institution that procures large quantities of raw materials, resources, and any finished product, will frequently award similar contracts where both price and quality criteria are important evaluators that are weighted. The model will guide companies in determining the effects of these weighted criteria on contractor/supplier ranking and subsequently on contractor/supplier performance. The developed model for analysing the effect a strategy has on the outcomes of a project has been demonstrated as a tool capable for converting existing project data within organisation into decision support tools to help in deciding the strategy to select. The model can subsequently help clients to:

- **Decide on which strategy to adopt: lowest tender or best value tender;**
- **Know the probability distribution of final cost and project time to expect and how likely they are to occur, especially when it can go wrong;**
- **Spot and eliminate extremely low or high tender prices.**
- **Ultimately increase stakeholders' satisfaction.**

The model can also be tailored to individual companies' needs. Furthermore, the model can be extended to other types of projects from different sectors, not just educational facilities. The results here are particularly beneficial to companies that deal in the educational facilities sector of construction. However, the straightforward approach to data collection, data pre-processing and eventual model development using MCS can allow the extension to any relevant dataset or type of project.

5.4 LIMITATIONS OF THE STUDY

1. More detailed best value tender selected projects.

The developed model would have benefited greatly from knowing the contractors' quality scores in these projects. Section 4.4 gives a demonstration on what the model can do when the quality criteria, weights to the criteria, price to weight ratio, and contractors' quality scores are known. However, the model would have also benefitted more from knowing the quantitative implications the quality scores have on project outcomes. Indeed, the parameters for outcome in this research is limited to: Final Cost and Duration. There is difficulty in quantifying quality, clients would have their own way of doing so. The model could be further improved by partnering with a client to develop the model that can also incorporate a quantified quality to its parameters. Furthermore, the developed model could have also benefited had it been tailored to a company's needs. The dataset used to develop the model is from the BCIS, however the results of the model may not be applicable to every company. The results would be useful to companies that work in the Educational facility sector. However, the blueprint given in this thesis can be mirrored to any company that is looking to conduct this analysis.

2. Limited to Educational Facilities sector.

The model focused on Educational facilities projects, the projects used to validate the model were from an industry client. Therefore, these projects were double-checked to make sure the facts were correct. The thesis briefly used Industrial facilities projects to prove that applying a model that has been based on Educational facilities project to the Industrial facilities sector or any other sector will produce misleading results.

3. Too reliant on data?

When awarding a contract, the real world only awards one contract to the winner. So, for example if one had a contract to build a new classroom, we cannot build two identical classrooms; with one using the lowest tenderer and the other using the best value tenderer whose price is not the lowest price. And simultaneously build multiple classrooms to get an overall probability distributions of project outcomes. Therefore, it is not possible to truly verify the models developed. The only way to continually verify the model is if there is a healthy dataset of projects that have used the two strategies. The model is heavily reliant on data. Section 3.4.3 mentions the difficulties in collecting historic data as a barrier in applying probabilistic models.

5.5 RECOMMENDATION

First it is important to understand that even when the best possible contractor is selected, a project can still go wrong. Project problems are not just the sole responsibility of the contractor; more collaborative efforts are needed to solve issues in a project. Adversarial relationship and blame culture makes project issues more difficult to solve.

Data should be considered an asset, not just an information that is stored and never to be looked at again. Thus, the construction industry need to use the data available to them on past projects to support the decisions they make; in this case the strategy in which to select a contractor. The model developed in the research should be used as an aid when selecting a strategy not the basis of selecting a strategy. The model here does not advocate a strategy but shows the probability distribution of outcomes for a contractor selection strategy. Thus, it is important for clients to award contracts based on realistic tenders submitted and not just the lowest tender offered. More collaborative effort and early contractor involvement can potentially incentivise a contractor to be more honest when estimating prices early-on.

Only an arrogant modeller assumes that its model is complete. It has been noted that selecting on the lowest tender is relatively straightforward, best value on the other hand can be selected in different ways. Particularly, in ways that weights tender price to quality when analysing tenders: 60/40, 50/50 etc. The model indeed has the capability of incorporating the different selection criteria and subsequently analysing the effect it has on project outcomes. This would result in analysing the history of past project on how projects in the different selection criteria have fared. The notion is that each client will have a different method on selecting contractors on best value, therefore understanding the client's requirement is crucial to the model achieving the results needed.

Furthermore, to determine the likely outcomes, it may prove useful to take the detailed bill of quantities, critical path network, and the probabilities associated with them and model them independently to sum the results. This goes beyond just analysing the outcomes associated with each strategy. For example, consider a wall is to be built which consists of excavating a foundation, constructing a foundation, and erecting the superstructure. The excavation may be delayed by poor ground conditions, unexpected braced services. Constructing the foundations may cost more due to heavy rain, and deeper excavation because of a different soil; which would then result to more materials used. The superstructure may also cost more and be delayed due to poor weather (sub-zero temperatures), delays to foundations, staff not available, etc. Each of this clearly has an associated probability which could possibly be evaluated. However, it is likely that there is a correlation between each of these events that will make the probabilities difficult to evaluate.

It may also be possible for a client to use a probabilistic bill of quantities and costs to produce a probabilistic distribution of the likely outcome costs. Remember as the number of items in the bill of quantities increases then the standard deviation of outcome costs is proportional to

$$\frac{\mathbf{1}}{\sqrt{\boldsymbol{N}}}$$

5.6 FURTHER RESEARCH

The model can be applied to other sectors of the industry, the research only looked at educational facilities projects. However, applying it to other sector increases the chances of the model produced being accepted by industry practitioners. There is a high chance of encountering clients involved in different types of projects and in different sectors of construction. Therefore, applying the model in a different sector will give clients the opportunity to know what strategy works best in a sector, and in their own company. This would also eliminate the possibility of a client believing that one strategy fits all.

In Section 4.3.3 the model showed that the lowest tenderer in Educational facilities projects will likely fail to meet the client's expected duration. Why? This is possibly linked to the fact that clients do not place enough weight on meeting deadlines. Section 4.3.6 showed the tender information of three projects; the criteria used to select the contractor and what each contractor scored in each criterion. The winning contractor in all three cases scored 60% or below for the Programme criteria which evaluates contractors on the speed and deliverability of executing the project. This is because the Programme criteria was weighted 10% as supposed to Price and Experience that were weighted 30%. However, using three project information to make any conclusion is unwise as the dataset is not enough. Therefore, a bigger dataset is needed to investigate why the lowest tenderer in educational facilities projects is more likely to miss an agreed time schedule.

In Section 4.3.5 it was concluded that if a client should decide to use the open tendering method, it is best to award on best value rather than solely on price. This is because it is more than likely that the client and the contractor are working together for the first time. However, the aim of the research was to compare the contractor selection strategies and not the tendering method. Therefore, a future model that incorporates the tendering method and the level of familiarity that comes with using selective or open tendering method is needed. As this would allow for a better comparison of tendering methods across different types of projects and in different sectors

Chapter 4 details the process undergone to develop the model, this was long and could subsequently put off prospective users; these steps included extracting the projects, eliminating repeated projects etc.

using Excel. The process time will be shortened by using an individual client's database as supposed to a nationwide database like the BCIS database. However, developing a tool that can sync project information directly to the model will eliminate these lead time.

5.7 FINAL REMARKS

The thesis has provided a model of determining the probability distributions of cost and time arising from choosing different contractor selection strategies in construction projects. This was executed by developing a MCS model that shows the probability distribution of likely outcomes for the lowest tenderer in a project that has selected the best value tender whose price is not the lowest price. In doing so, the model can justify to the client whether it is worth paying more initially for the best value contractor. El-Abbasy et al. (2013) recommended a further study that analyses what if scenarios to show how the lowest tenderer would have handled the project if he/she was not awarded the contract. The model developed in this thesis has been able to show this. The thesis does not advocate one strategy over another. However, the results derived from the research show that, at least in terms of final cost, going with the best value tender is not always worth it in the Educational facilities sector. Although, the best value tender will usually meet clients' expected duration. It boils down to what best value is to a client: lesser cost or meeting project deadline. Yu and Wang (2012) noted how the market should dictate whether a client should select the lowest tender strategy or the best value strategy. Just as clients should be encouraged to not always select the lowest price, it should also not be mandatory to use the best value strategy.

However, deciding on the strategy and subsequently the contractor to select may not alleviate all the problems that may go wrong in a project. Construction projects, by nature, can be volatile suffering from unforeseen issues. More collaborative effort is needed; especially between the client and the main contractor if problems are to be resolved.

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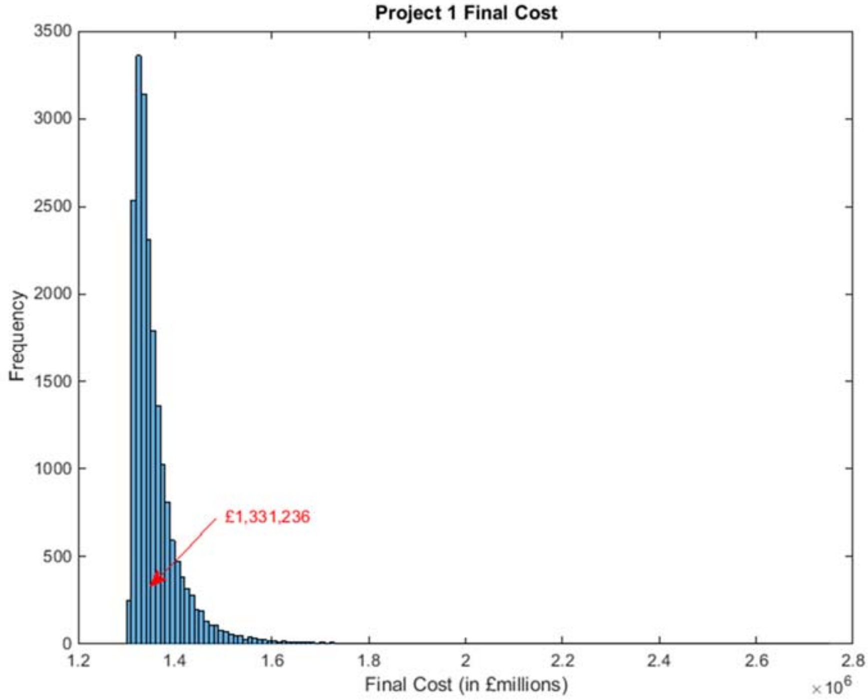
APPENDIX 1

Project 1 Final Cost (Dataset 1)



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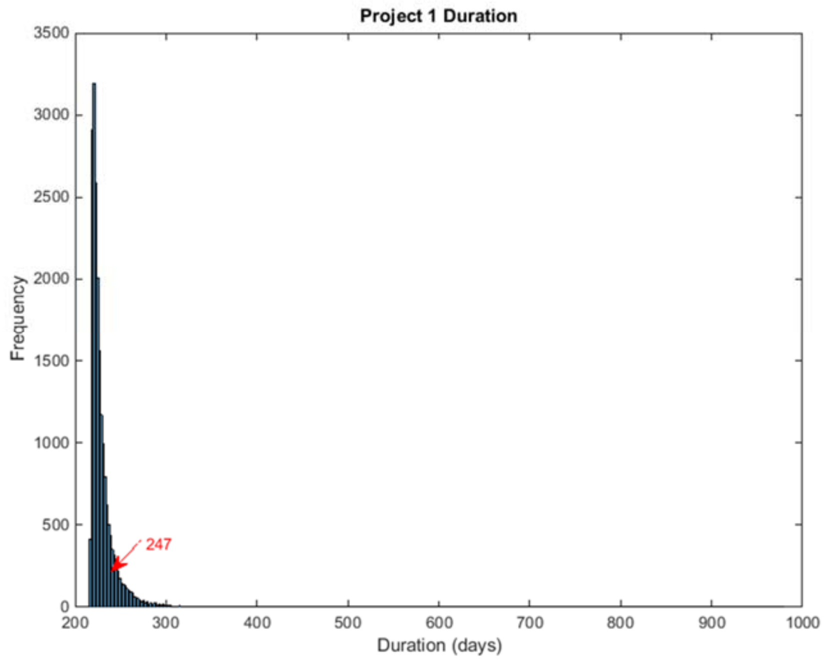

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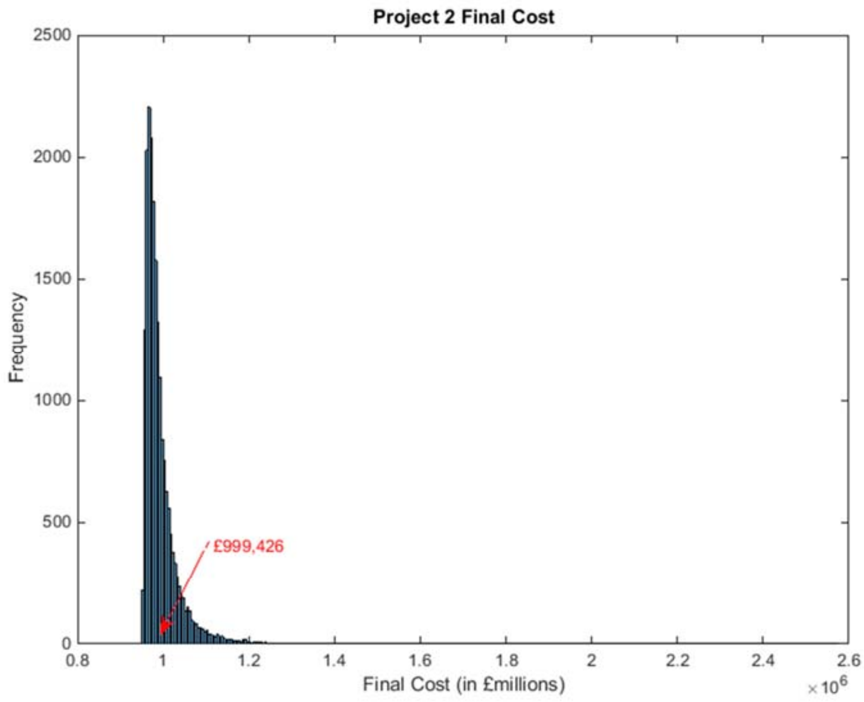

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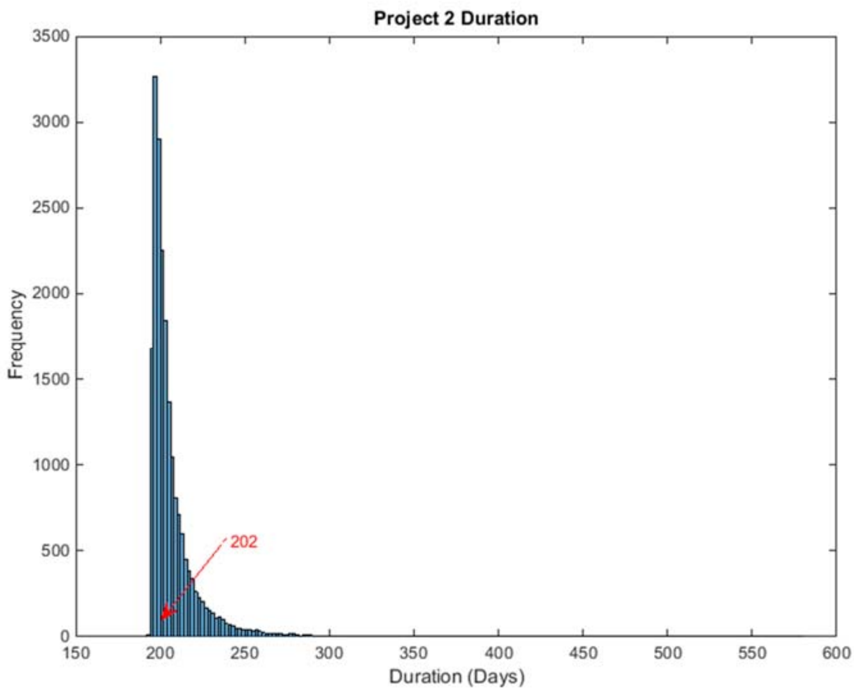

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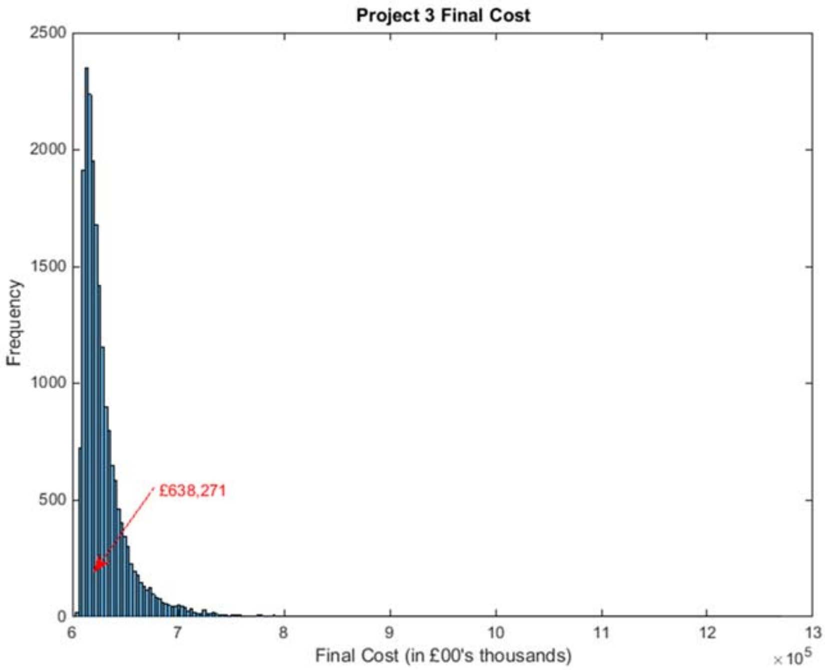

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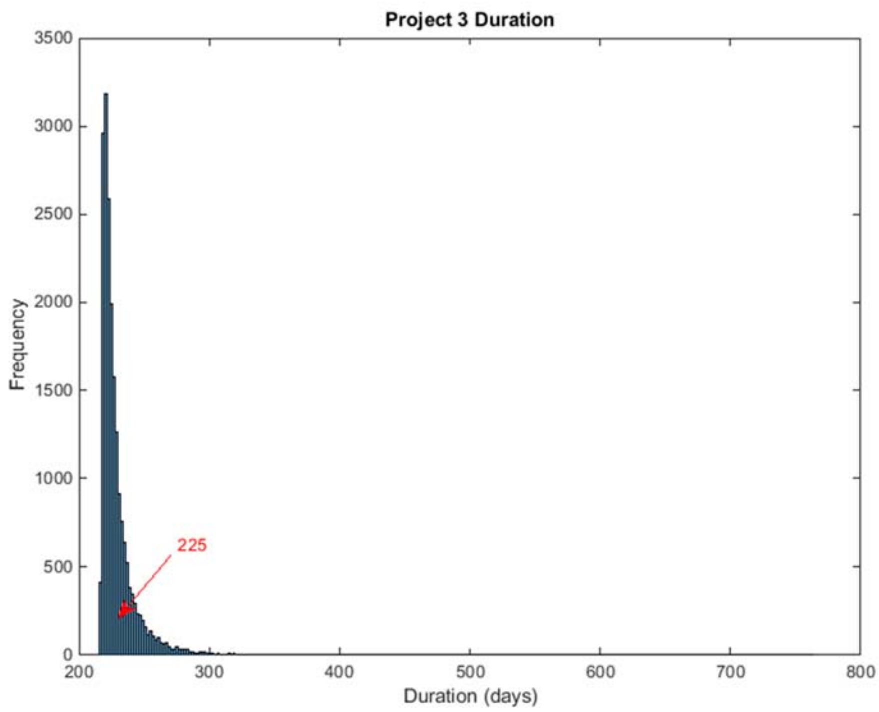

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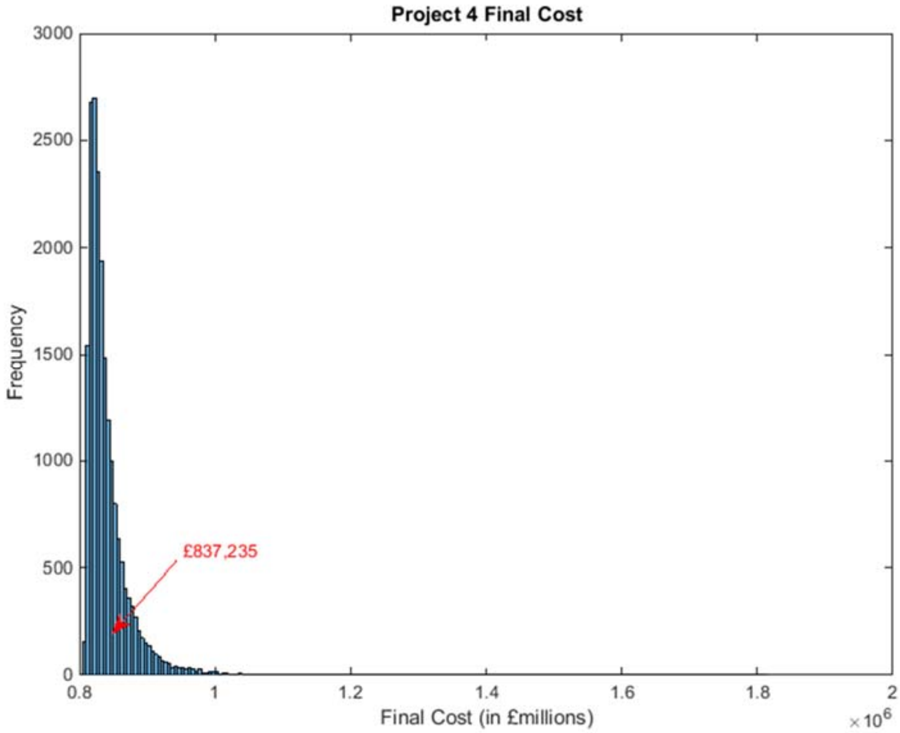

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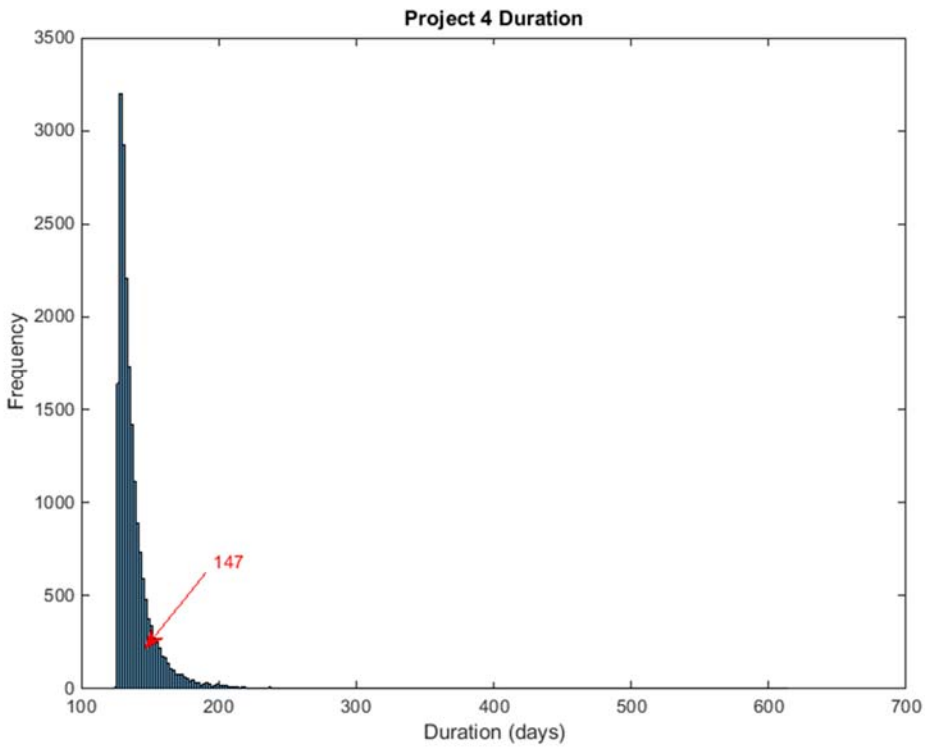

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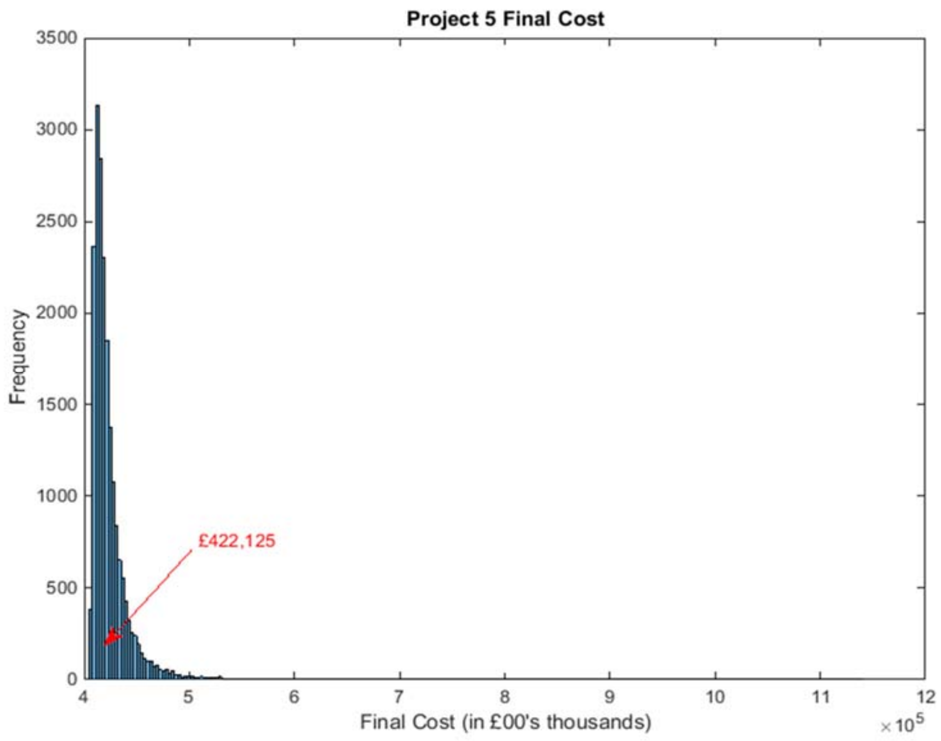

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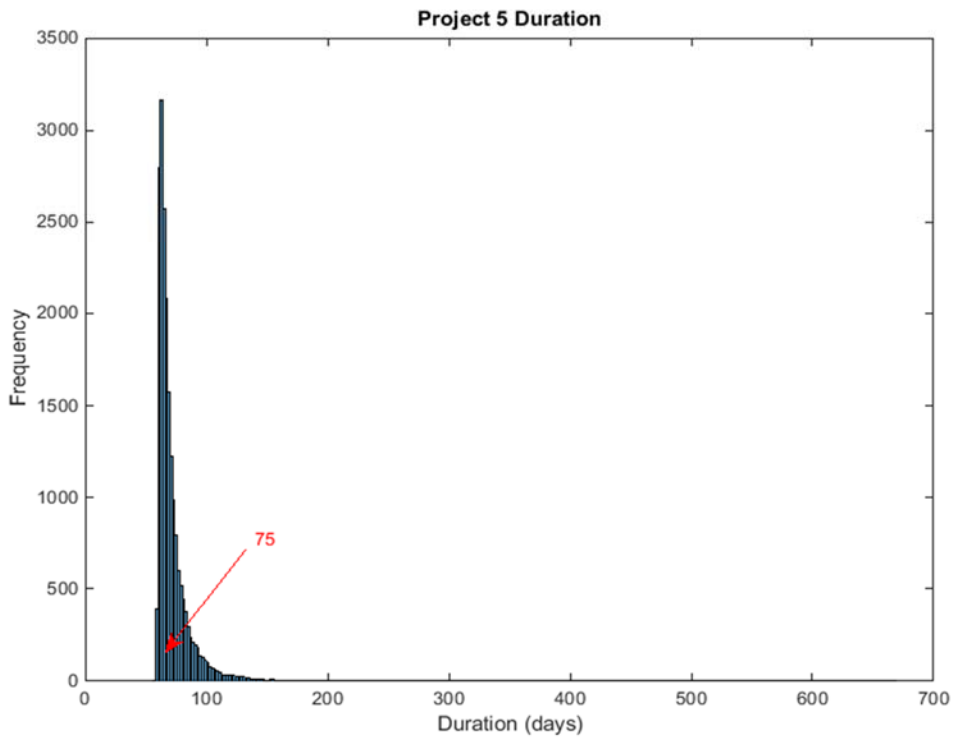

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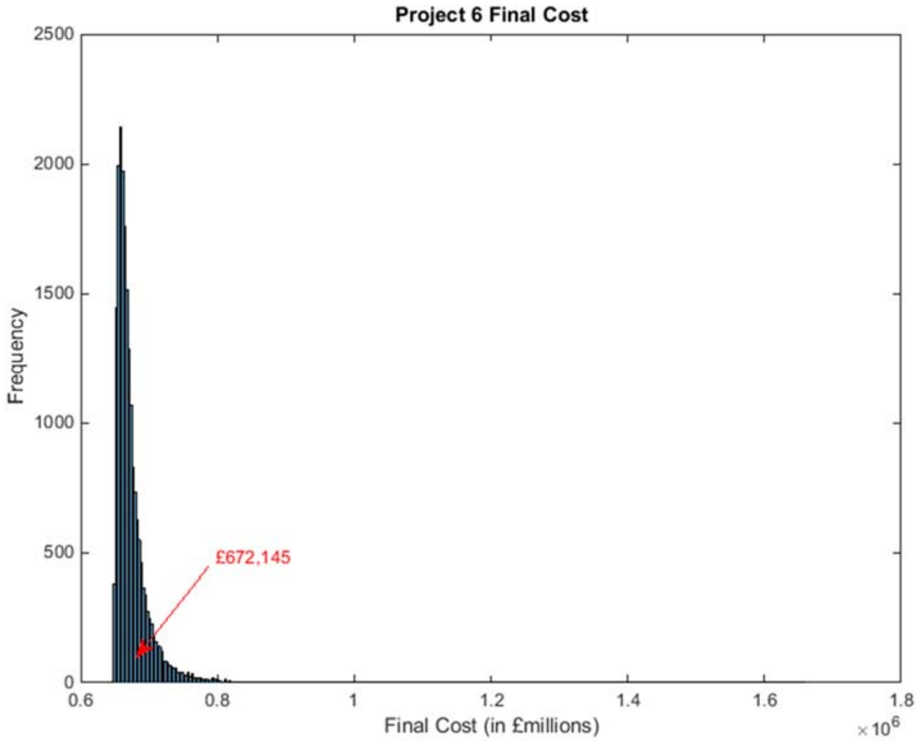

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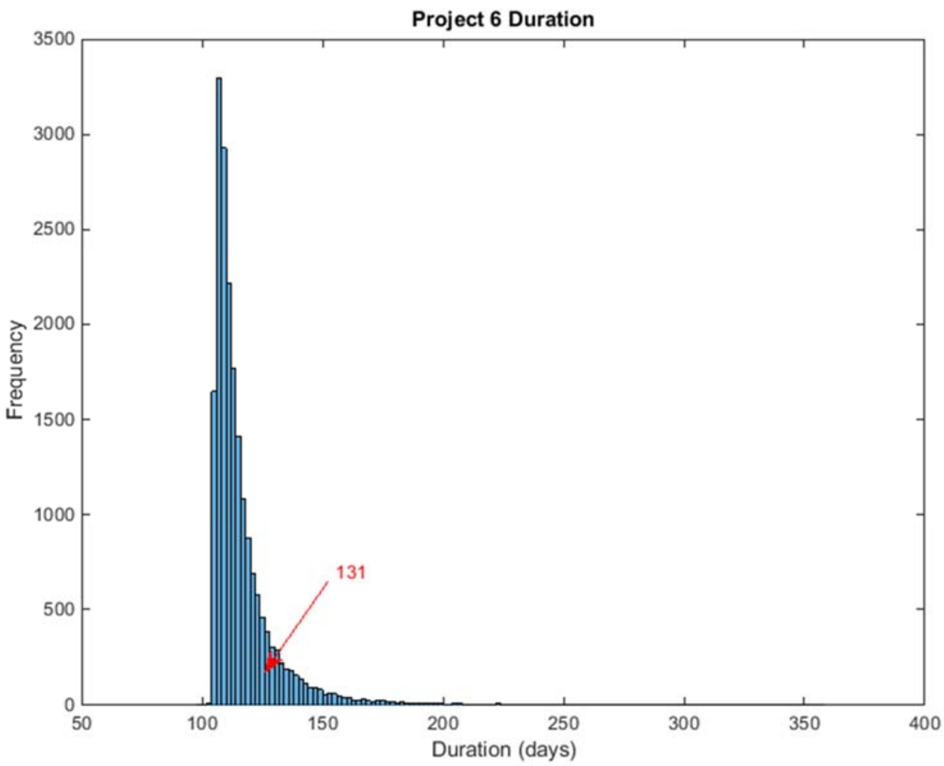

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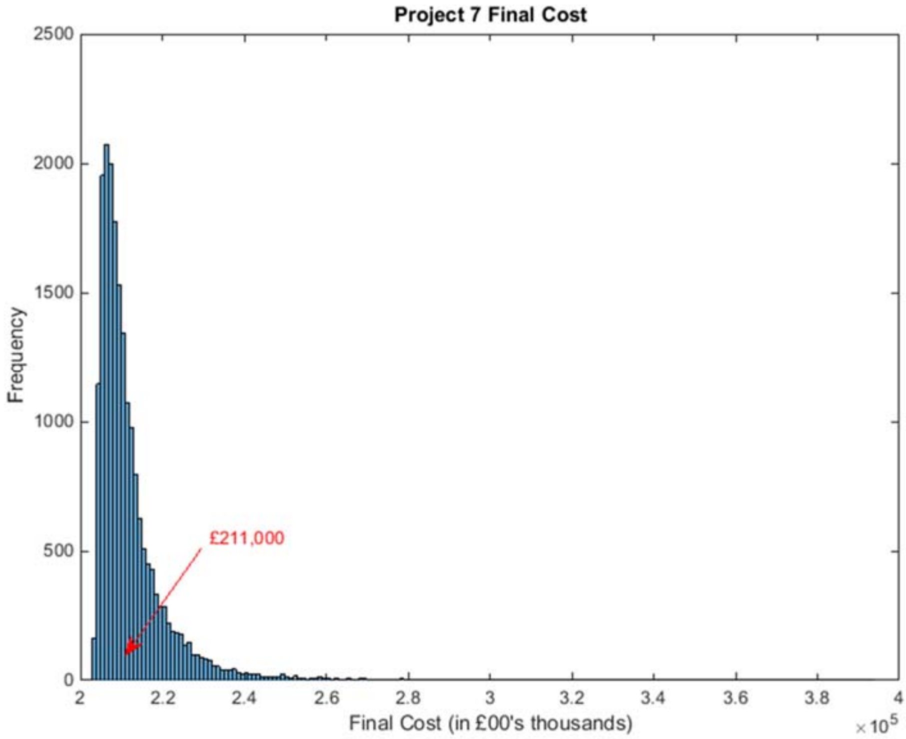

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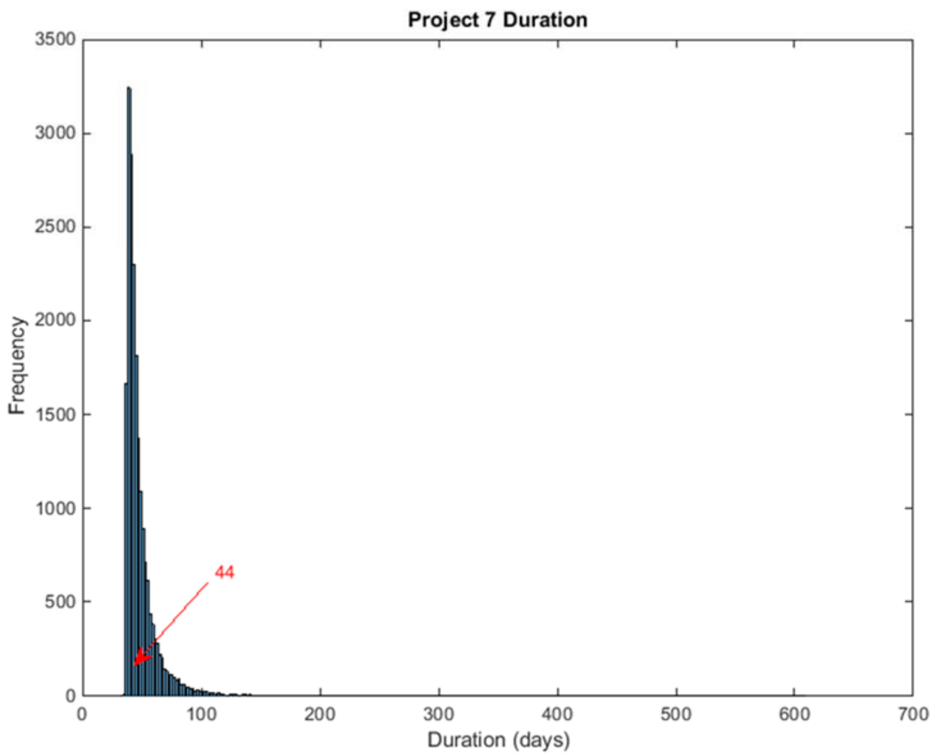

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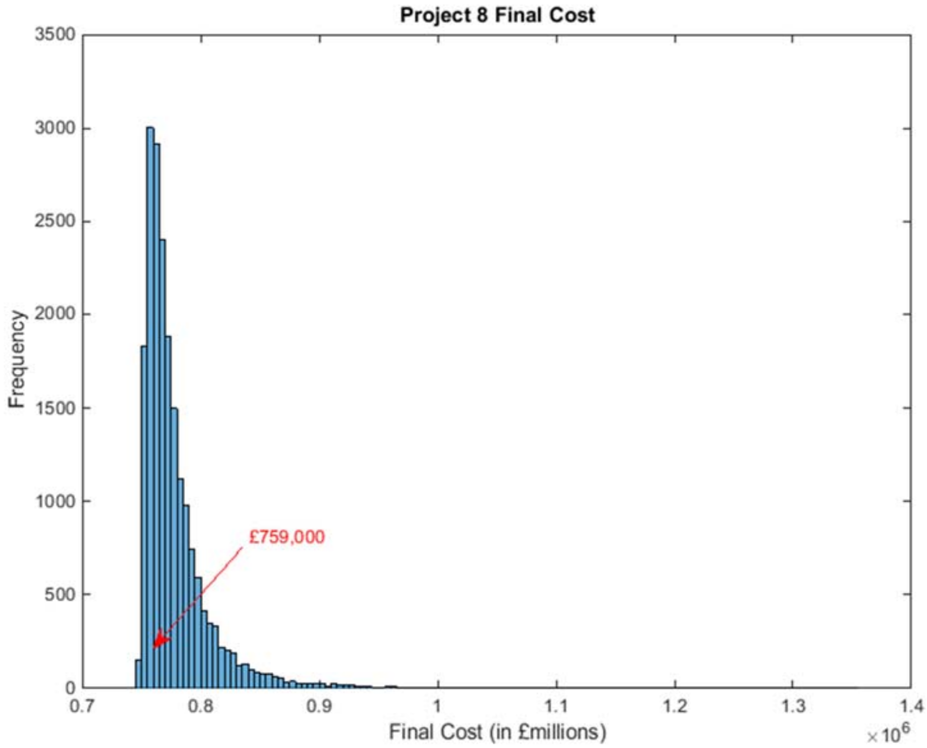

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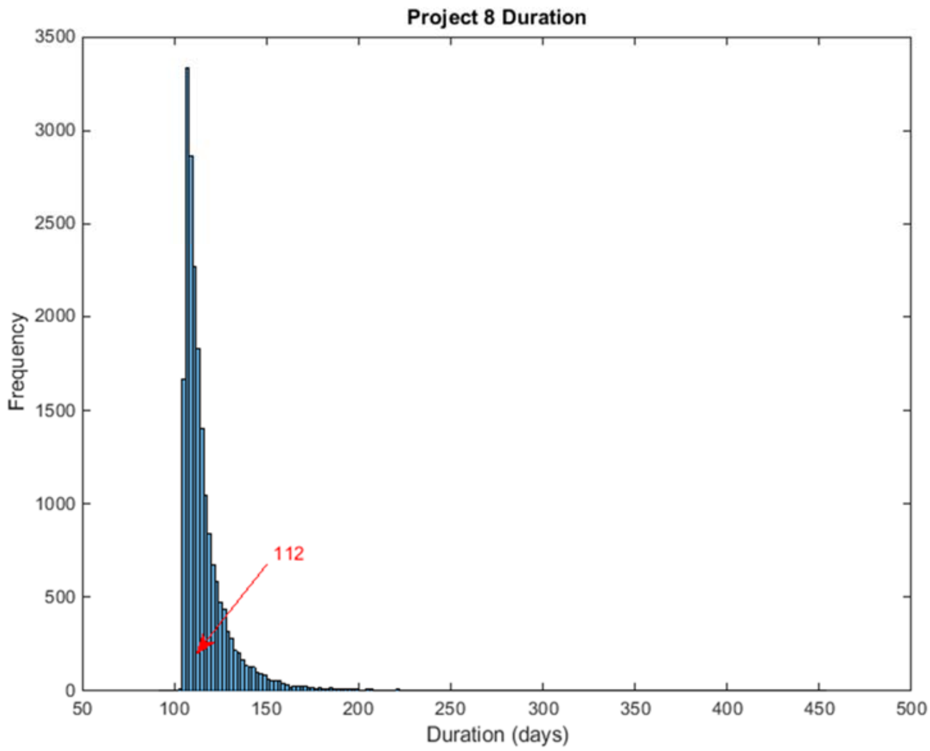

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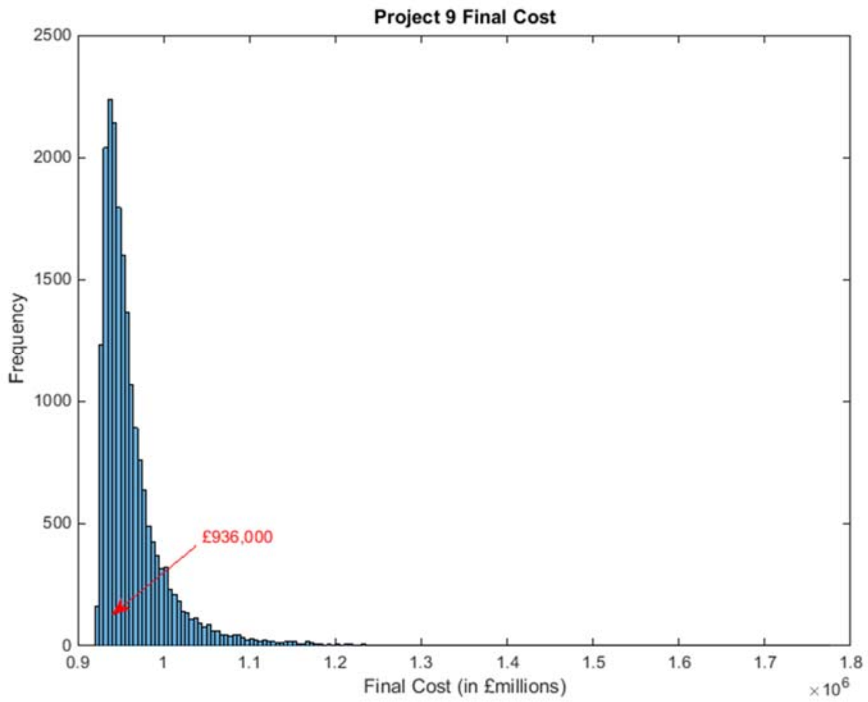

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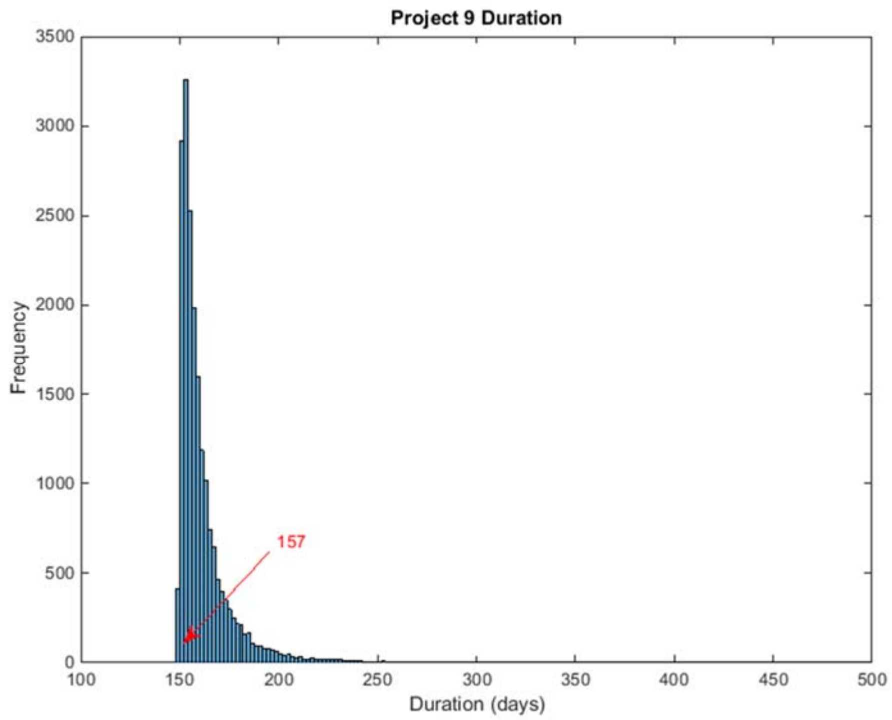

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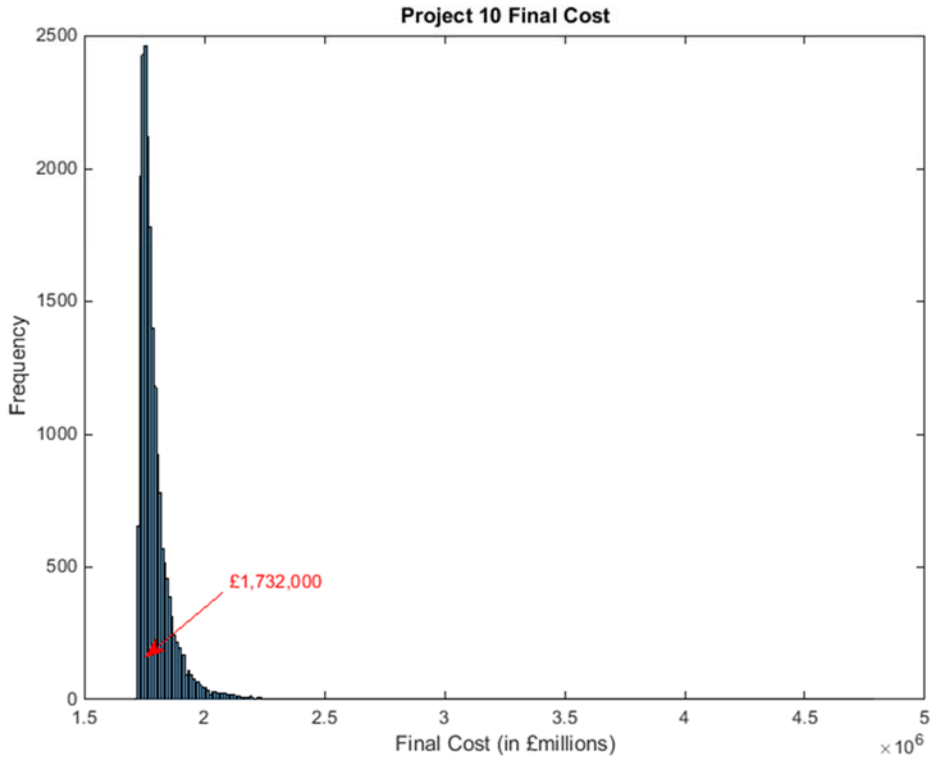

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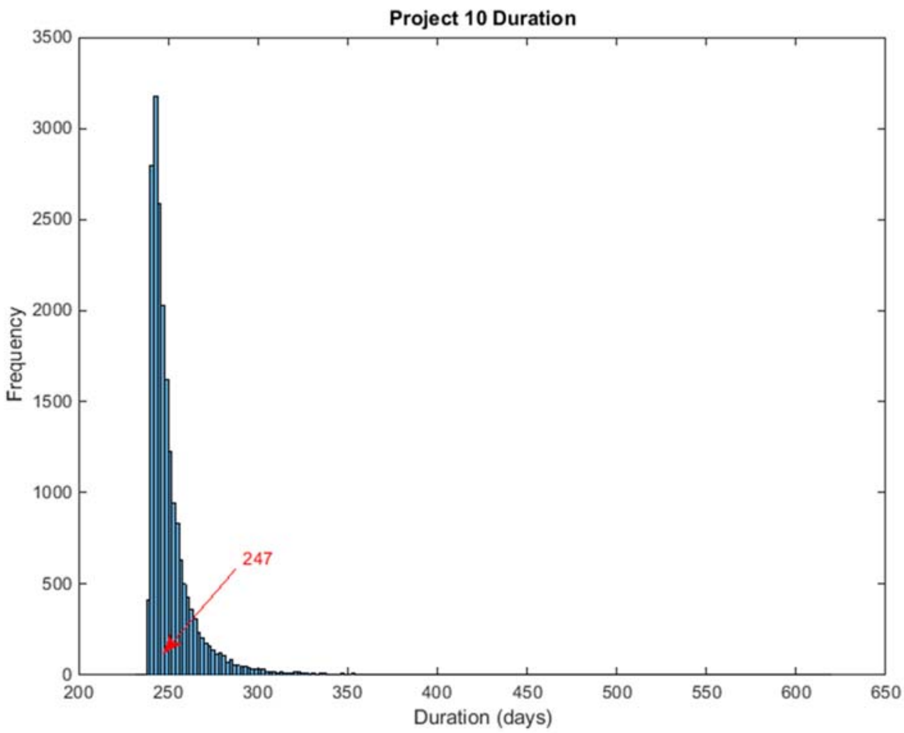
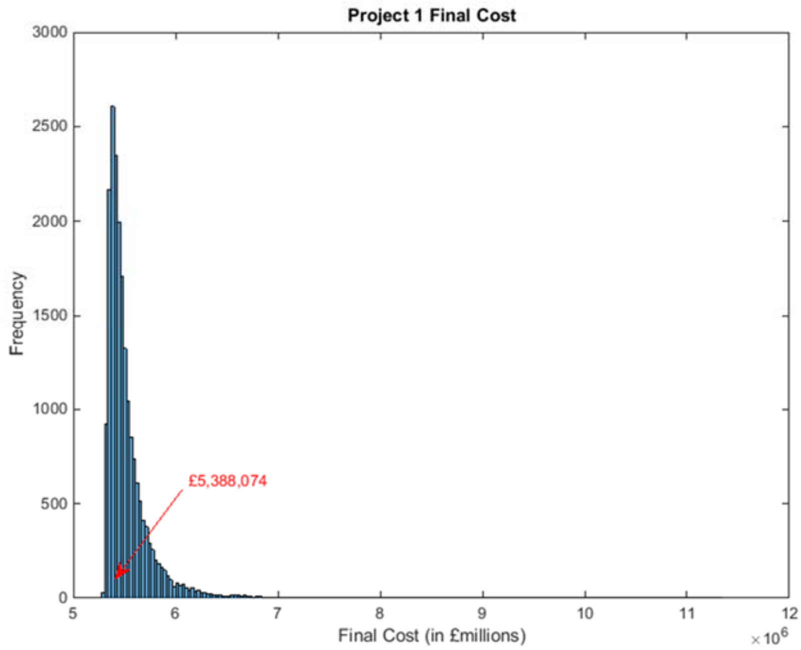


APPENDIX 2

Project 1 Final Cost (Dataset 2)



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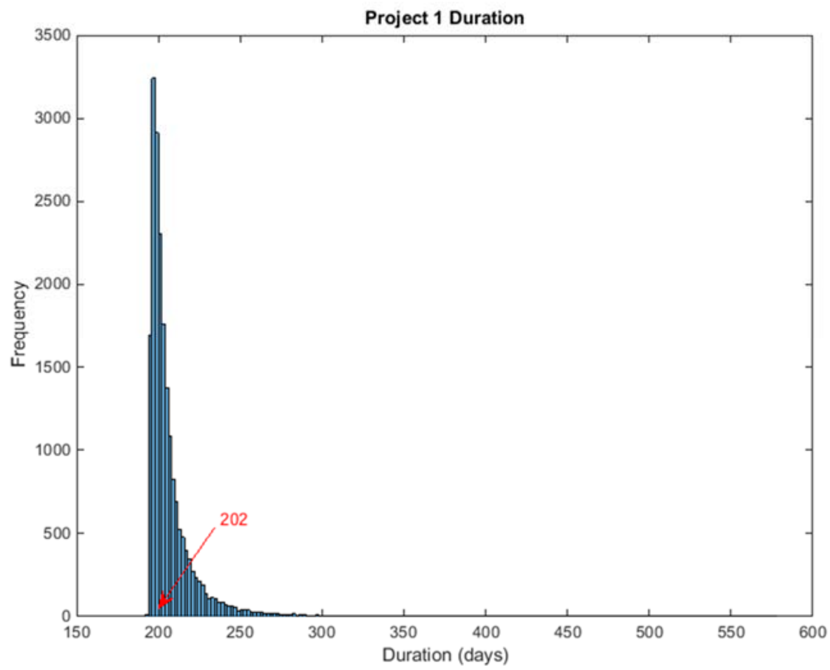
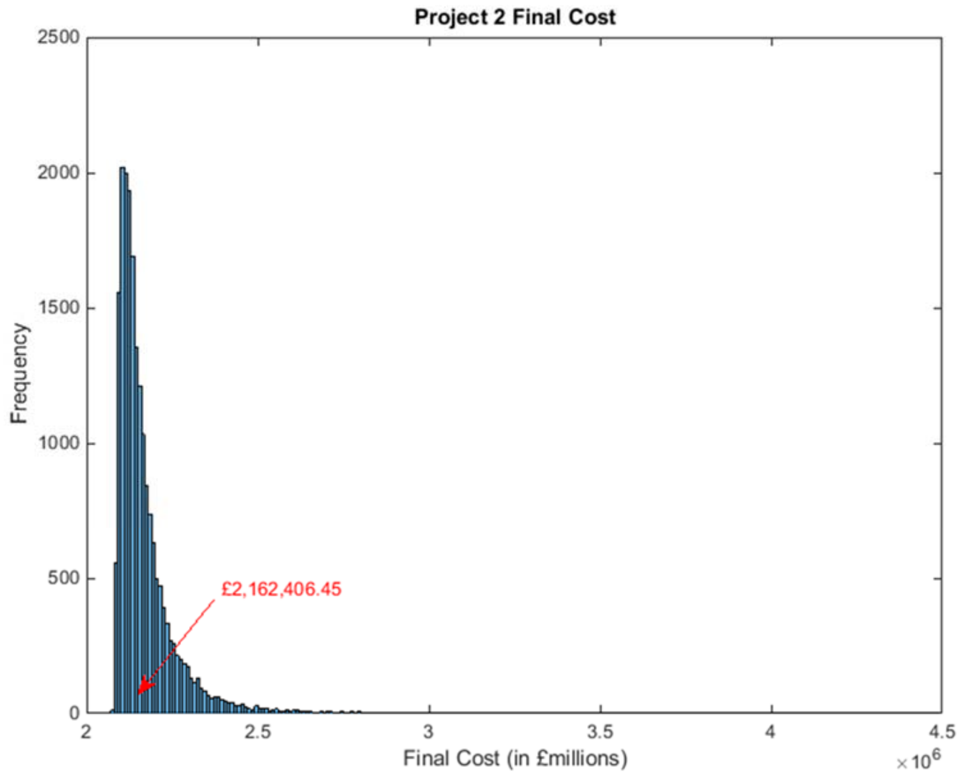


Project 2 Final Cost (Dataset 2)



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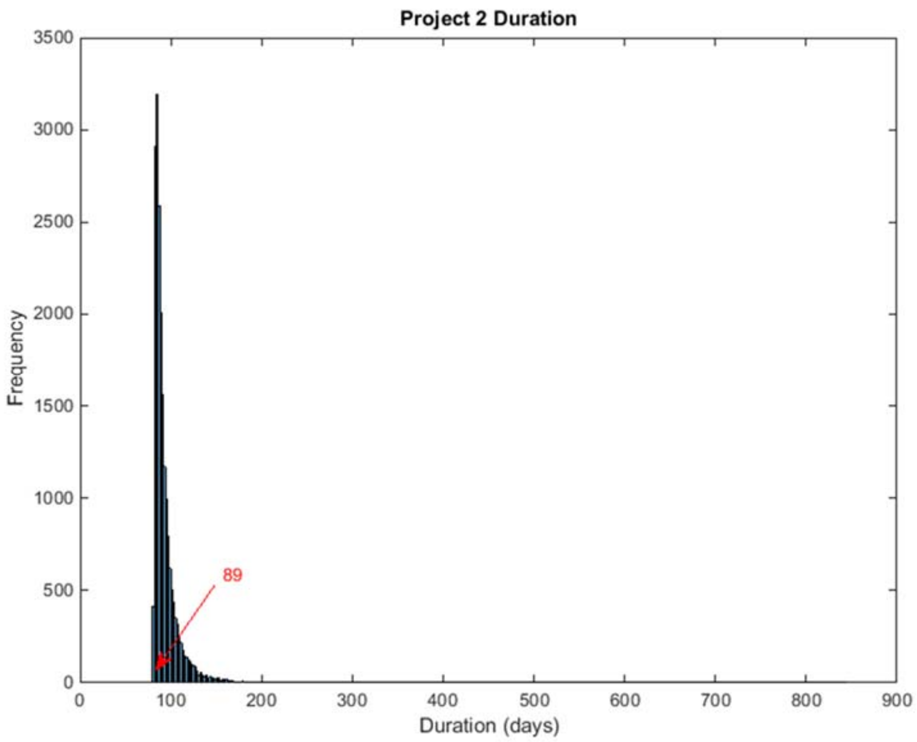

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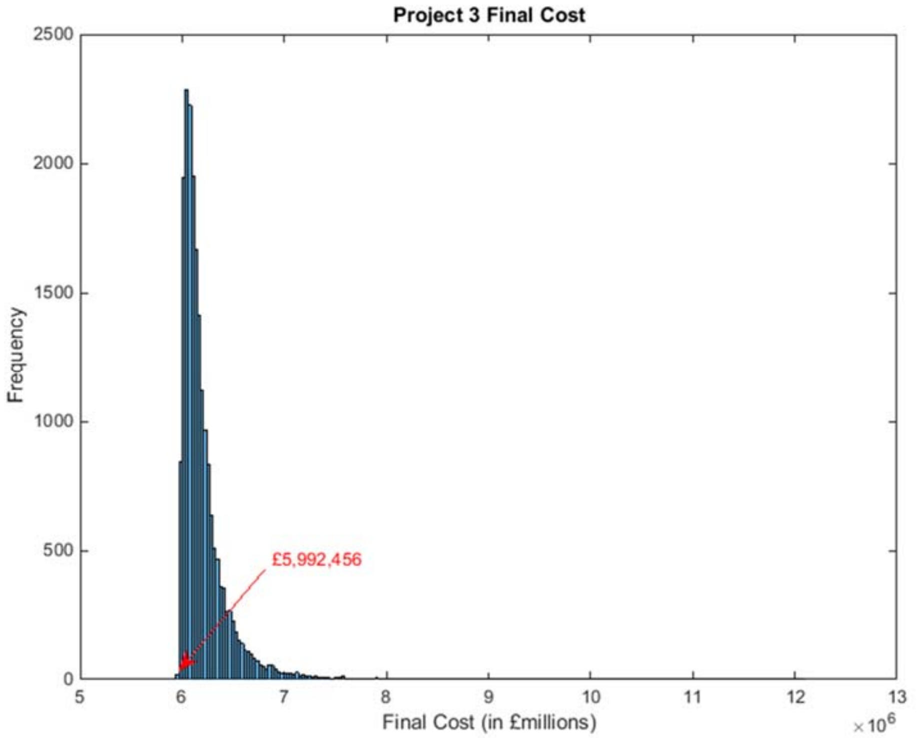

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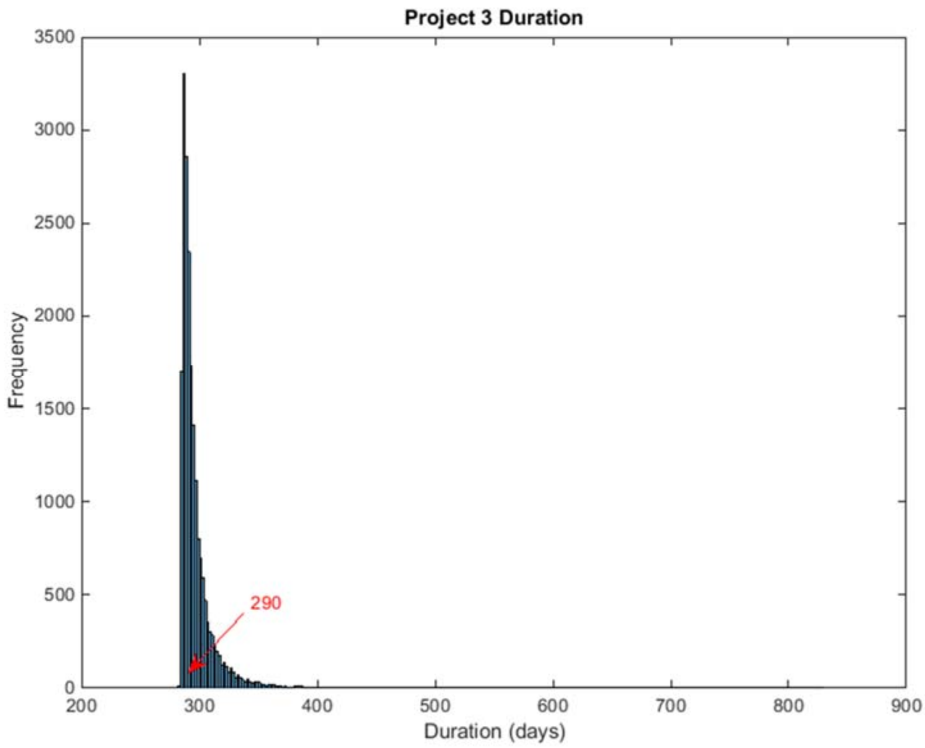

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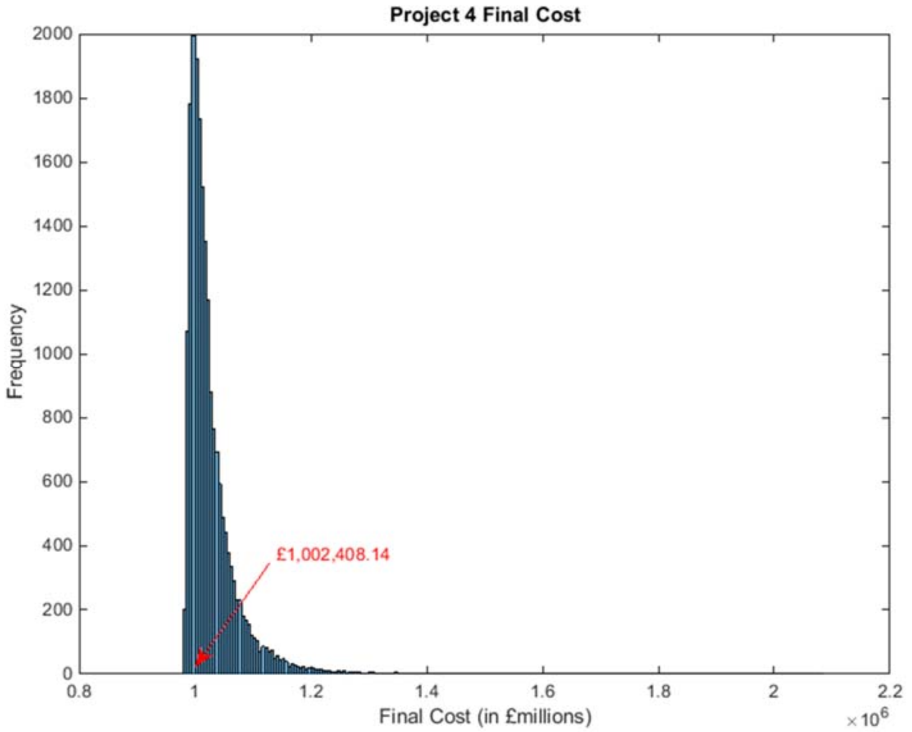

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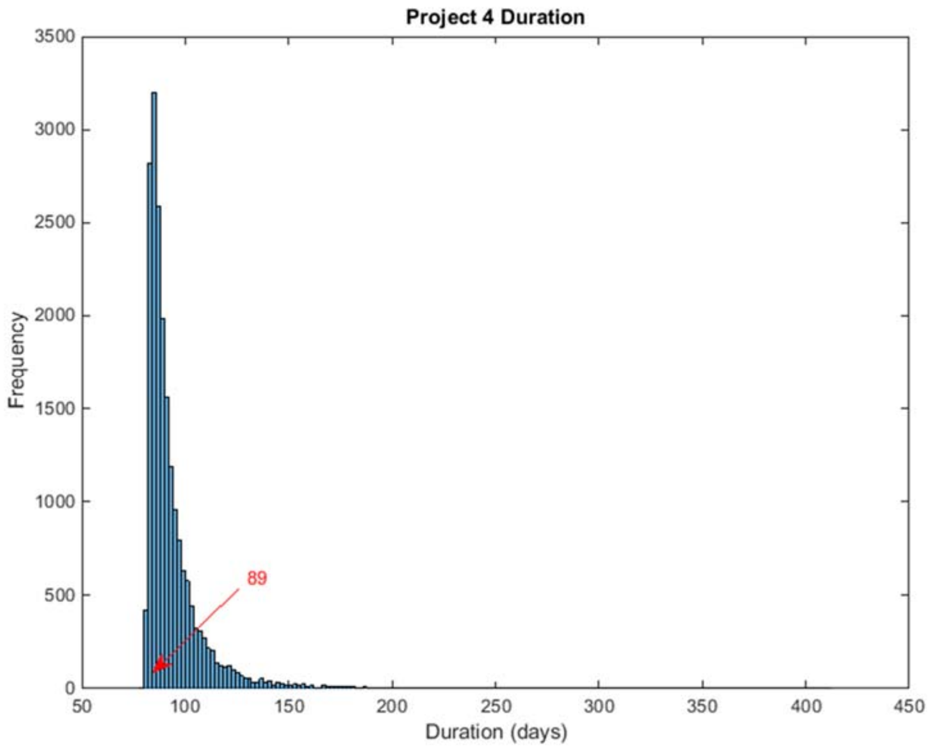

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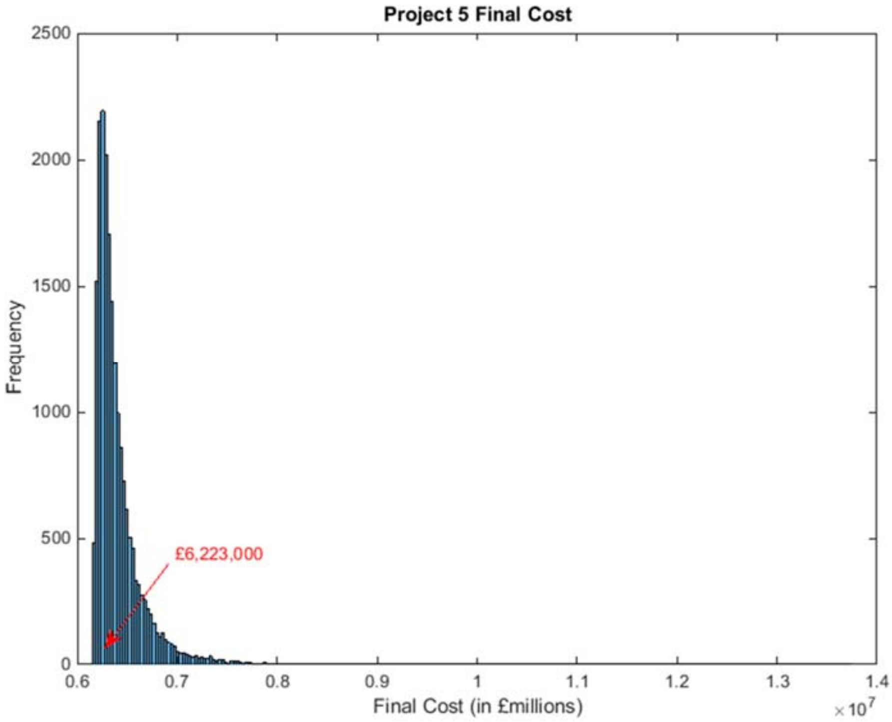

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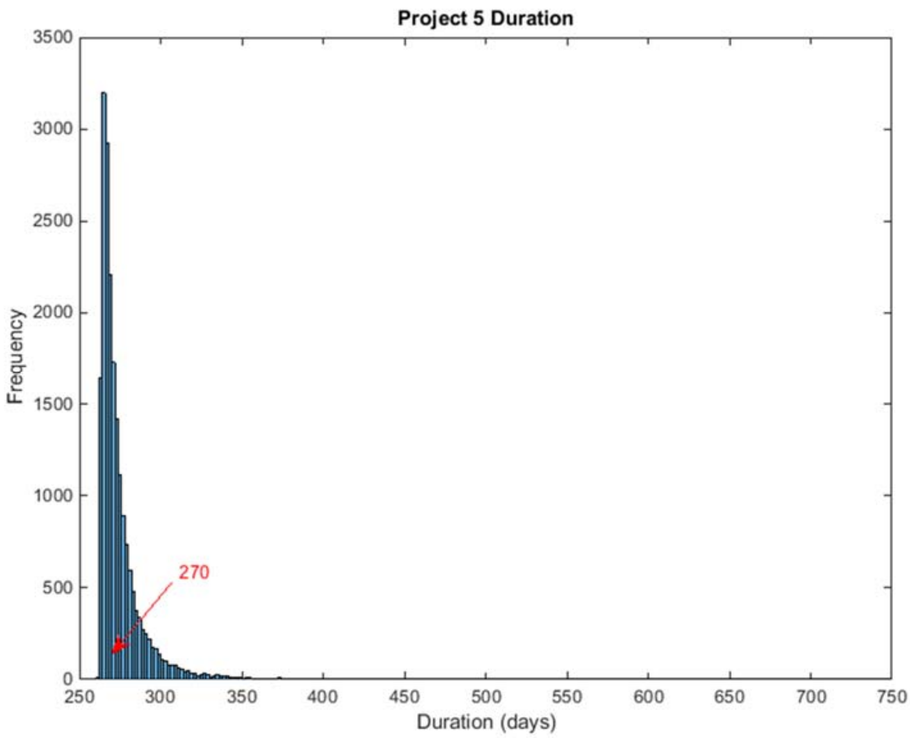
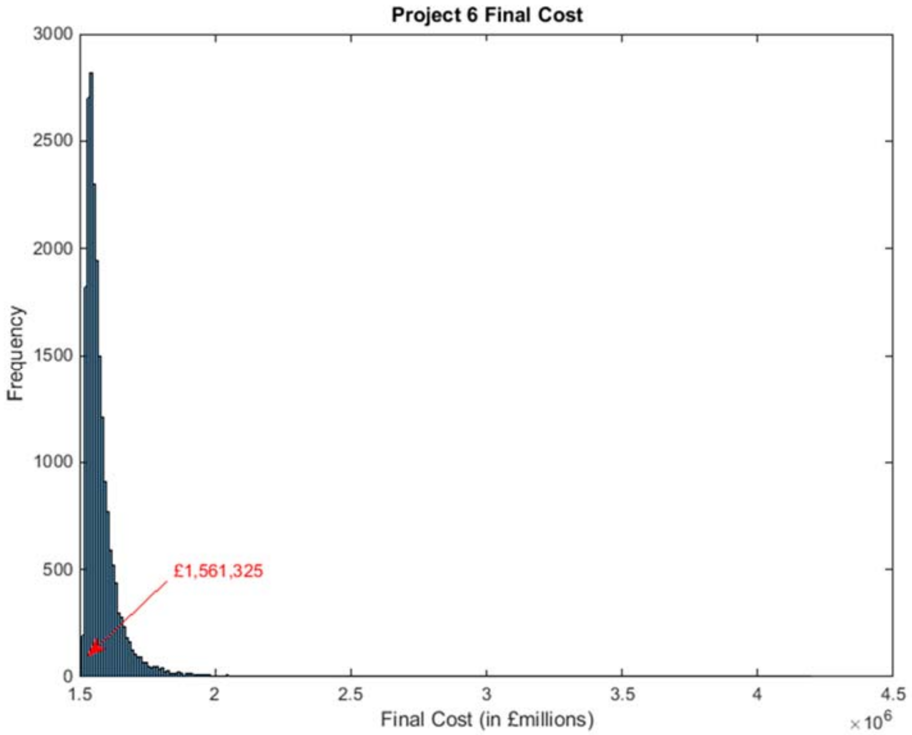


Project 6 Final Cost (Dataset 2)



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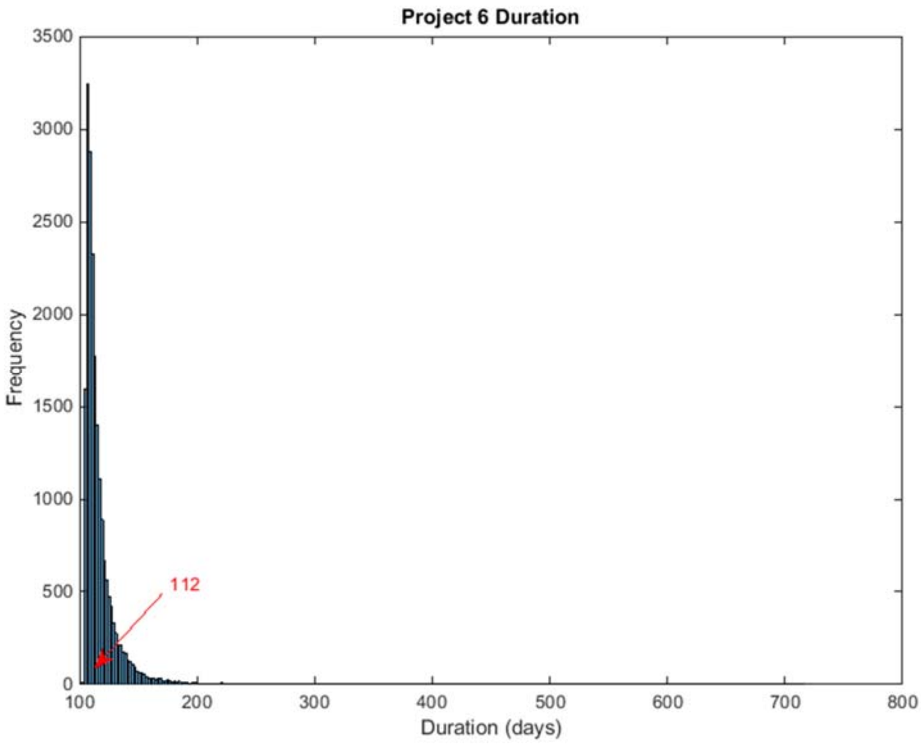

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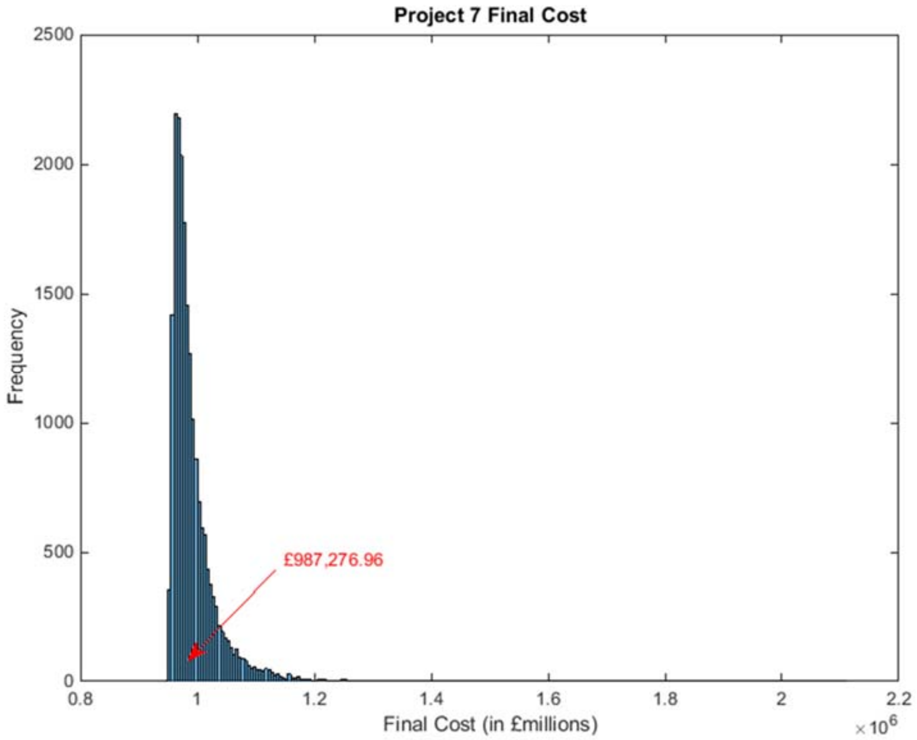

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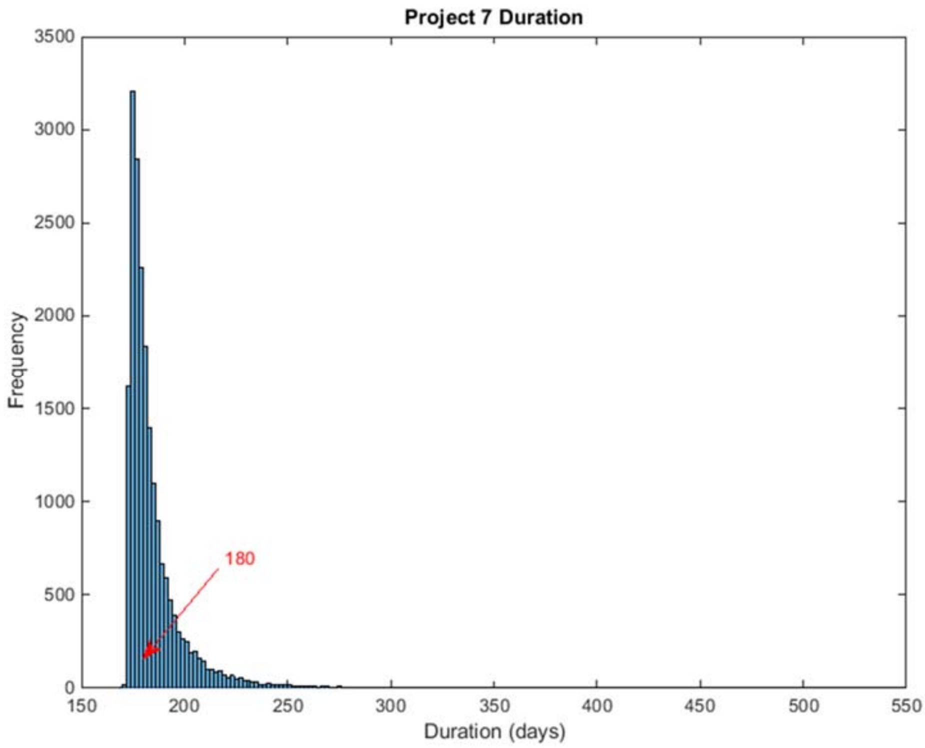

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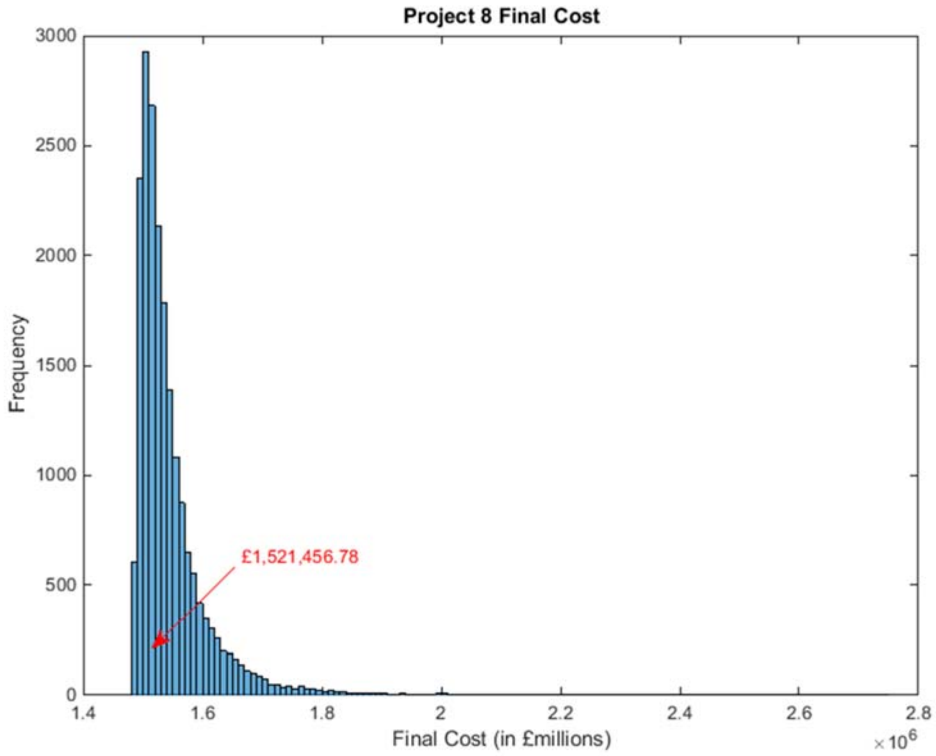

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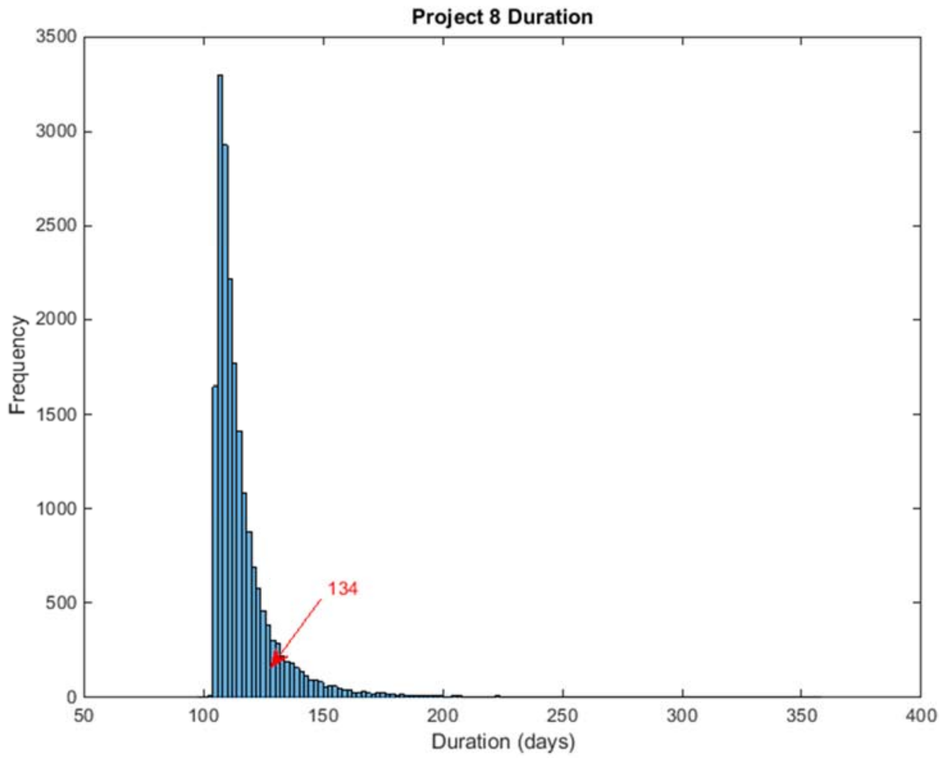

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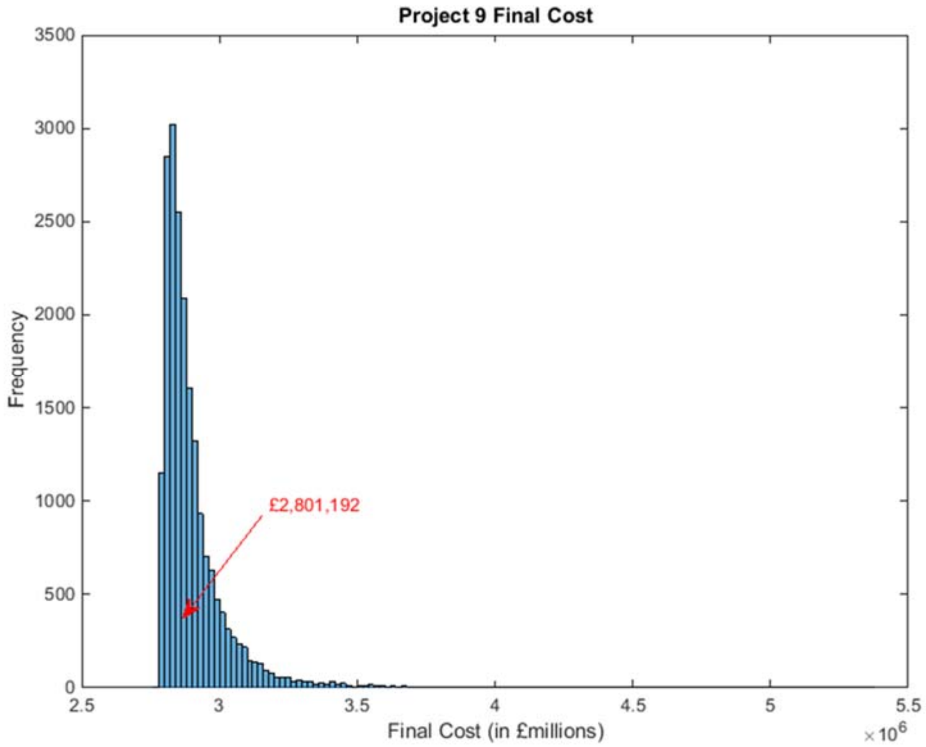

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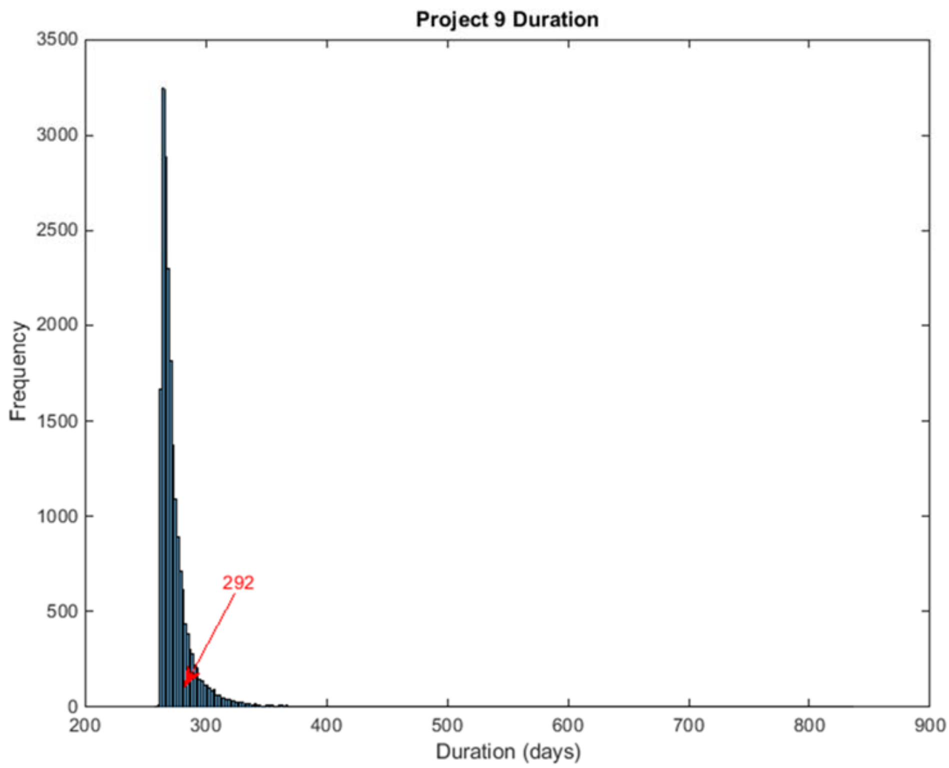

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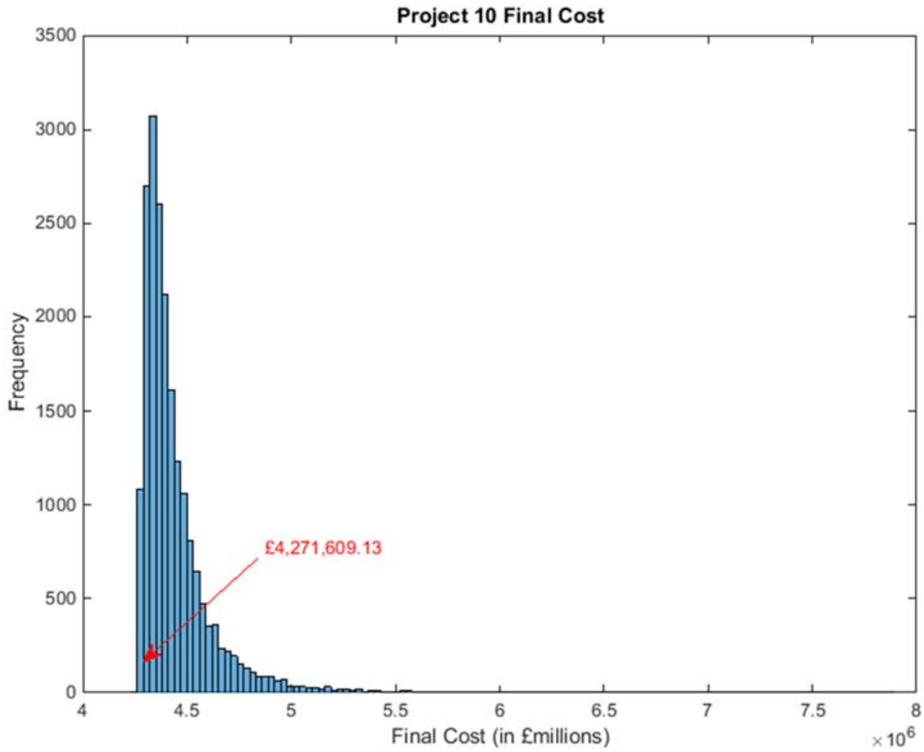

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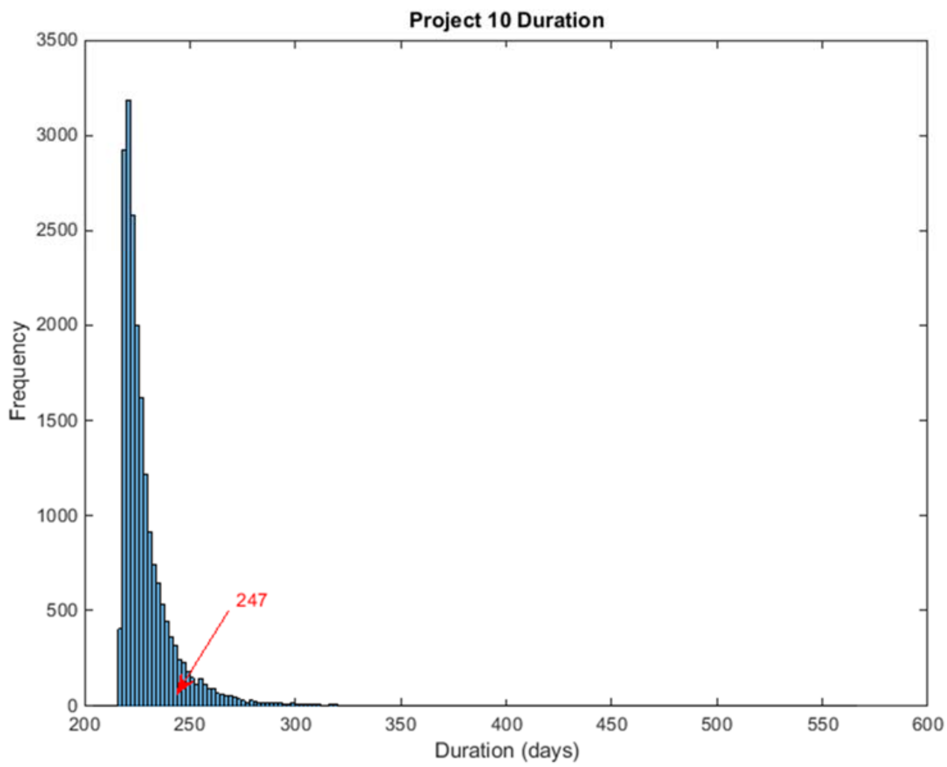

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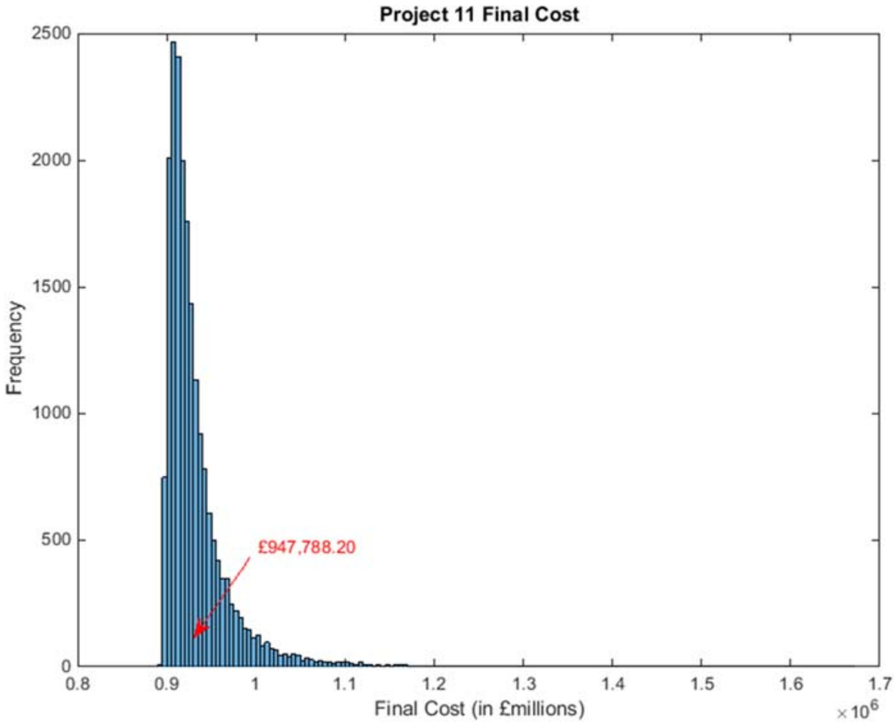

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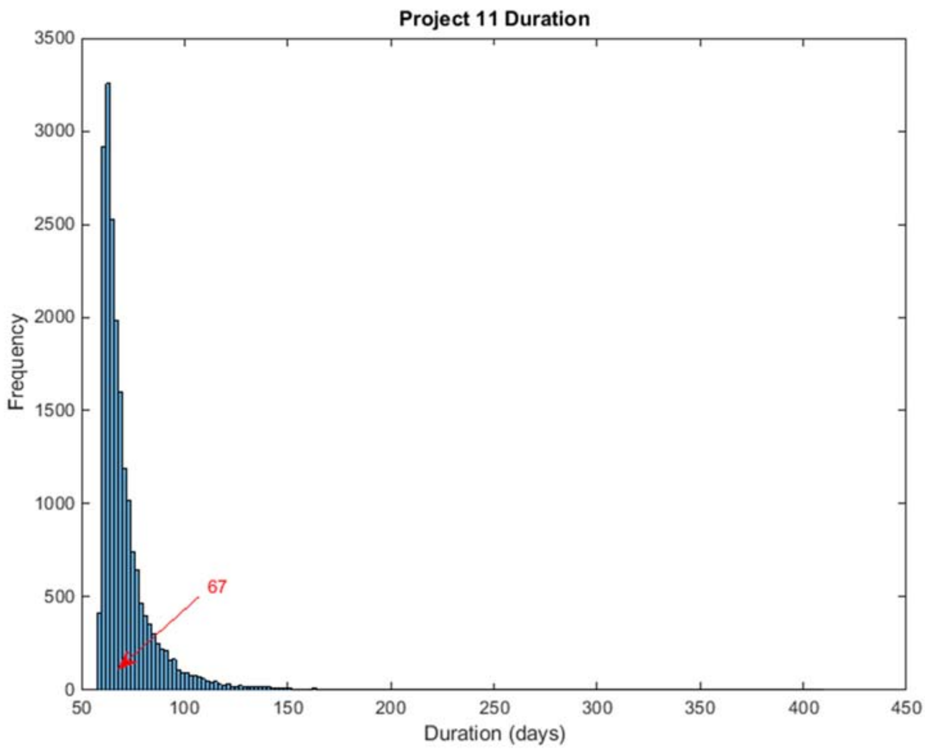

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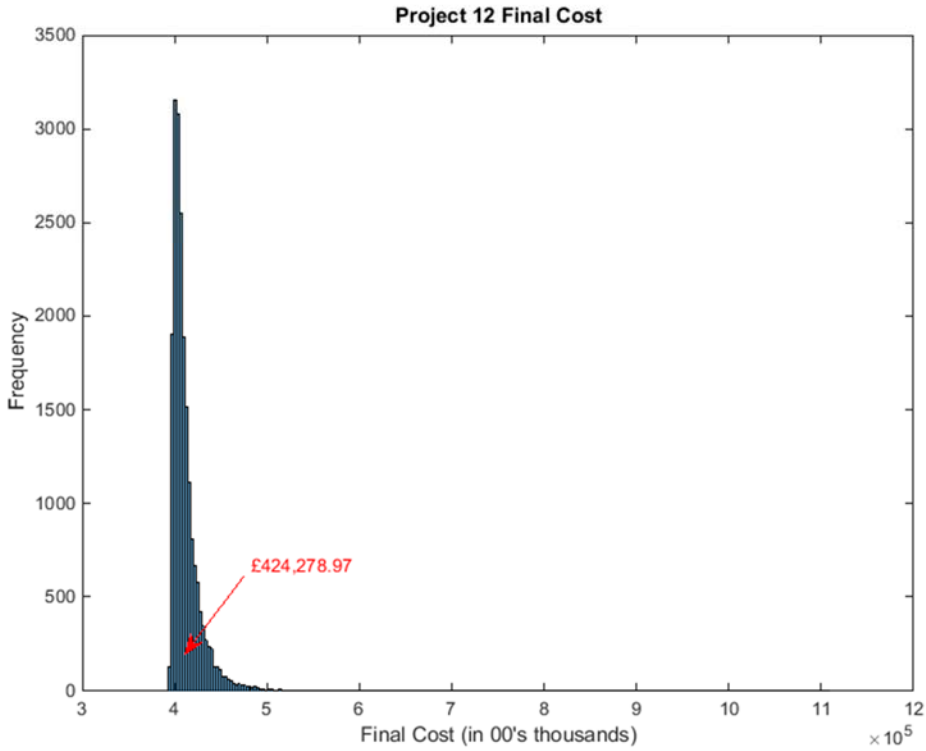

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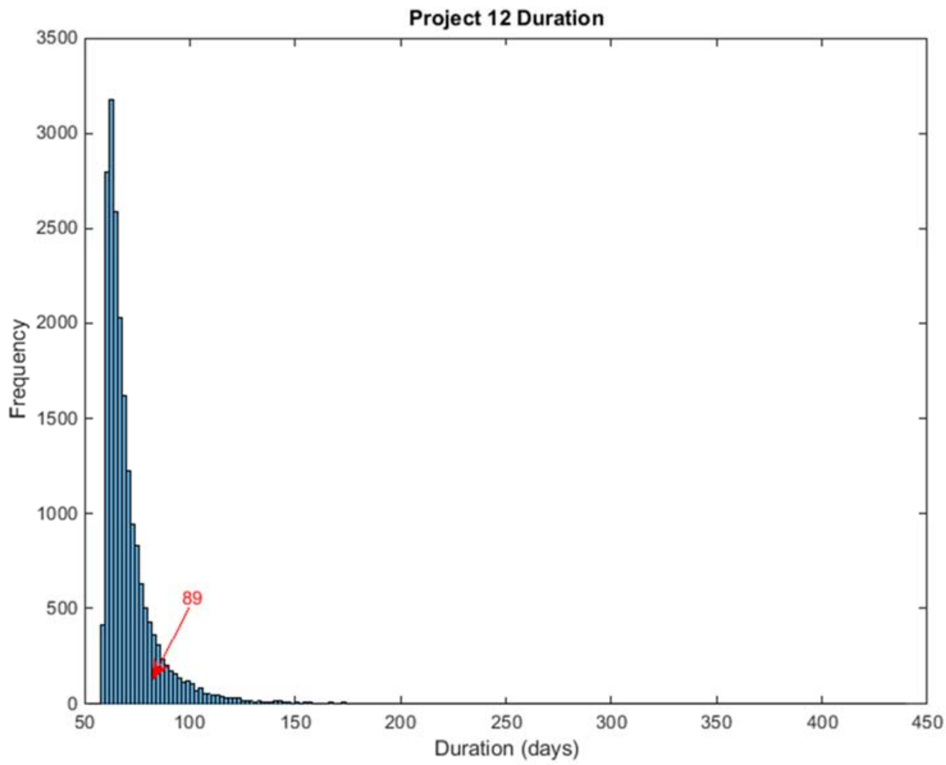

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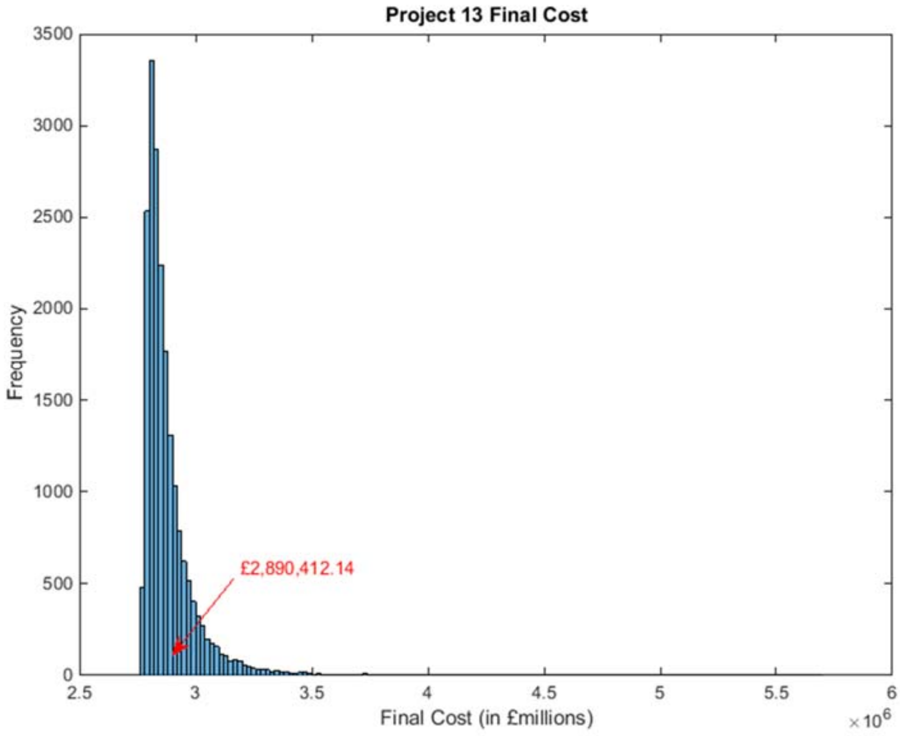

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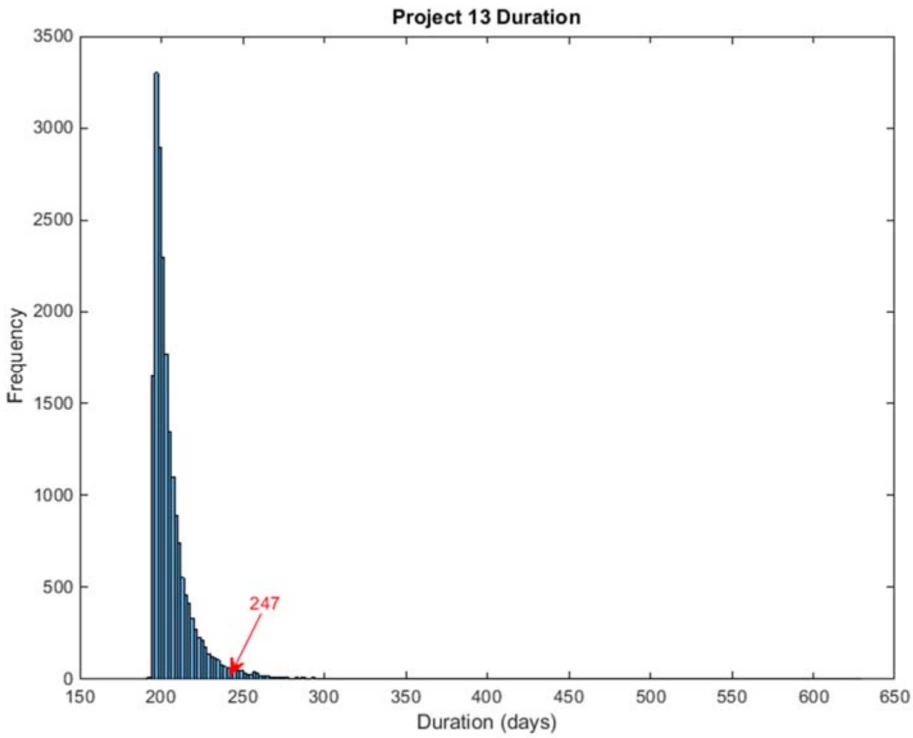

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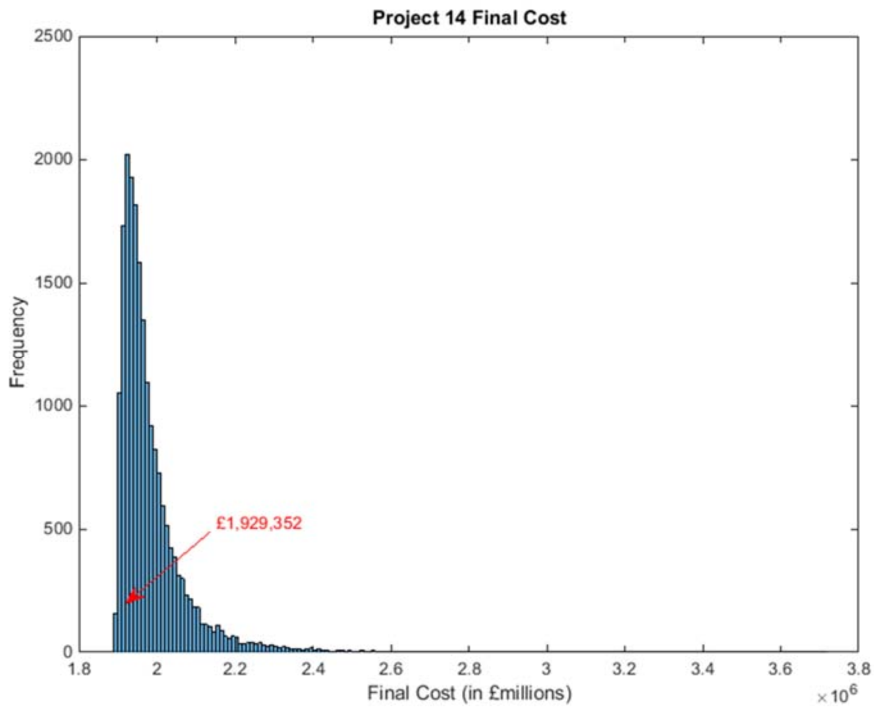

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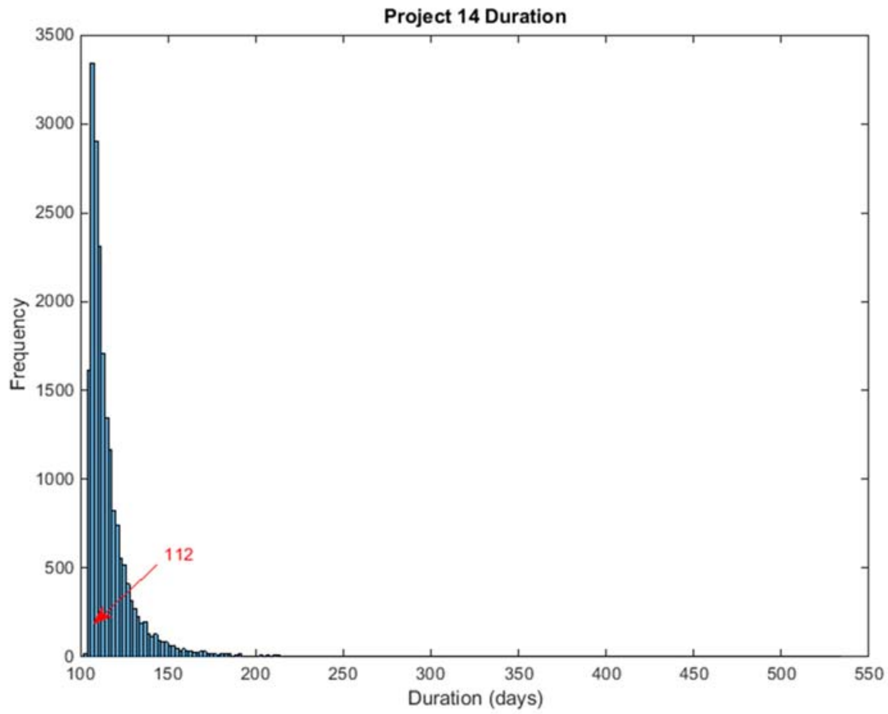

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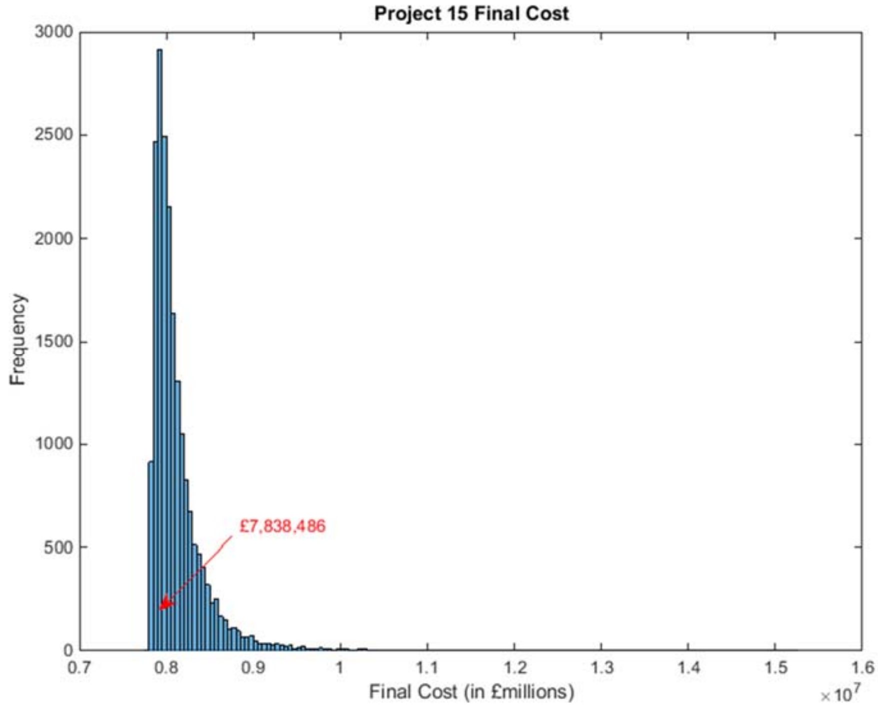

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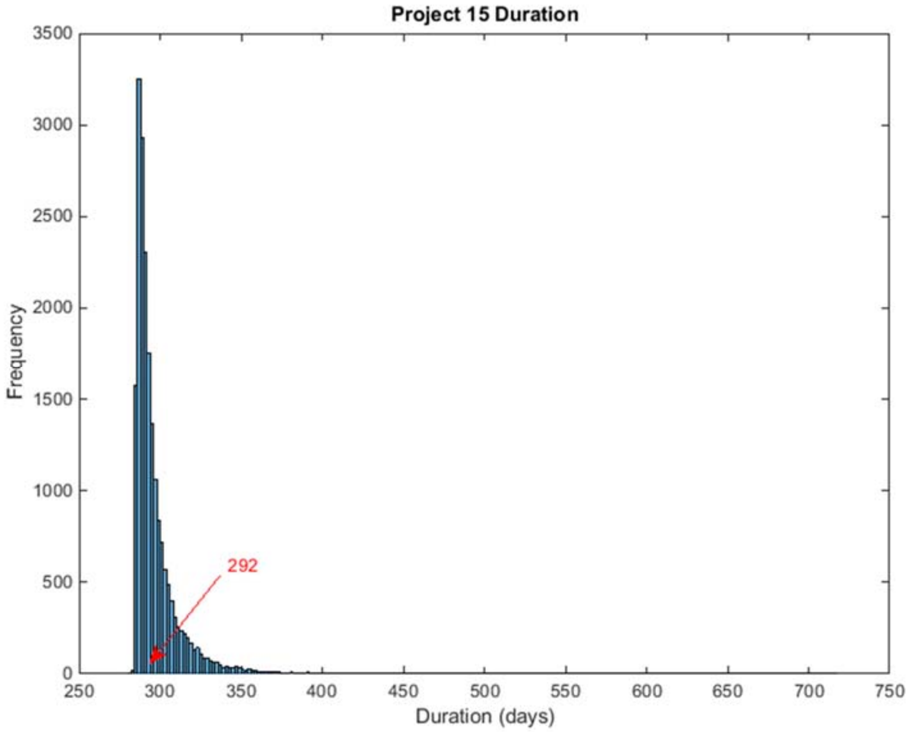

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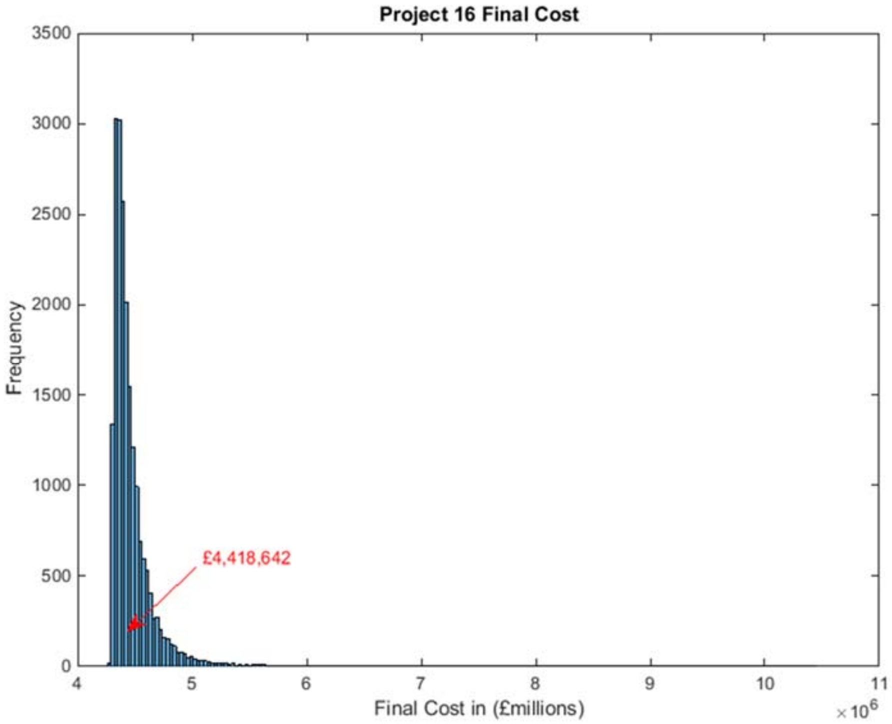

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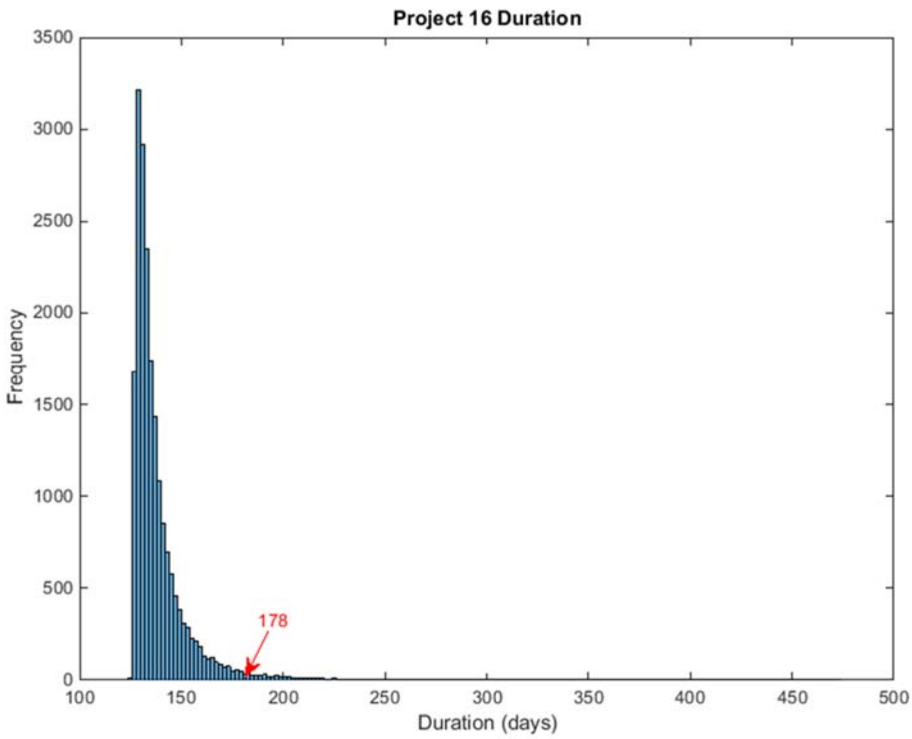

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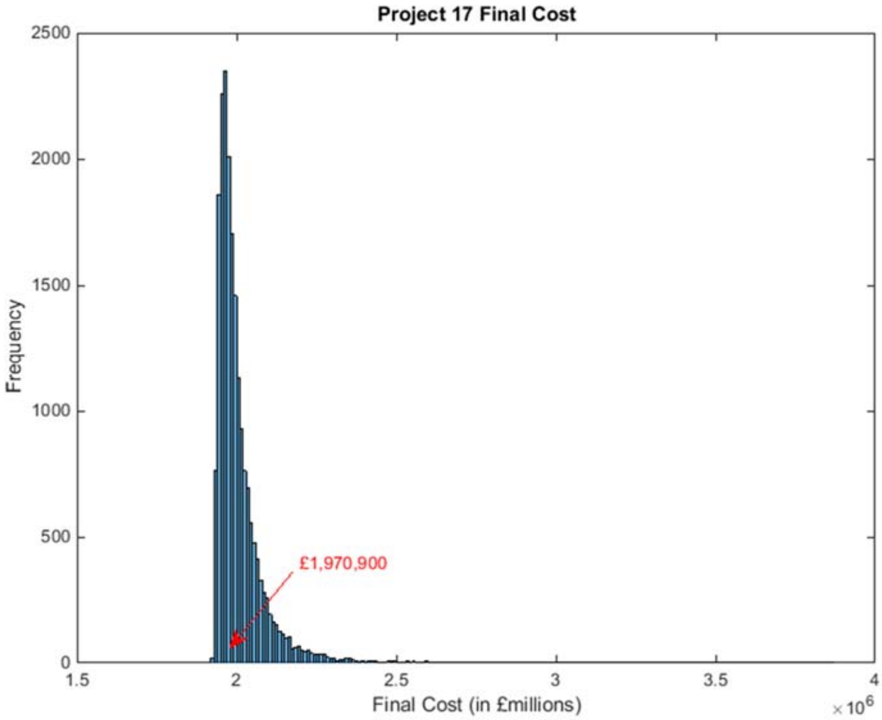

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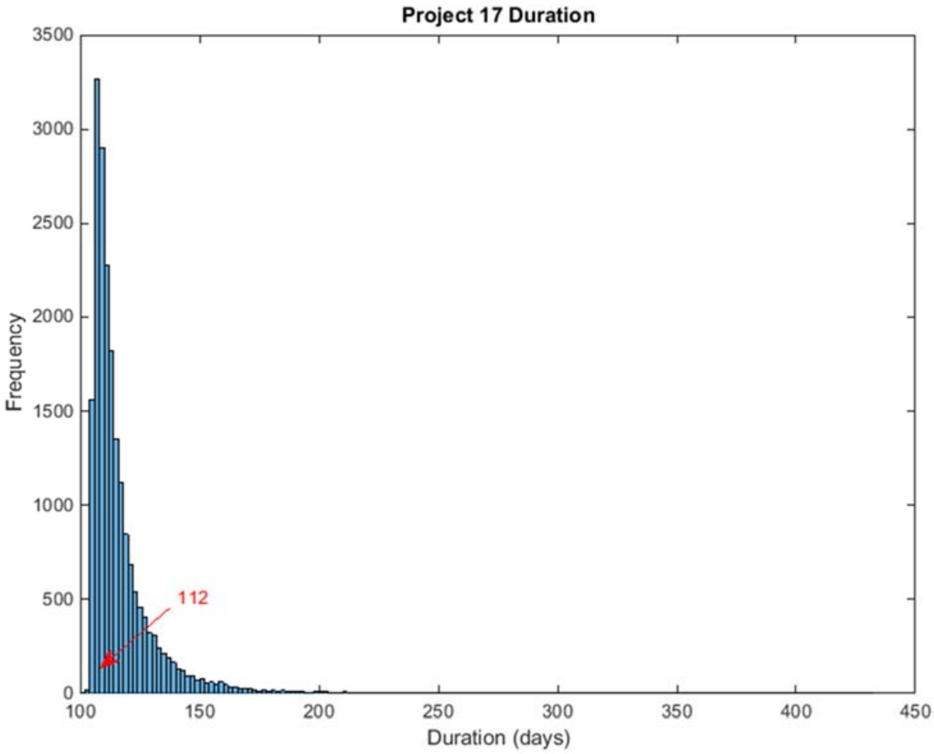

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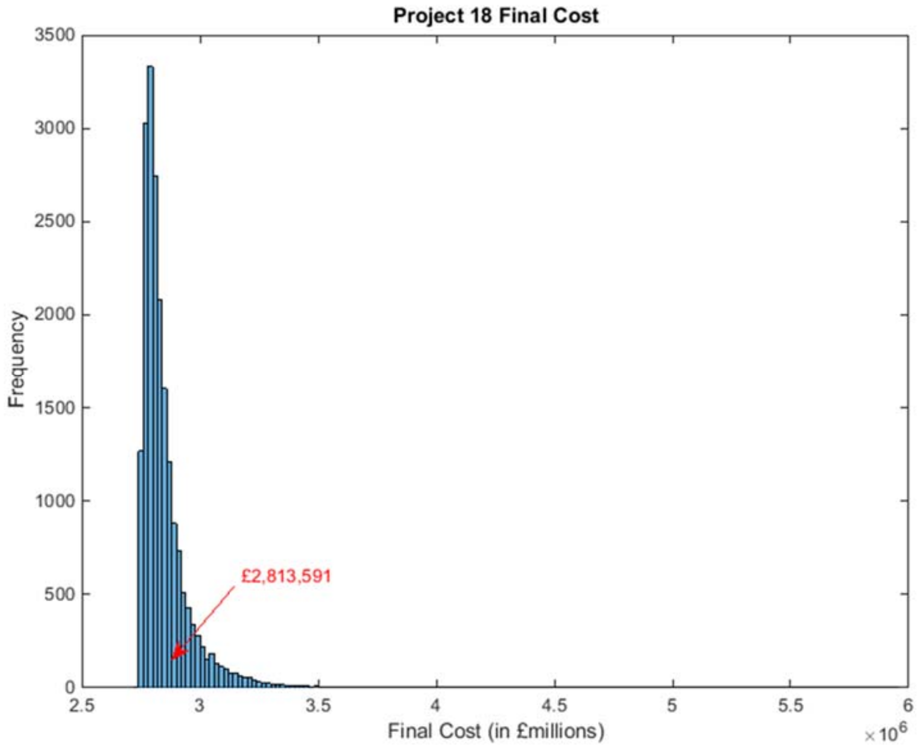

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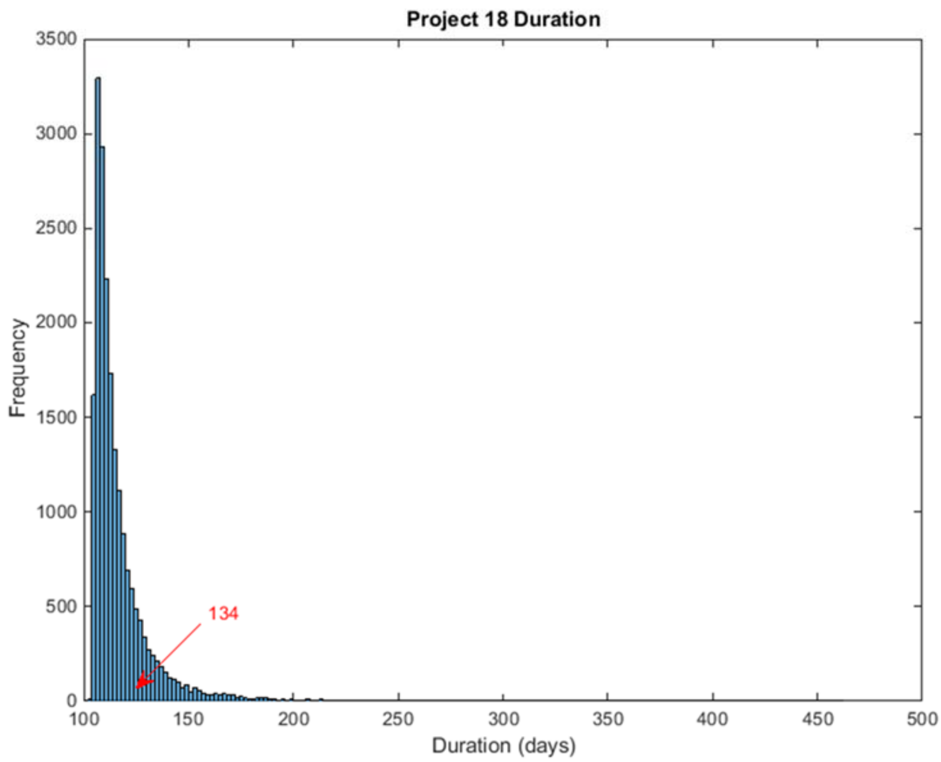

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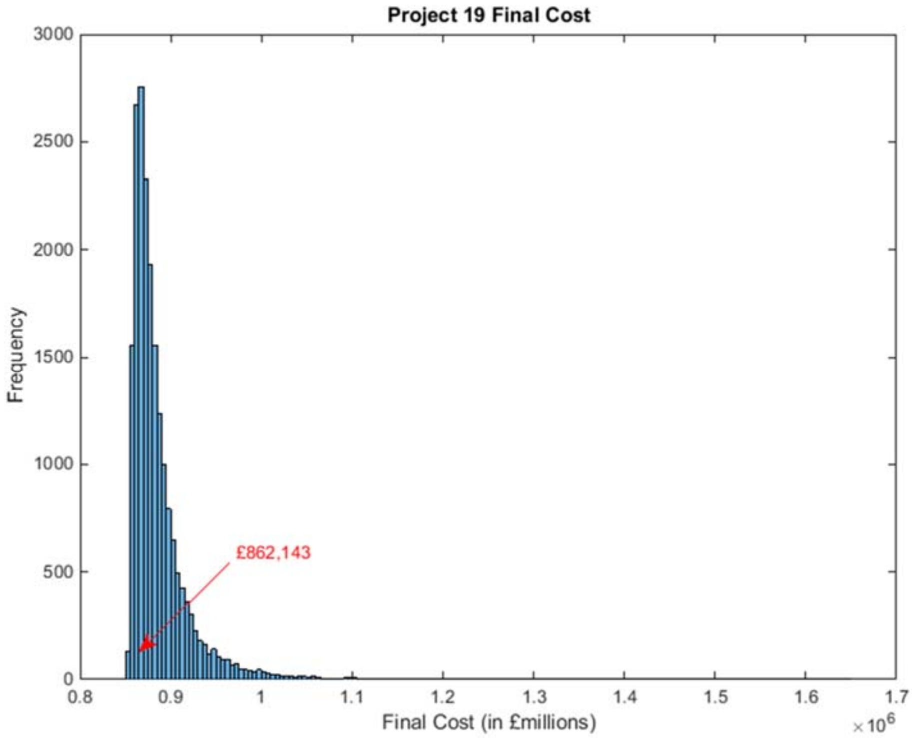

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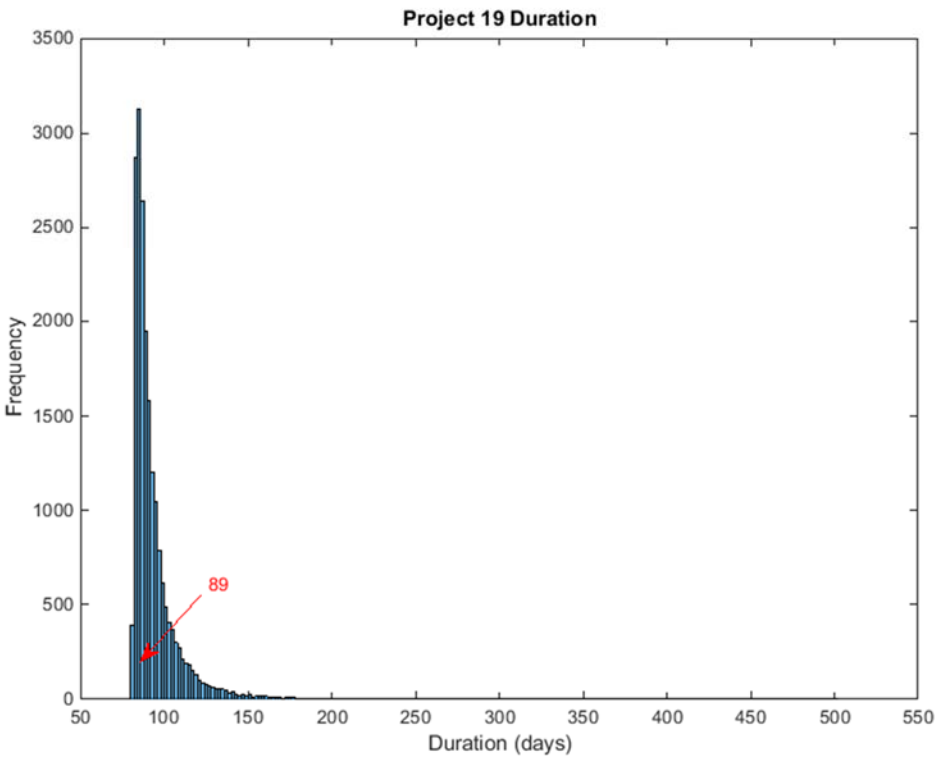

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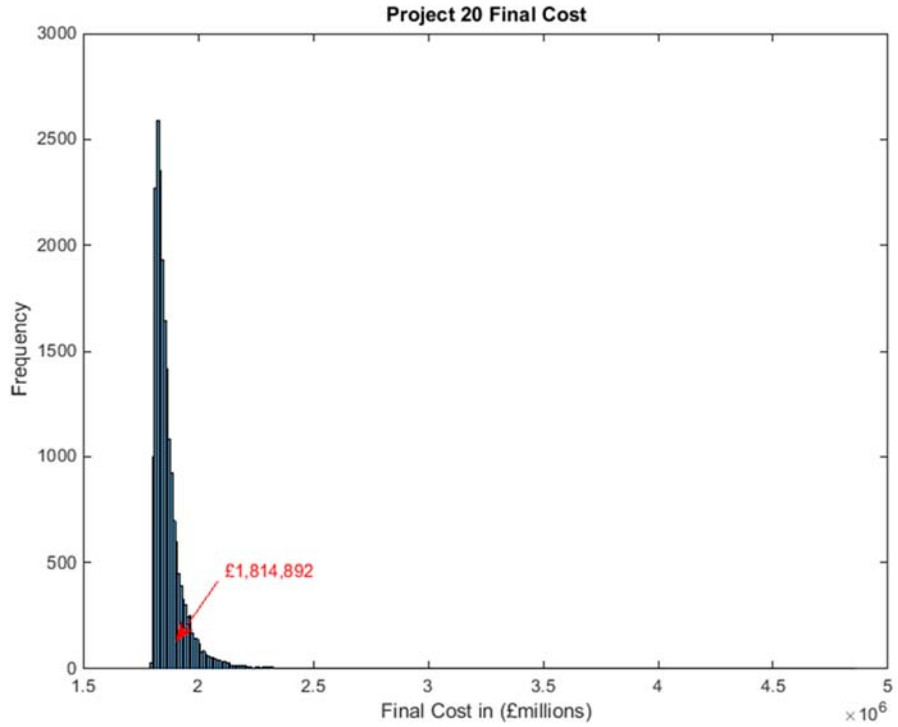

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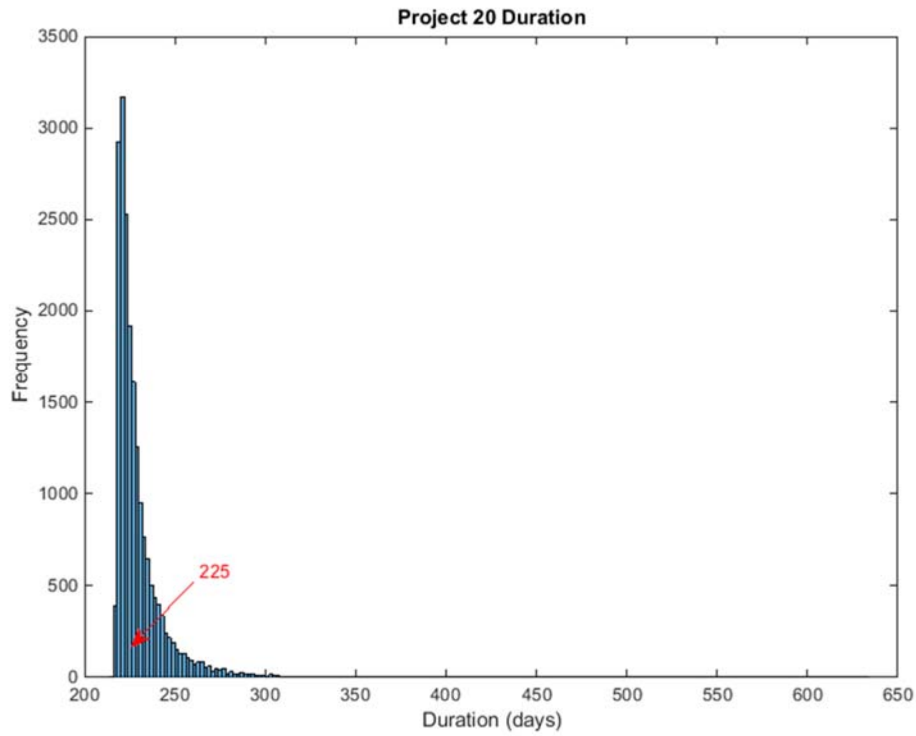
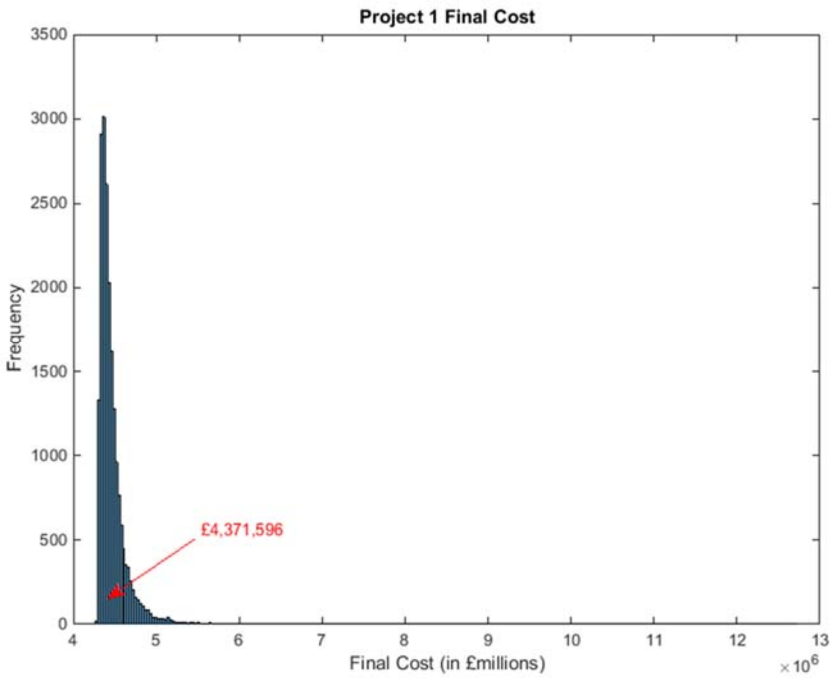


APPENDIX 3

Project 1 Final Cost (Dataset 3)



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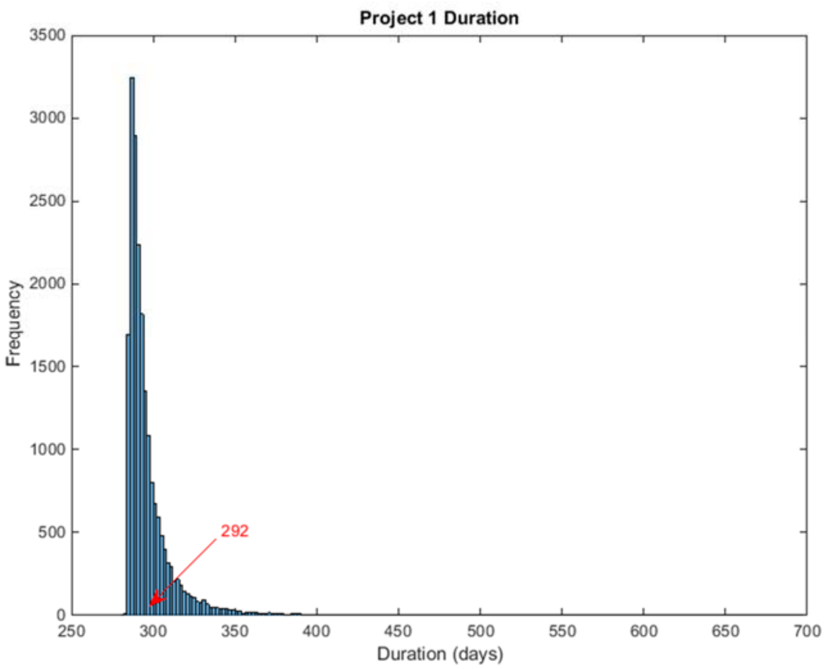

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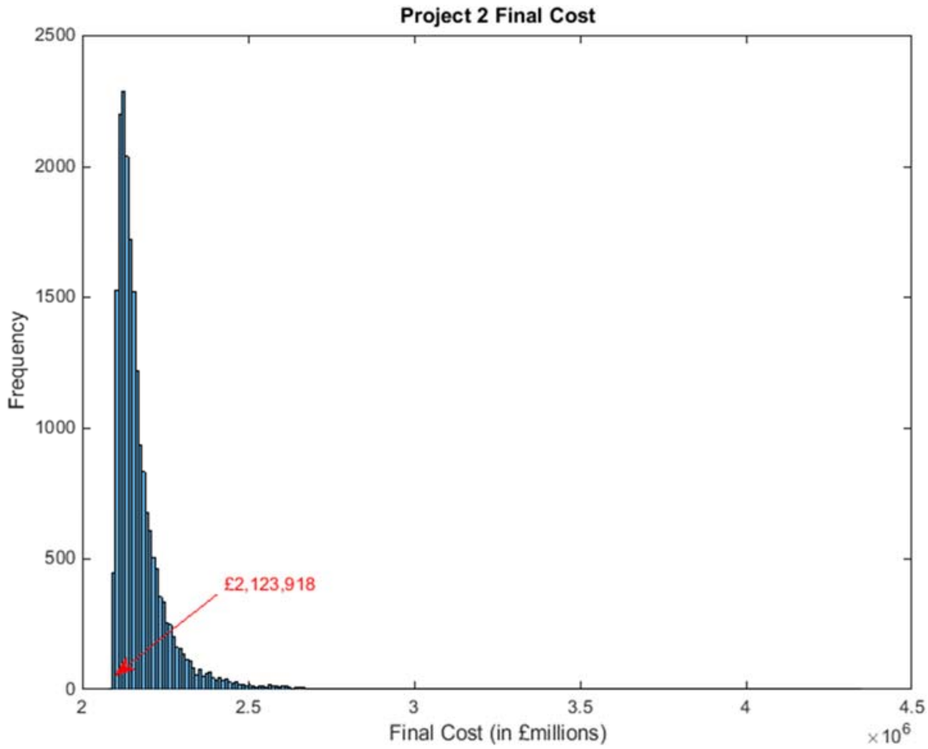

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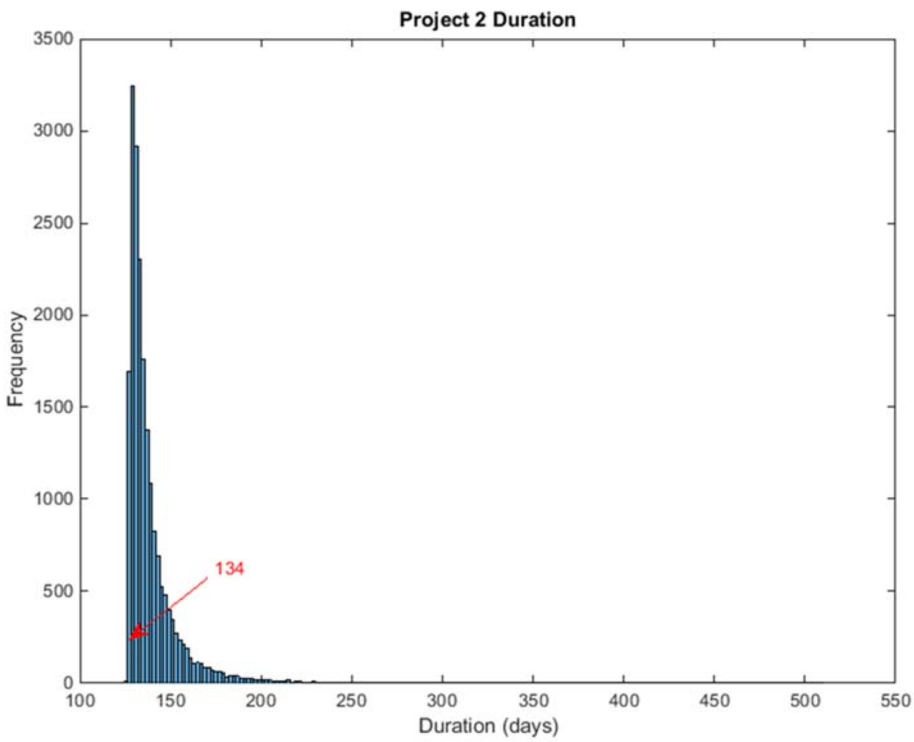

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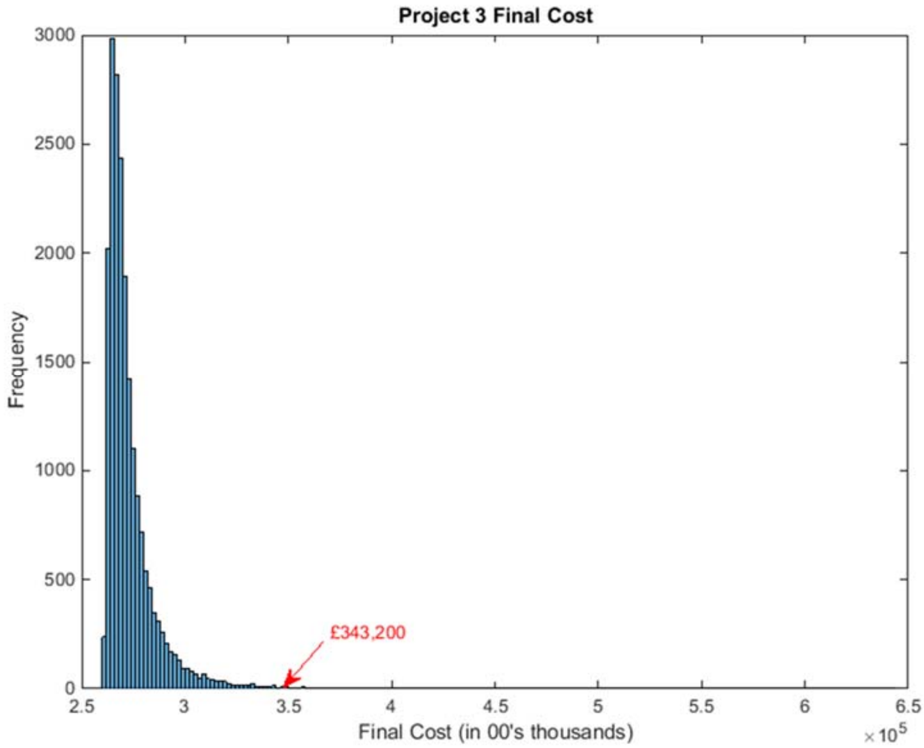

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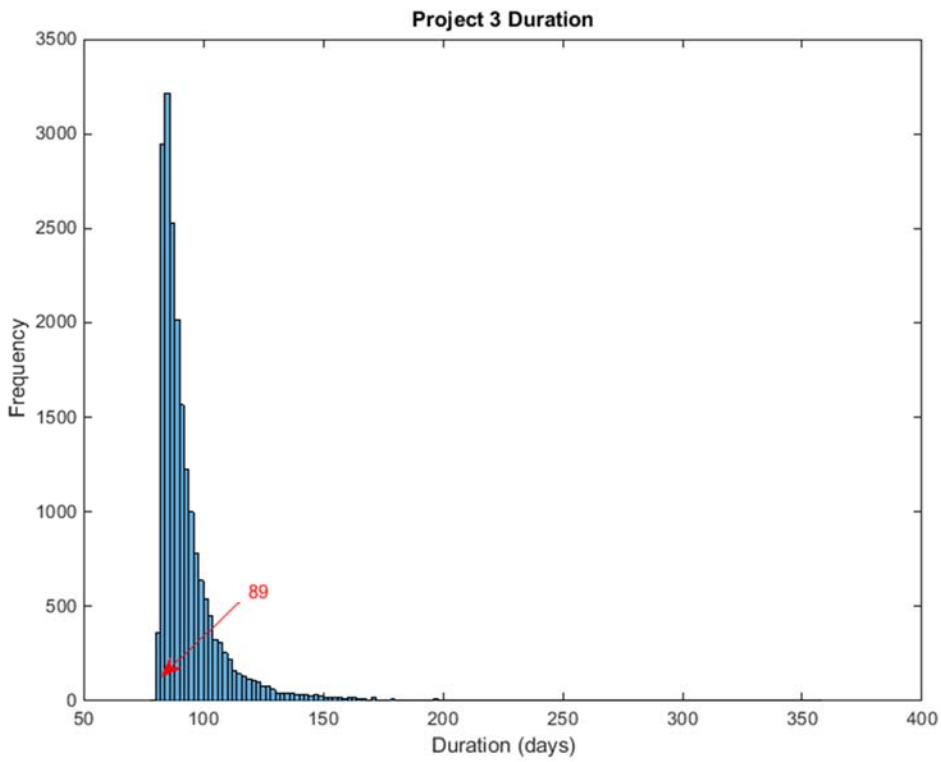

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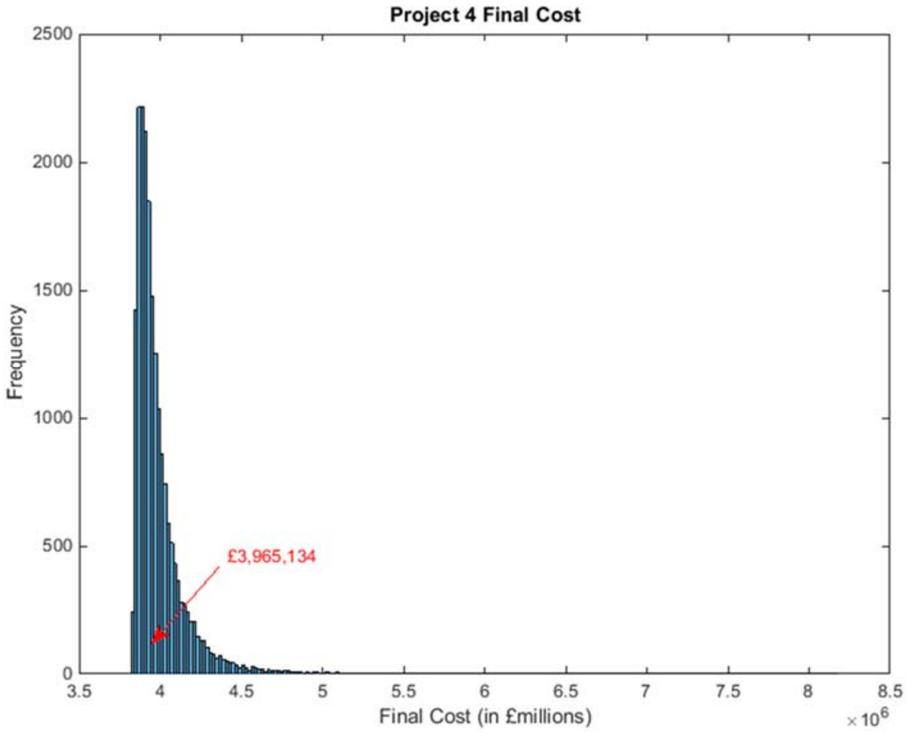
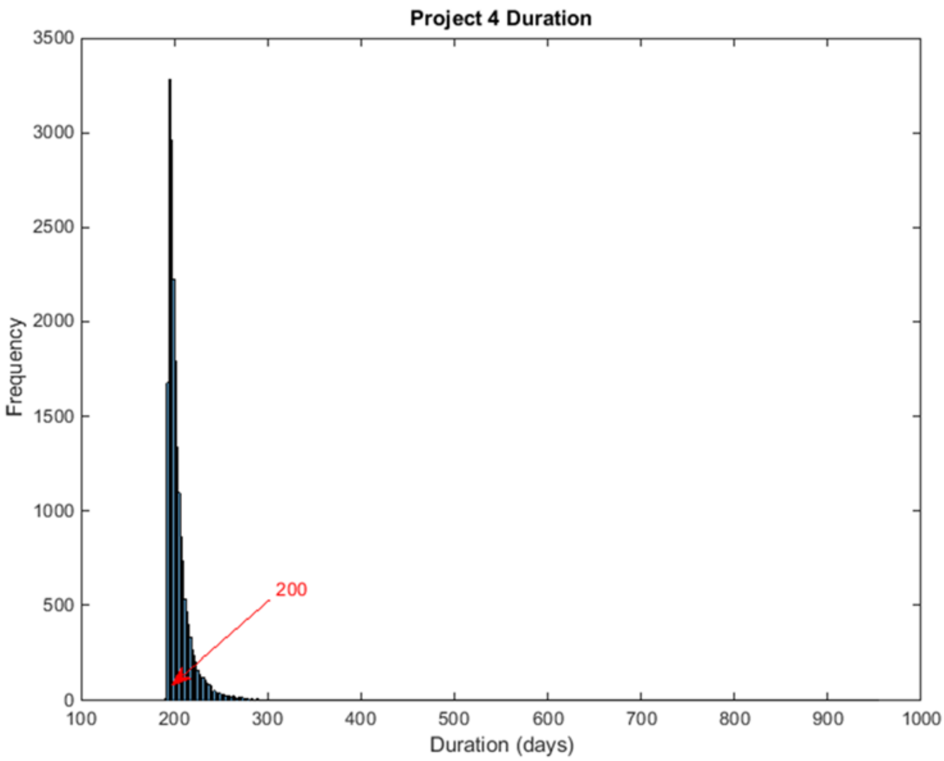


Project 4 Duration (Dataset 3)



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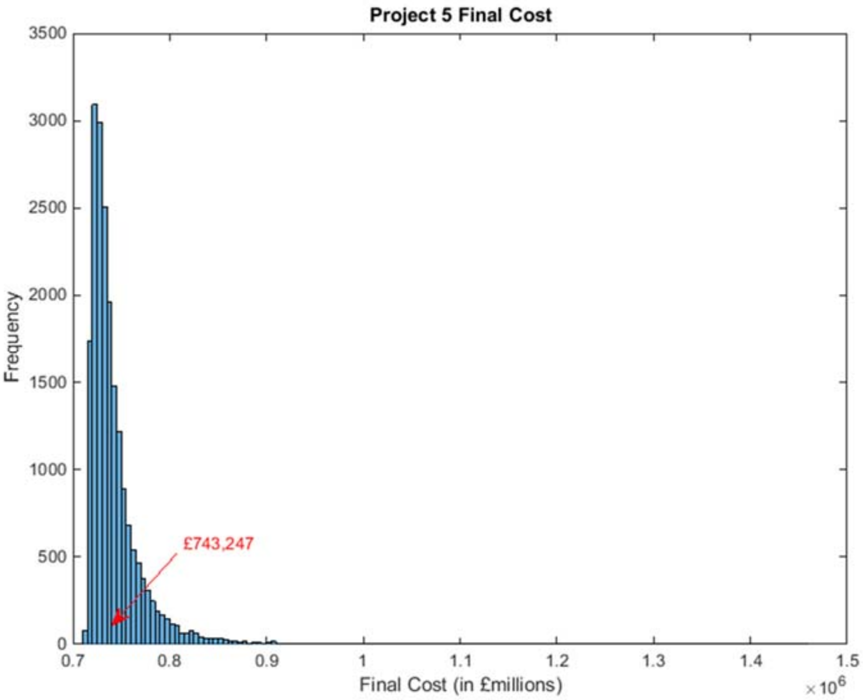

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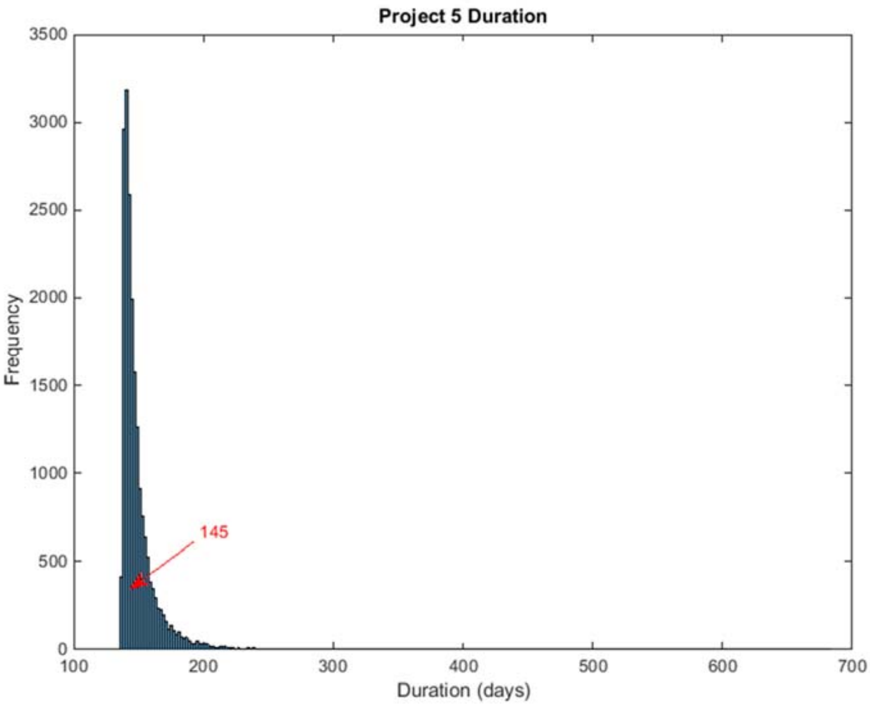

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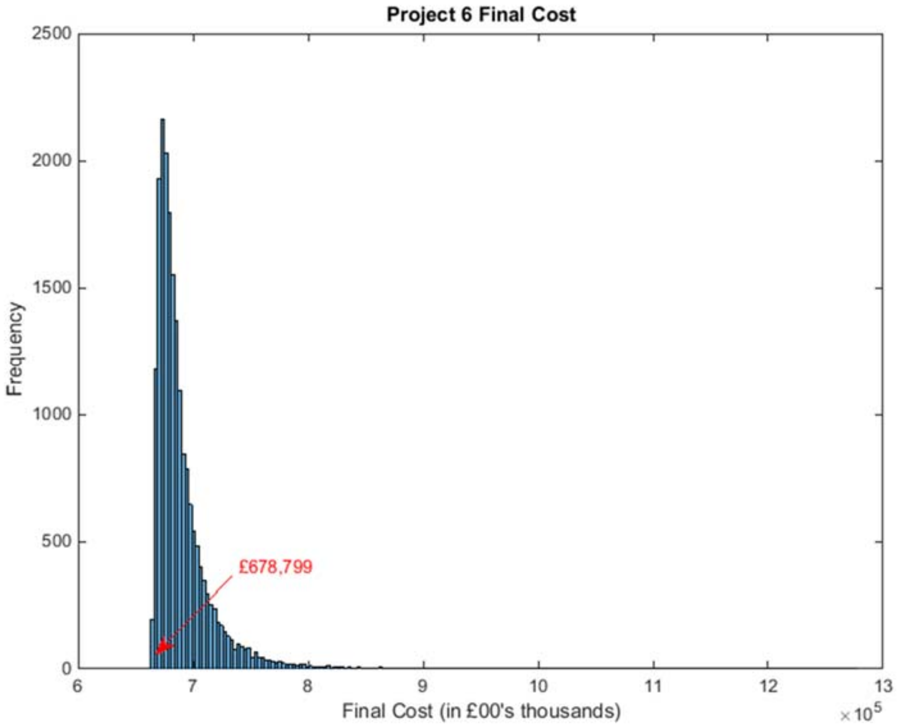
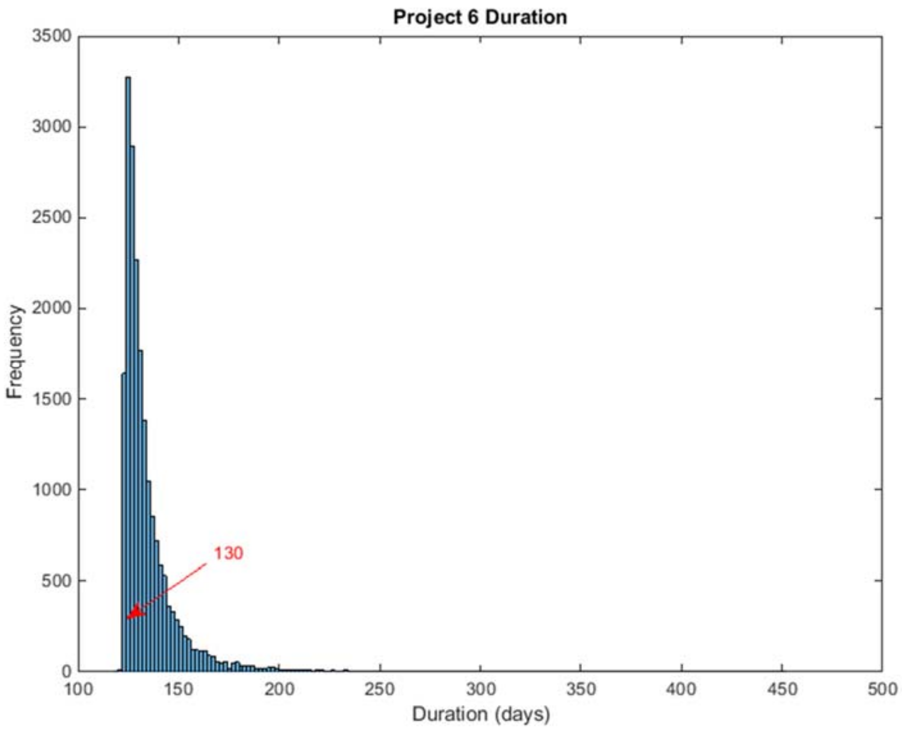


Project 6 Duration (Dataset 3)



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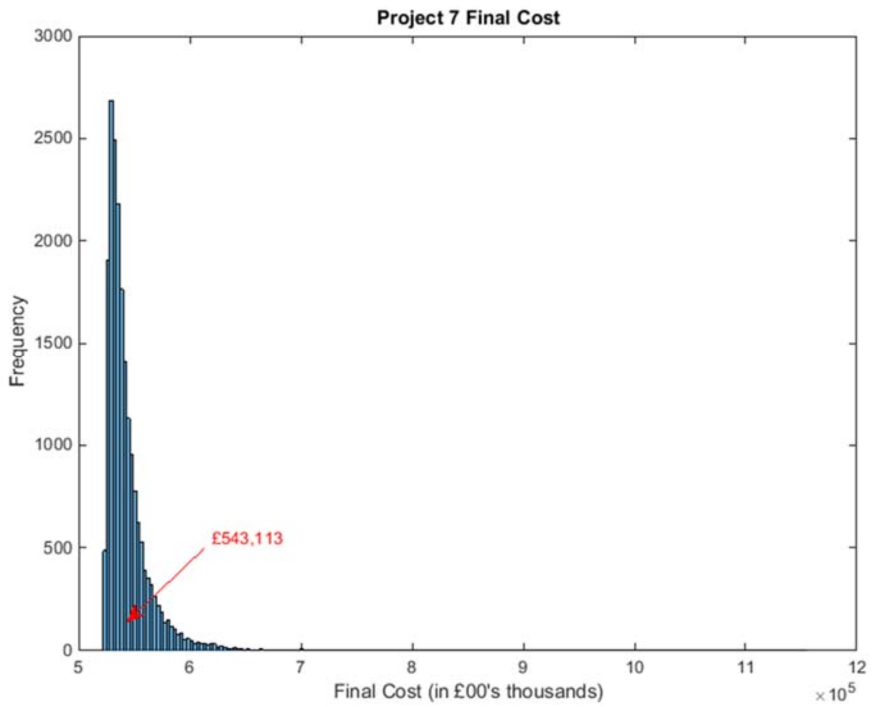
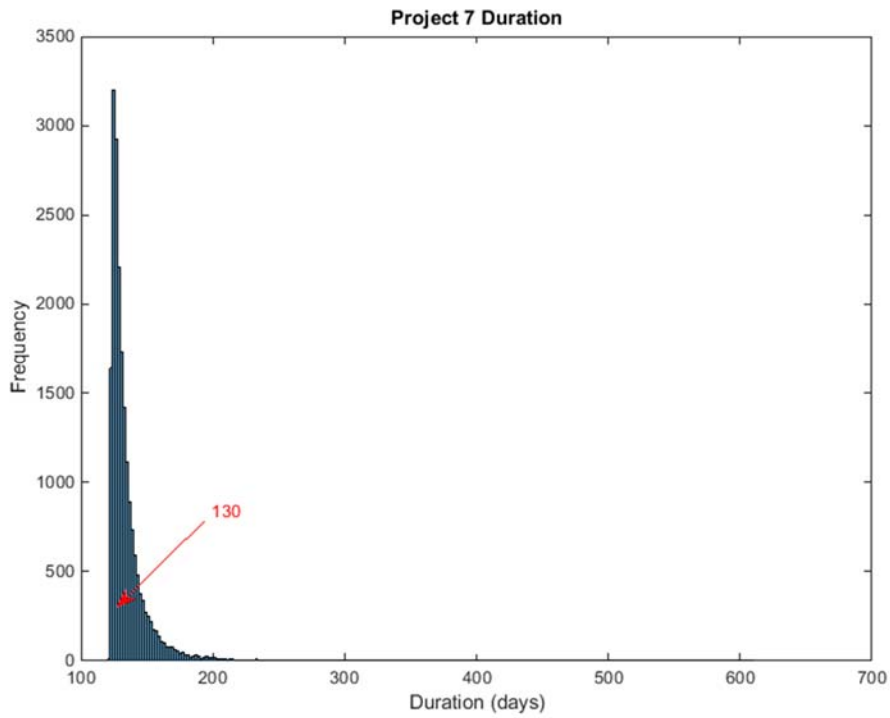


Project 7 Duration (Dataset 3)



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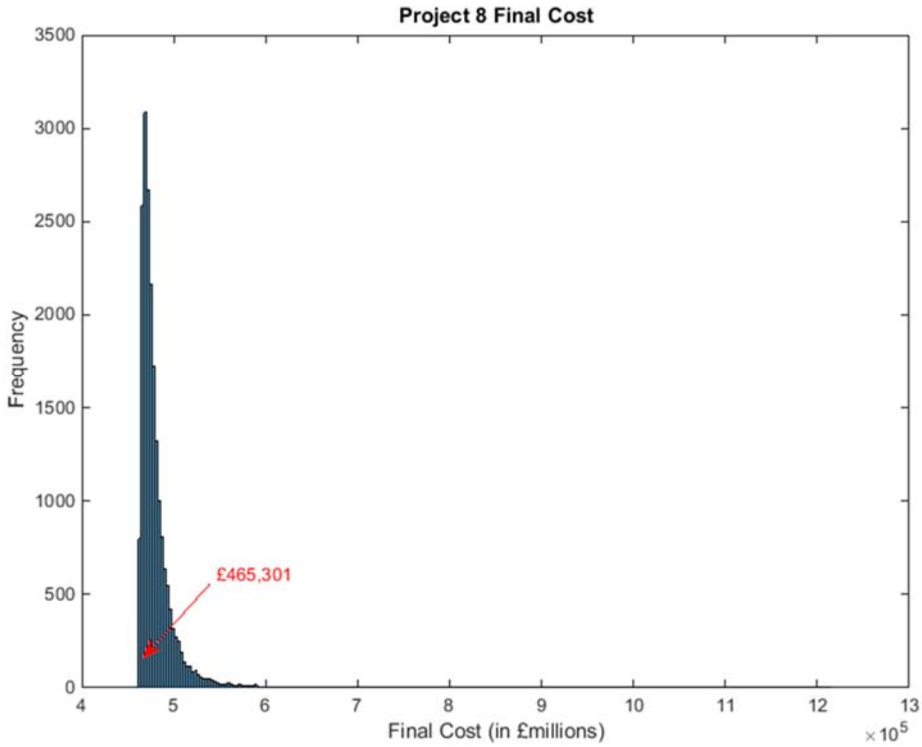

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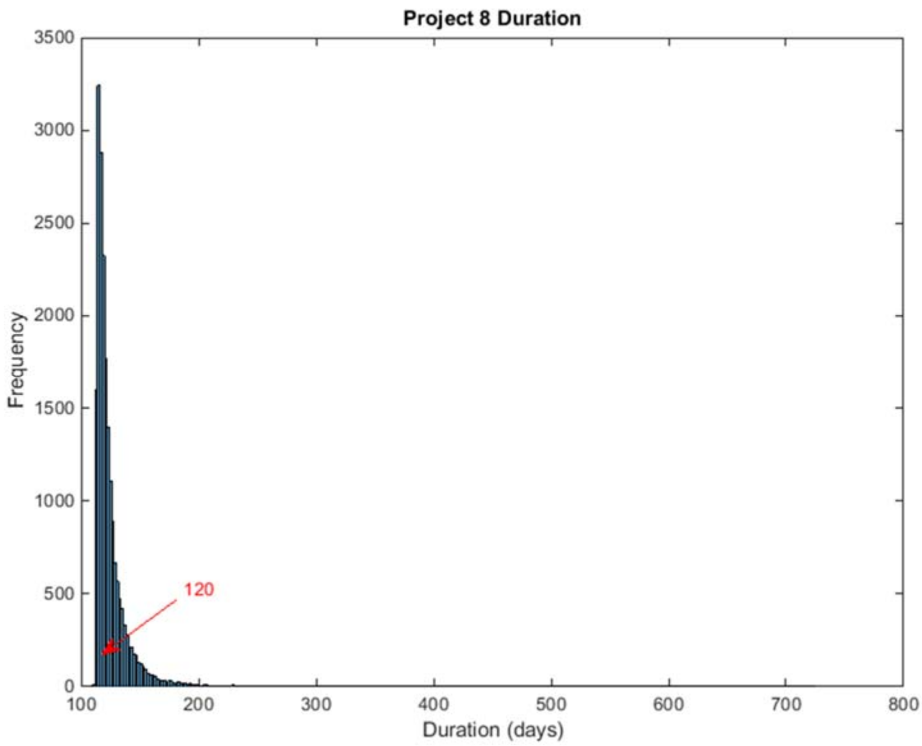

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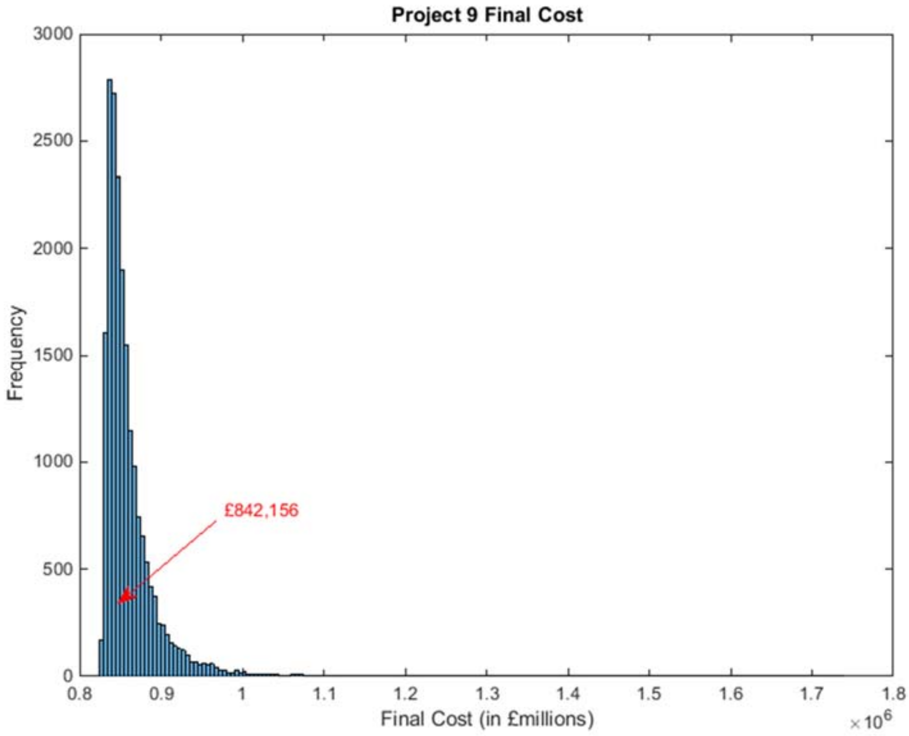

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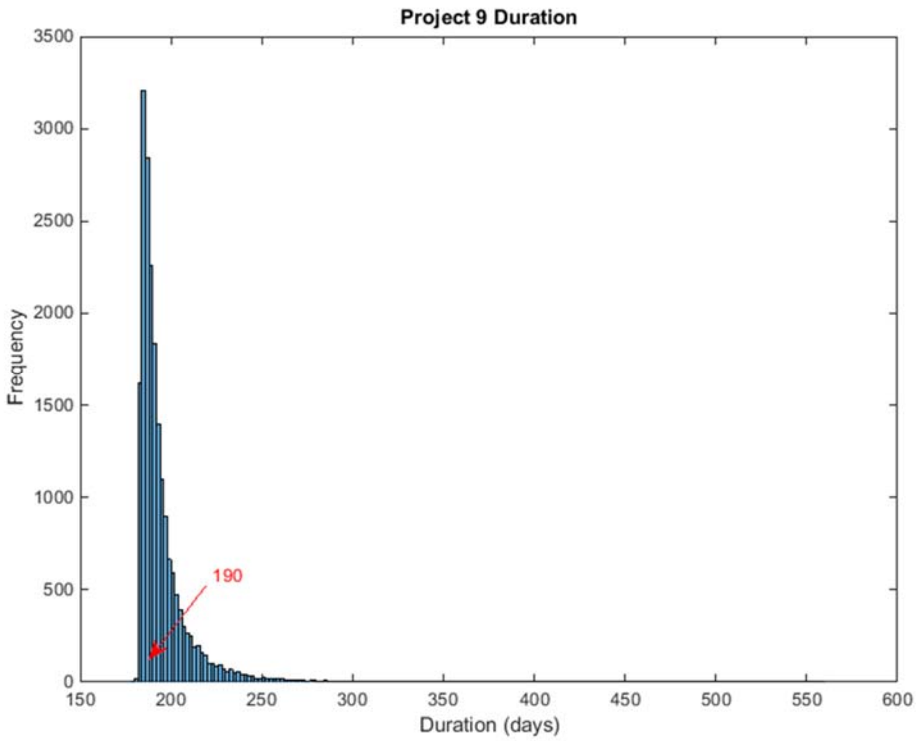

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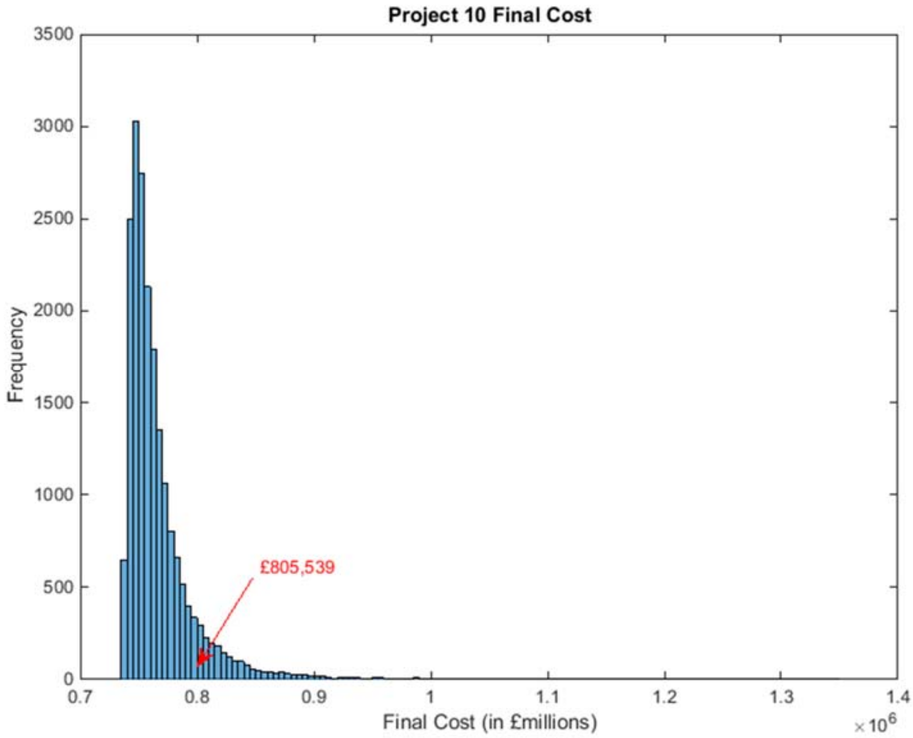

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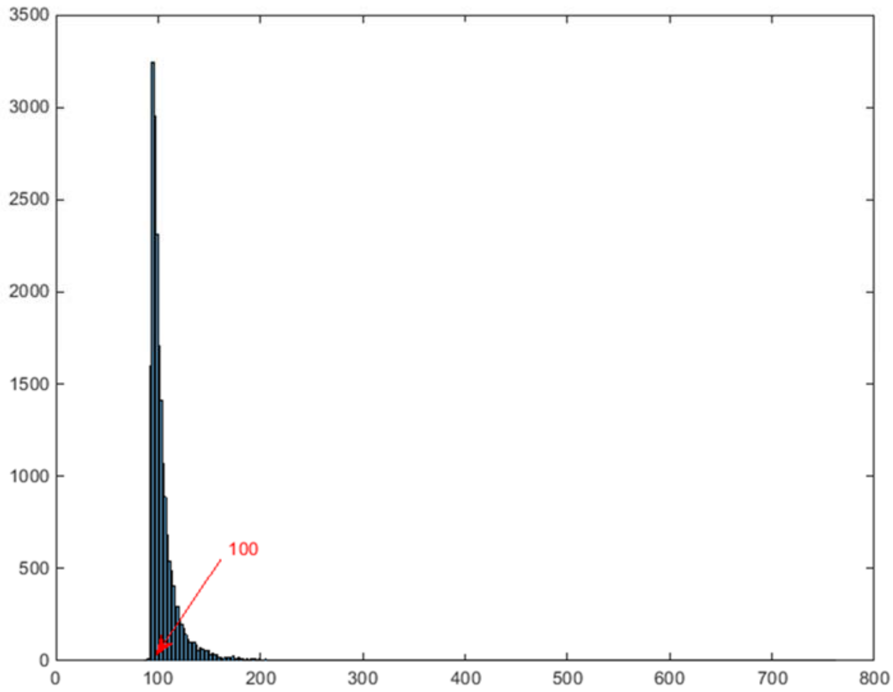

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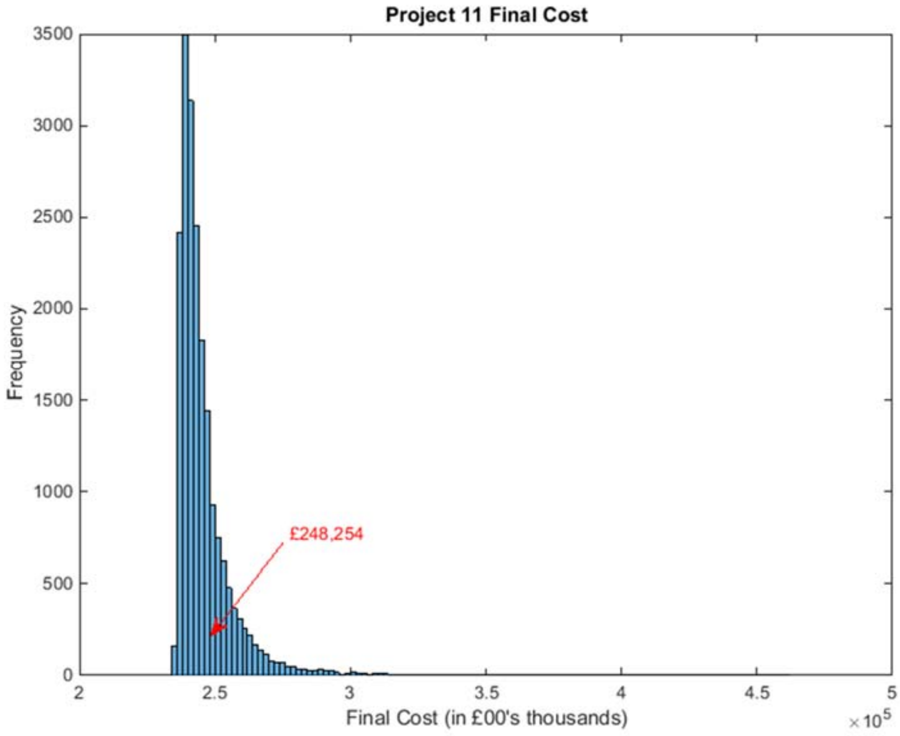

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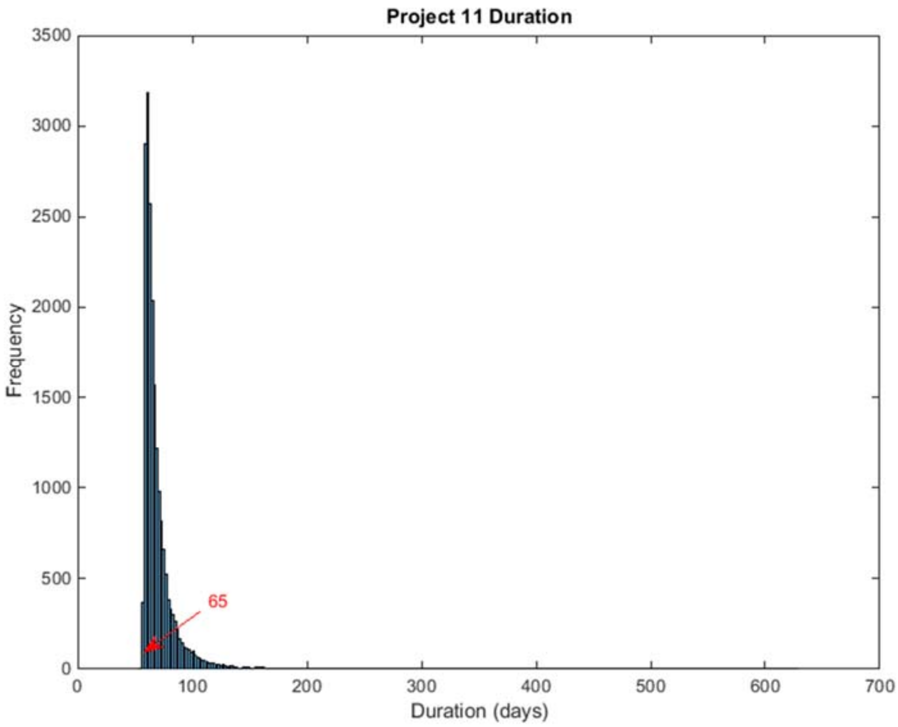

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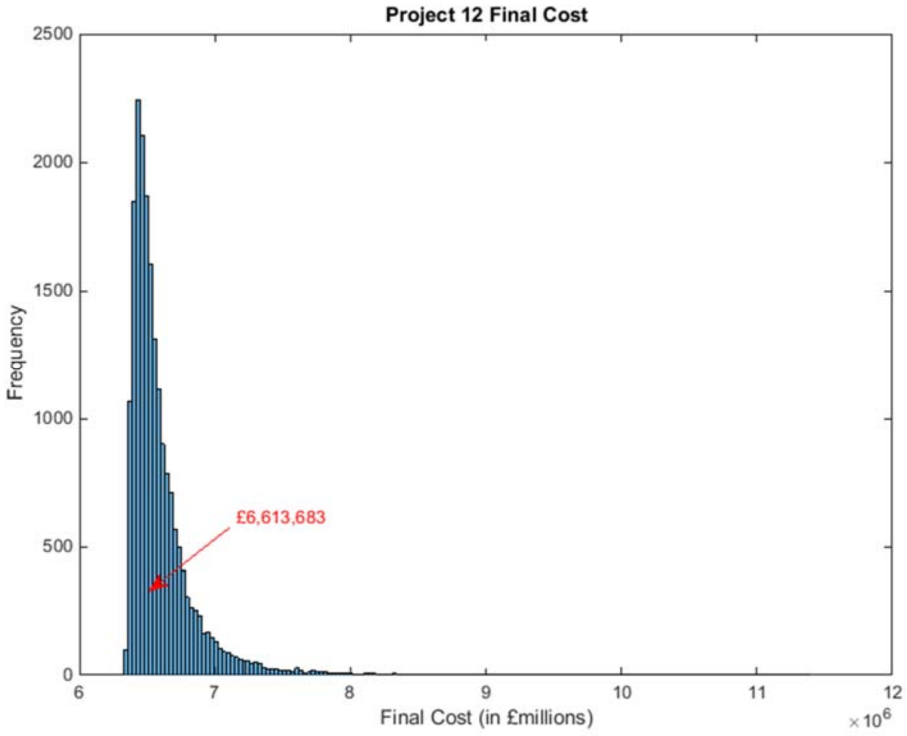

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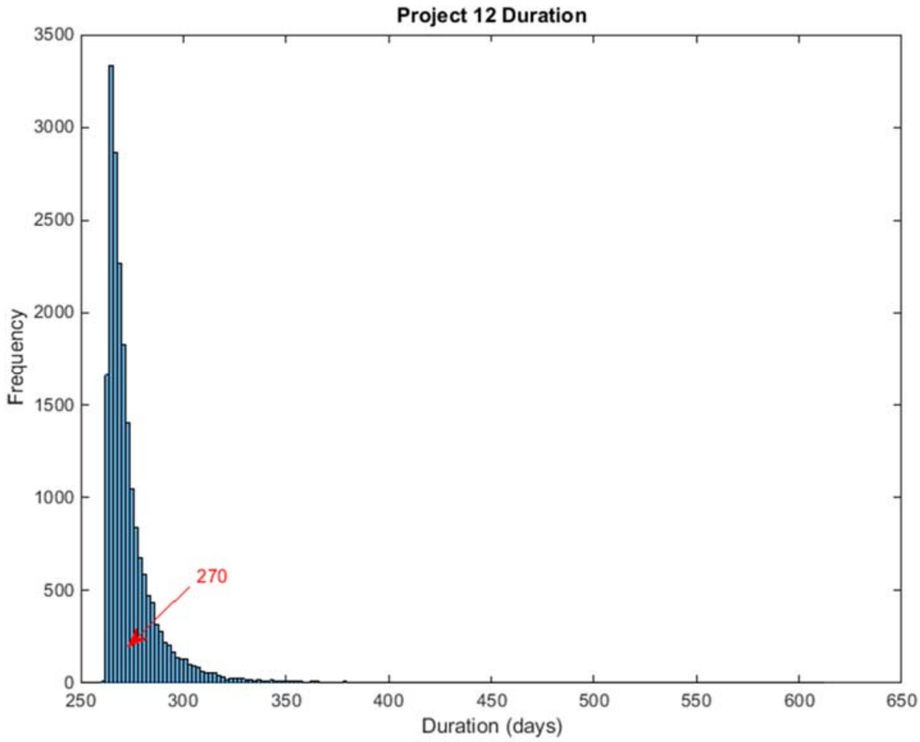

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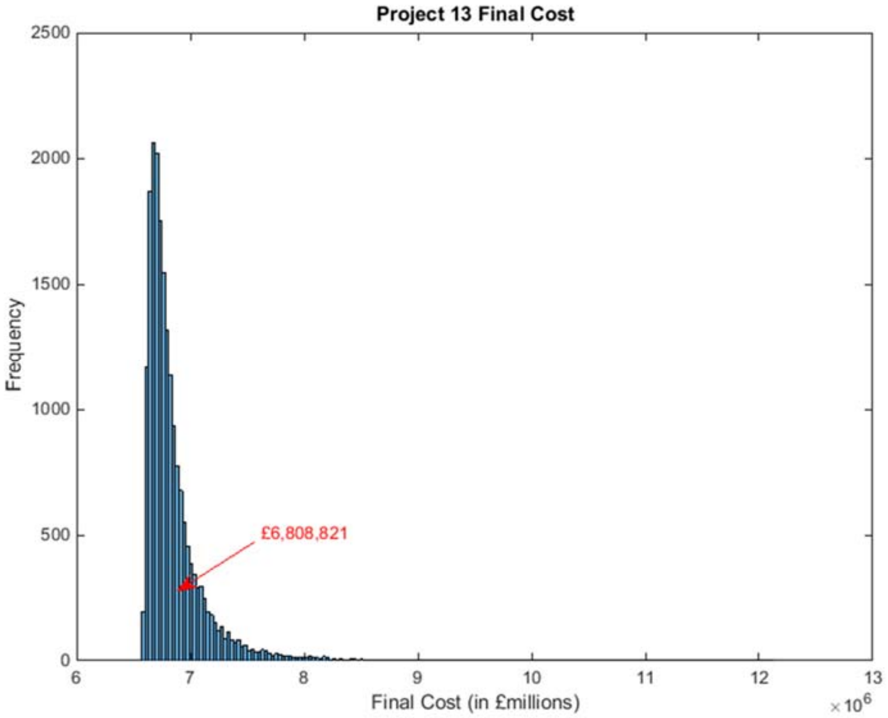

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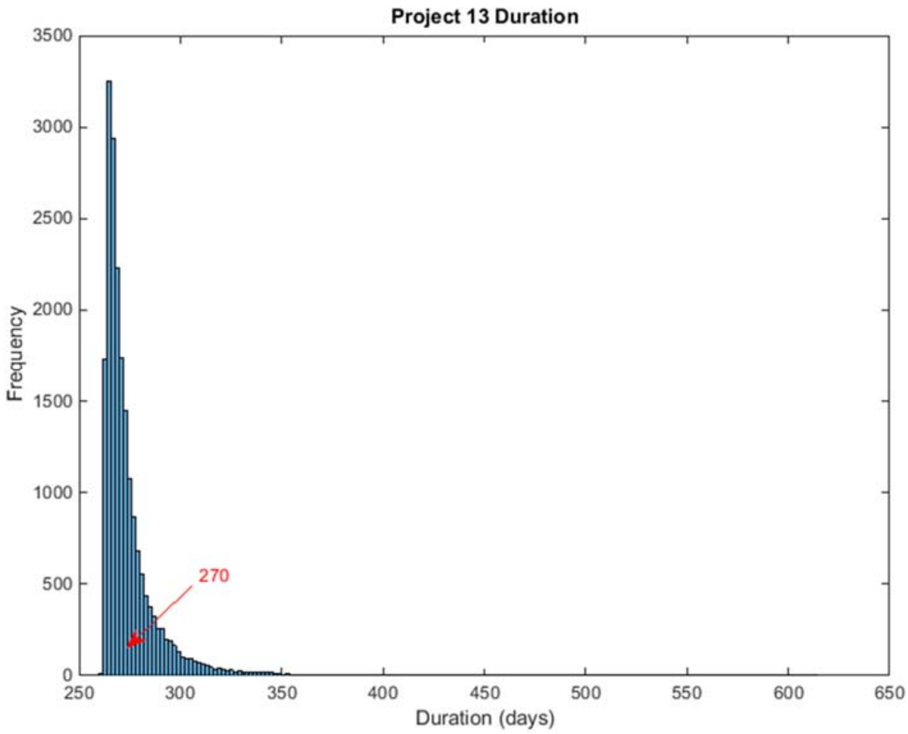

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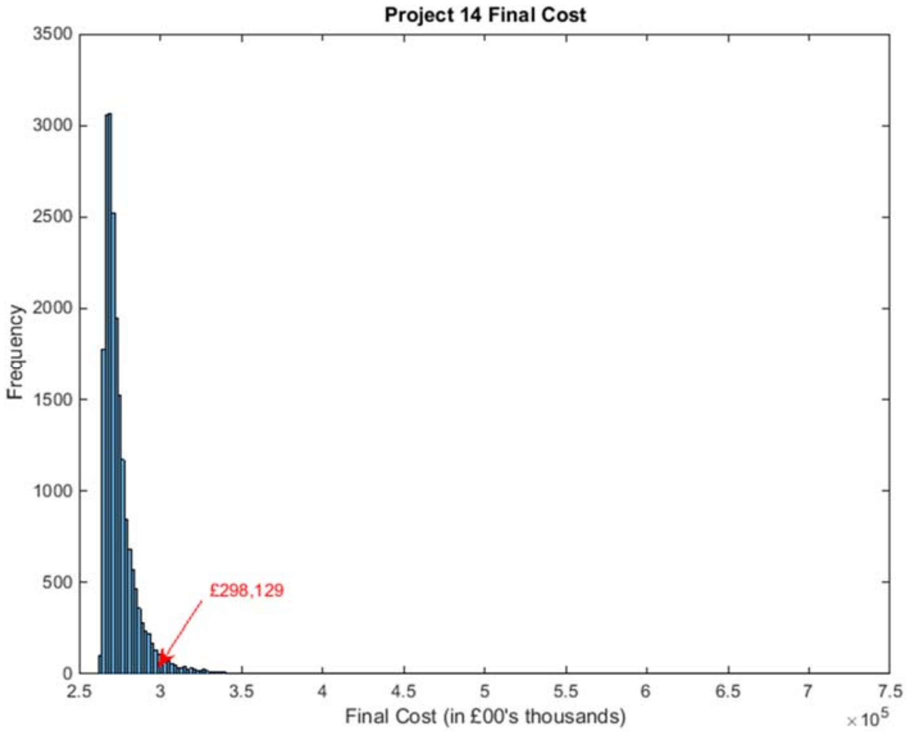

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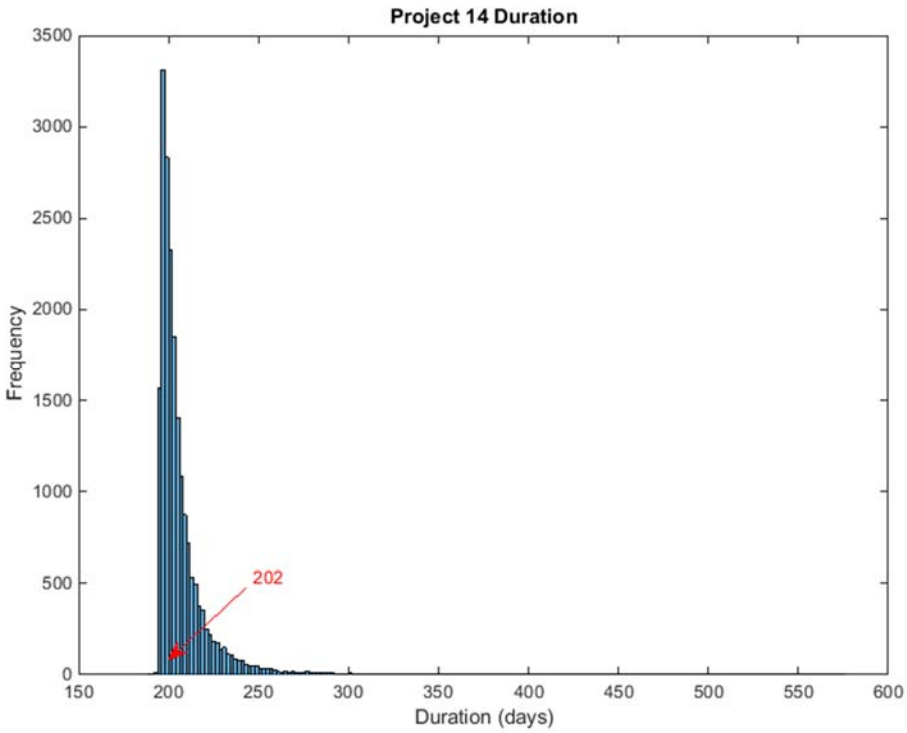

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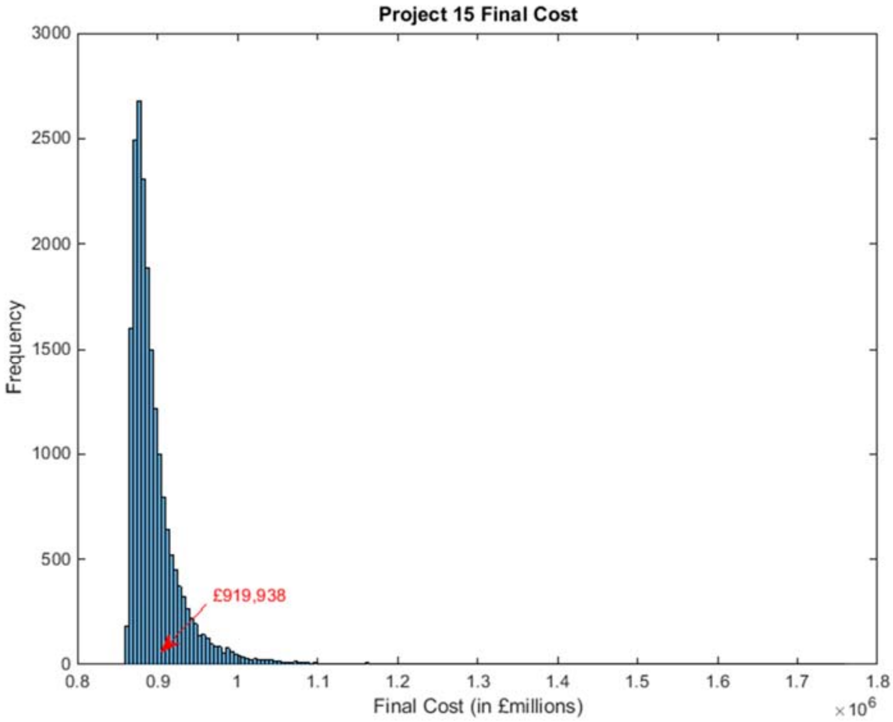

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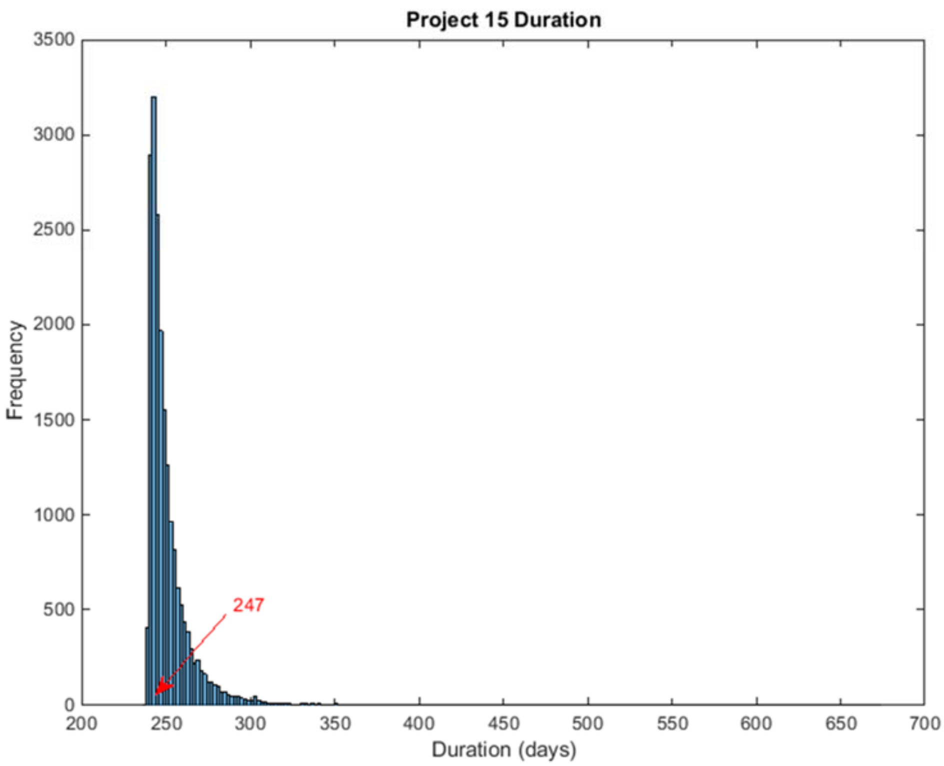

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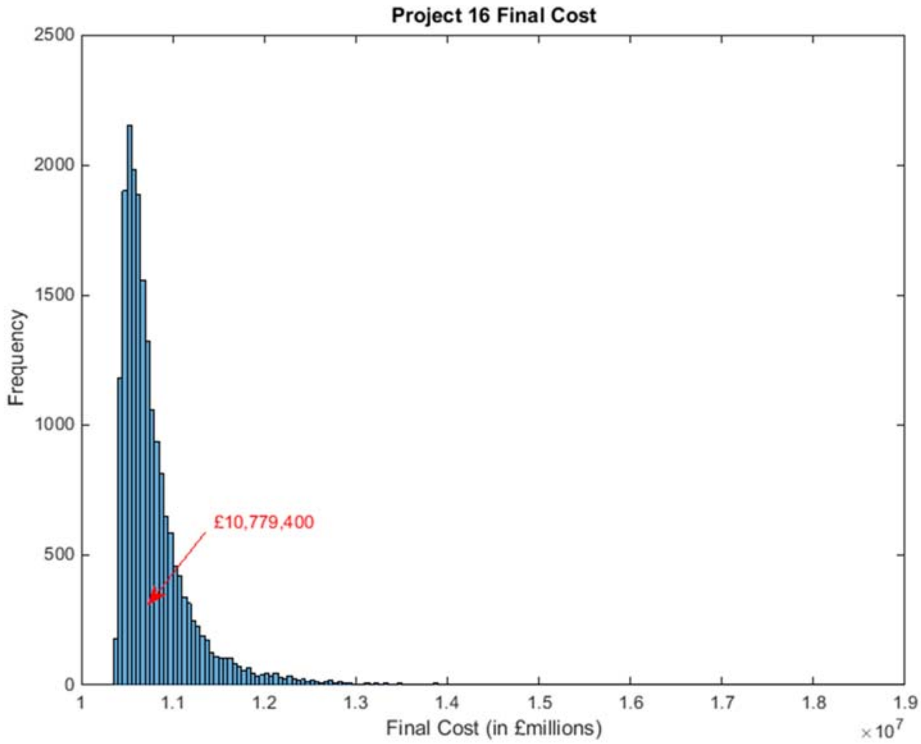

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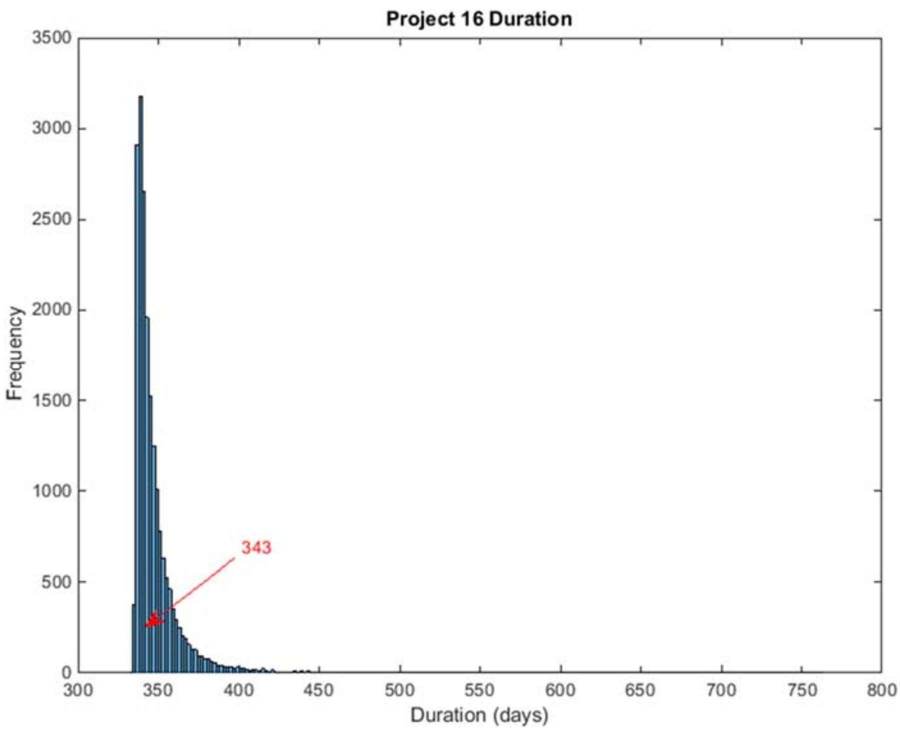

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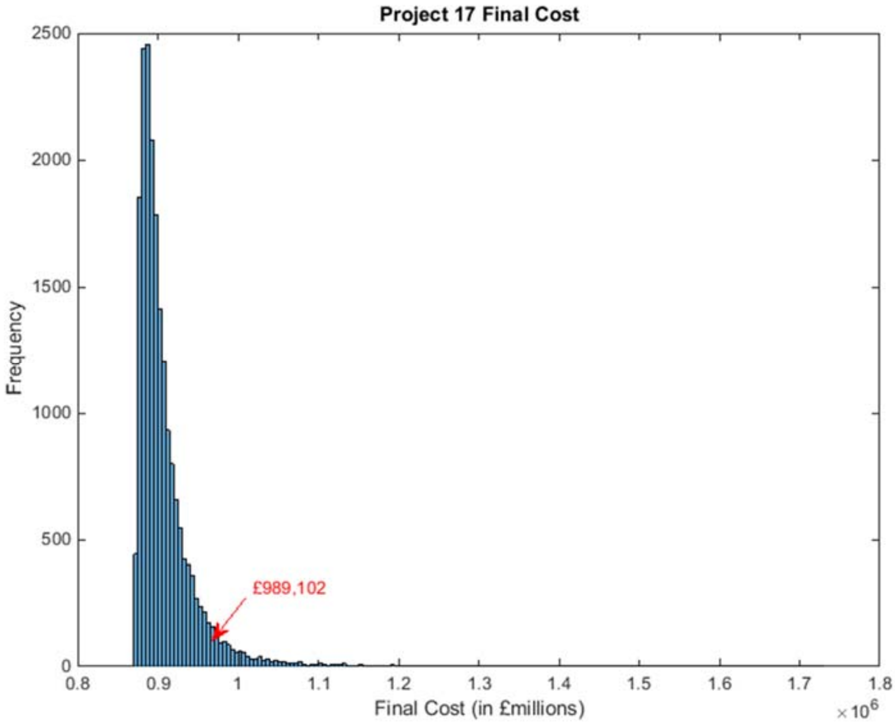

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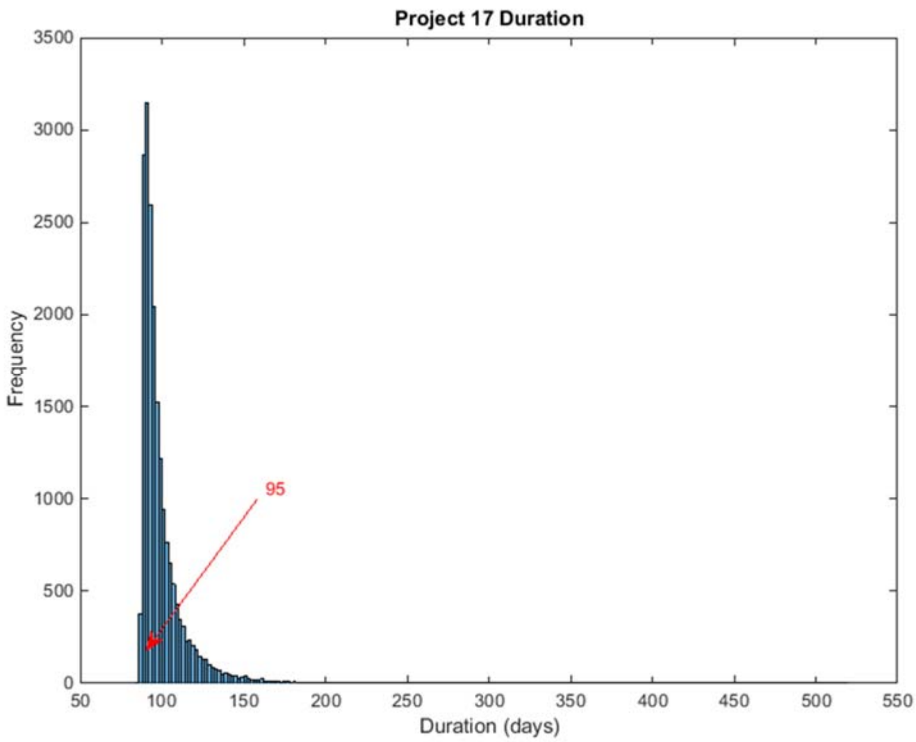

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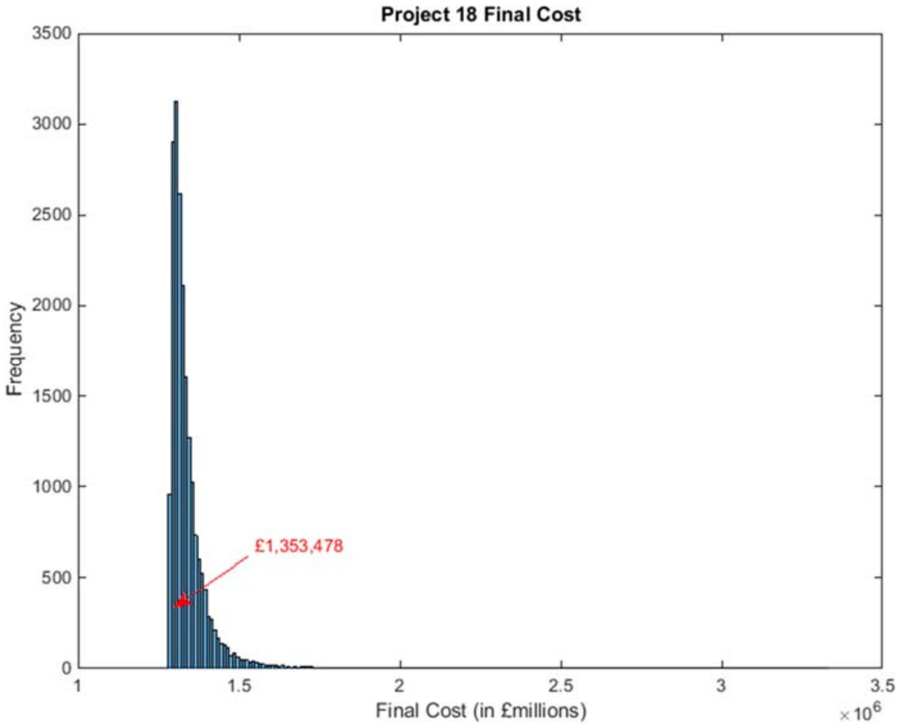

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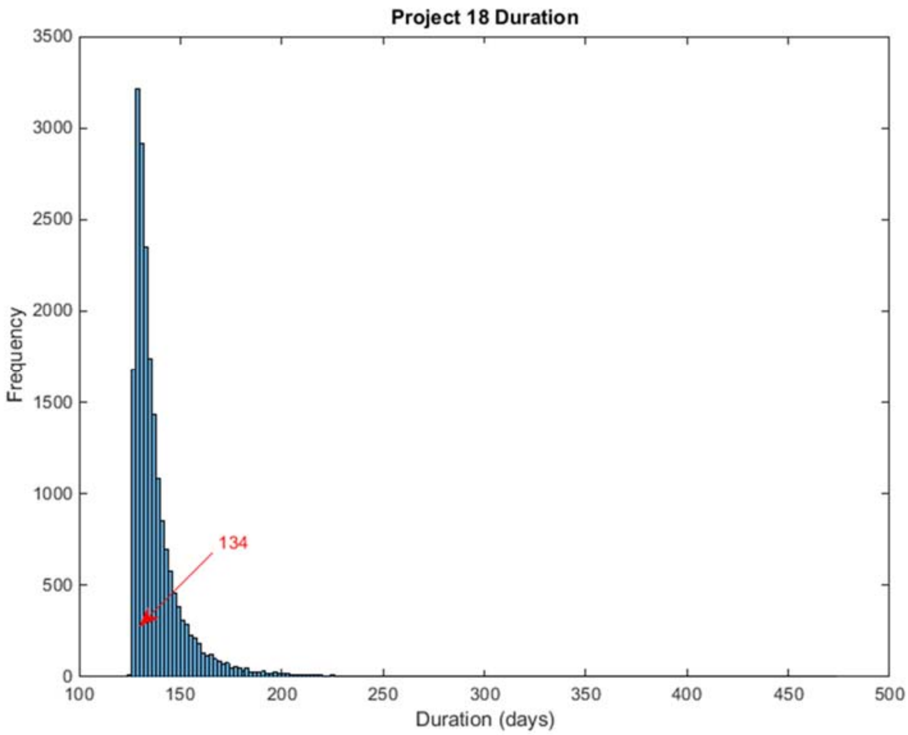

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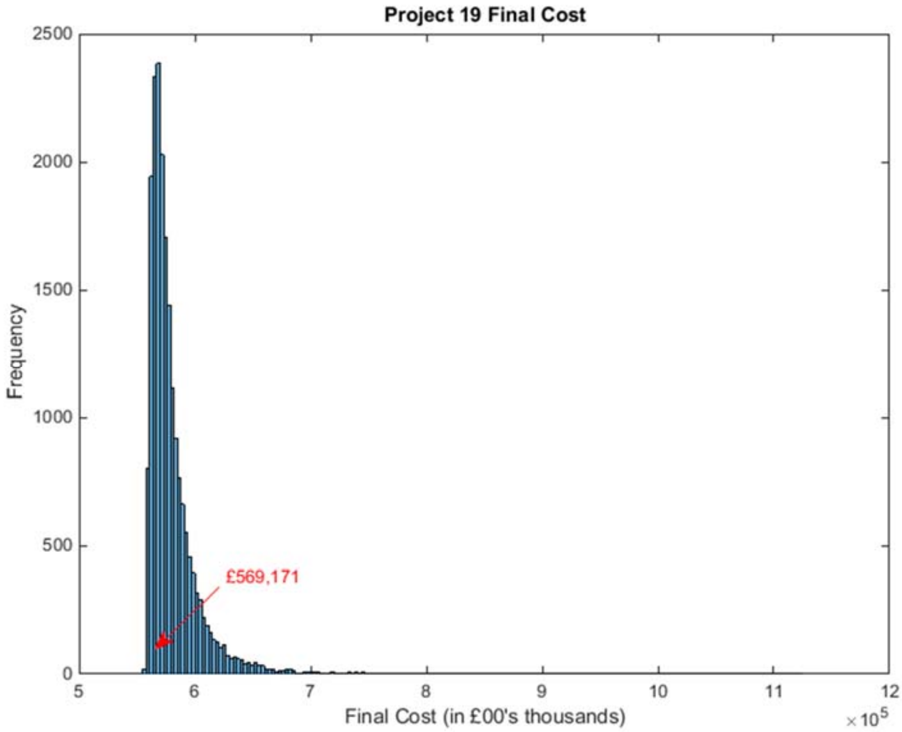

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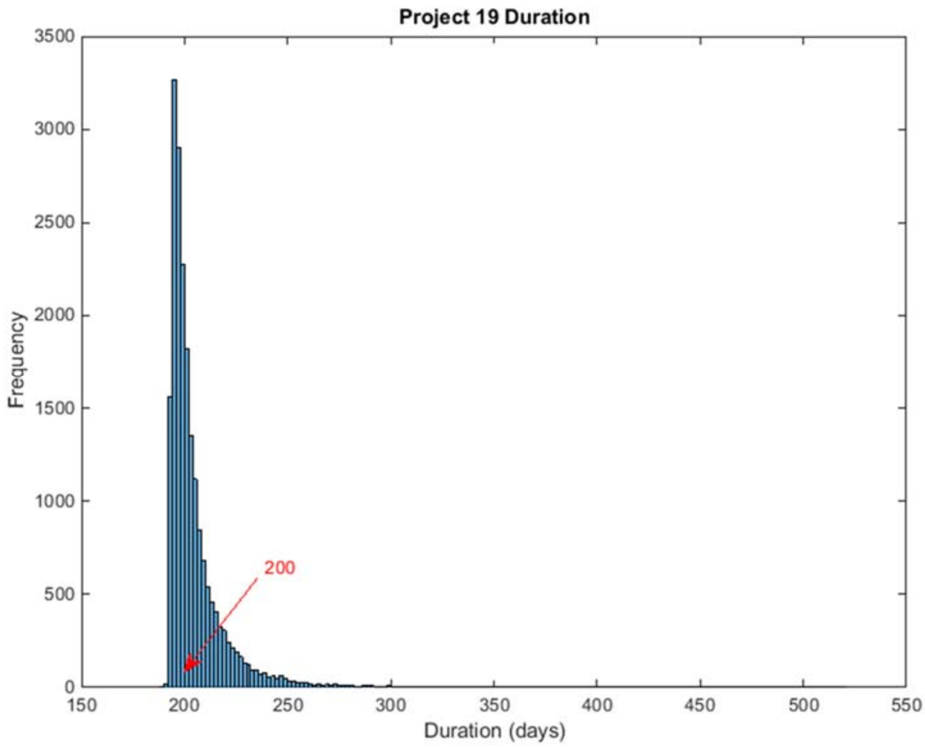

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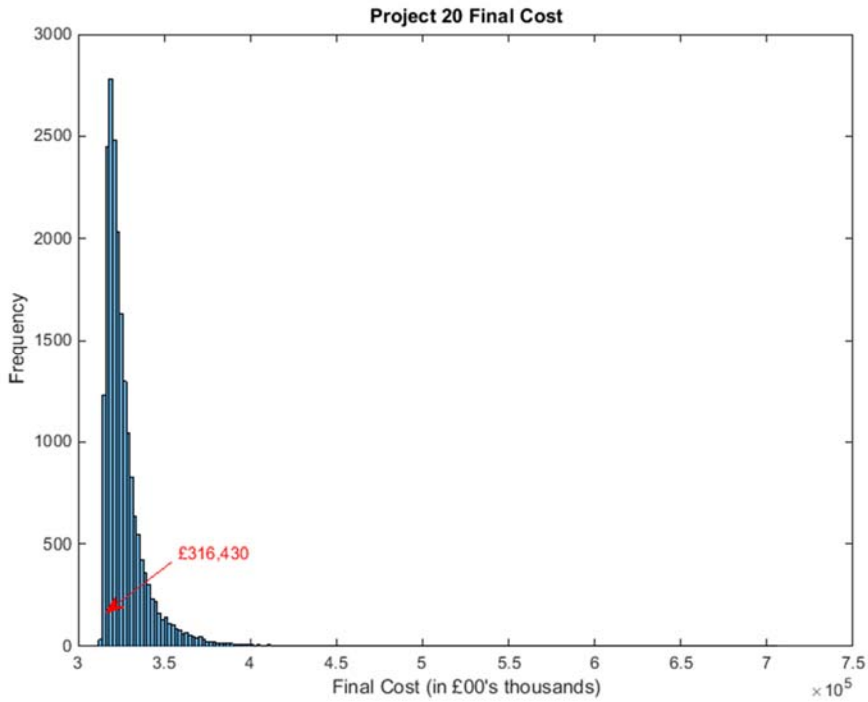

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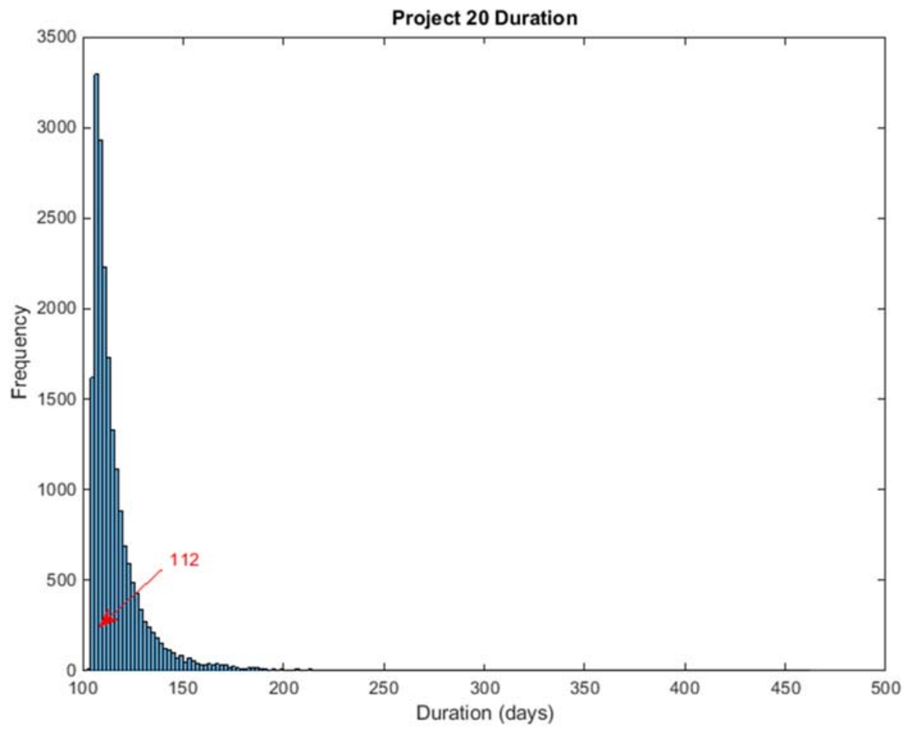


APPENDIX 4

1. Data Pre-processing; see section 4.2.1.

2. Derive correlations between Tender price, Overrun cost, and delay time from Dataset 1.

3. Calculate the mean and standard deviation of overrun cost (**y1** and **y2**) and delay time (**n1** and **n2**) to expect of the lowest tenderer from Dataset 1; see section 4.3.1 pg. 90.

4. Load the proposed tender of the project: identify all the bid prices, the lowest tender price, and the expected duration of the project.

5. Calculate the mean (**o**) and standard deviation (**p**) of the proposed tender prices identified in Step 4.

6. Input the mean and standard deviation of overrun cost and delay time to expect of the lowest tenderer calculated in Step 3.

7. Multiply the mean and standard deviation of overrun cost (**y1** and **y2**) by the mean of the proposed tender prices (**o**). This creates **y3**, and **y4**; see pg. 92.

8. Multiply the mean and standard deviation of delay time (**n1** and **n2**) by the client's expected duration of the project identified in Step 4. This creates **n3**, and **n4**; see pg. 93.

9. Input the correlations calculated in Step 2. Then instruct the model to generate 20,000 random lognormally distributed numbers given the correlation inputted $\mathbf{x} = \mathbf{A}\boldsymbol{\eta}$; see section 4.3 pg. 81.

10. The 1st variable are tender prices. Instruct it to always select the lowest tender identified in Step 4. The 2nd variable are overrun costs to expect for the project. Scale by multiplying the variable by **y4** and adding **y3**; see Step 7. The 3rd variable are delay times to expect for the project; Scale by multiplying the variable by **n4** and adding **n3**; see Step 8.

11. Calculate the total cost to expect of the lowest tenderer by adding the 1st and 2nd variable. Calculate the duration time to expect of the lowest tenderer by adding the client's expected duration identified in Step 4, to the 3rd variable.

APPENDIX 5

1. Calculate the ratio between every contractors' tender prices received for a project to the final cost of that project from Dataset 1. Then calculate the mean and standard deviation of the ratio; see pg. 110-111.

2. Calculate the mean and standard deviation of overrun cost (**y1** and **y2**) and delay time (**n1** and **n2**) to expect of the lowest tenderer from Dataset 1; see section 4.3.1 pg. 90.

3. Calculate the mean of tender prices to expect (**o**) by multiplying the mean of the ratio in Step 2 by the budget of the project.

4. Calculate the standard deviation of tender prices to expect (**p**) by multiplying the standard deviation of the ratio in Step 2 by the budget of the project.

5. Multiply the mean and standard deviation of overrun cost (**y1** and **y2**) by the mean of the proposed tender prices (**o**). This creates **y3**, and **y4**; see pg. 92.

6. Multiply the mean and standard deviation of delay time (**n1** and **n2**) by the client's expected duration of the project identified in Step 4. This creates **n3**, and **n4**; see pg. 93.

7. **y4** and **n4** in Step 7 and 8 are overwritten to deviate from the minimum to maximum possible standard deviation.

8. Allow the correlations to deviate from -0.8 to 0.8. Then instruct the model to generate 5,000 random lognormally distributed numbers given the correlation inputted $\mathbf{x} = \mathbf{A\eta}$; see section 4.3 pg. 81.

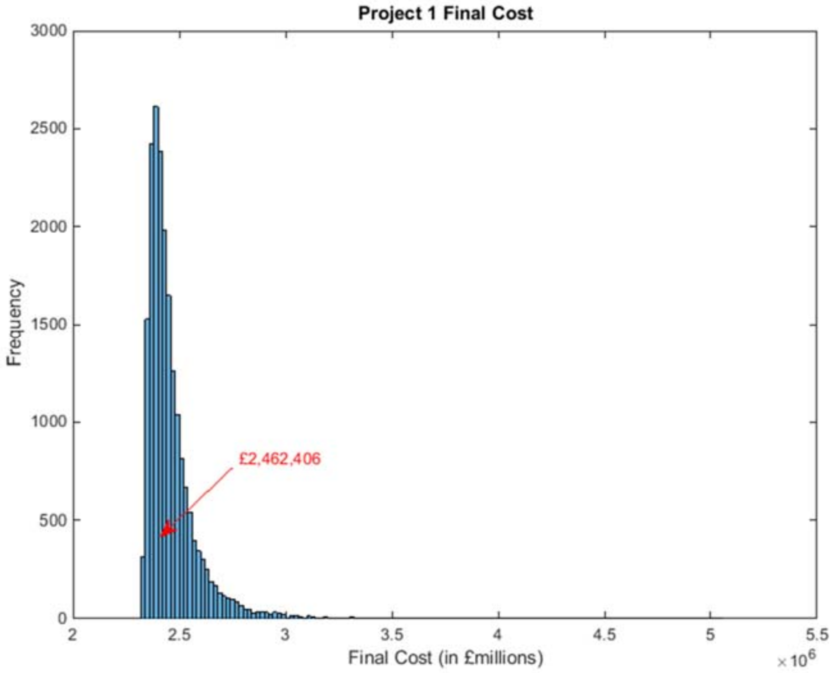
9. The 1st variable are tender prices to expect for the project. Scale by multiplying the variable by **p** in Step 4 and adding **o** in Step 3. The 2nd variable are overrun costs to expect for the project. Scale by multiplying the variable by **y4** and adding **y3**; see Step 5 and 7. The 3rd variable are delay times to expect for the project; Scale by multiplying the variable by **n4** and adding **n3**; see Step 6 and 7.

10. Calculate the total cost to expect by adding the 1st and 2nd variable. Calculate the duration time to expect by adding the client's expected duration identified in Step 4, to the 3rd variable.

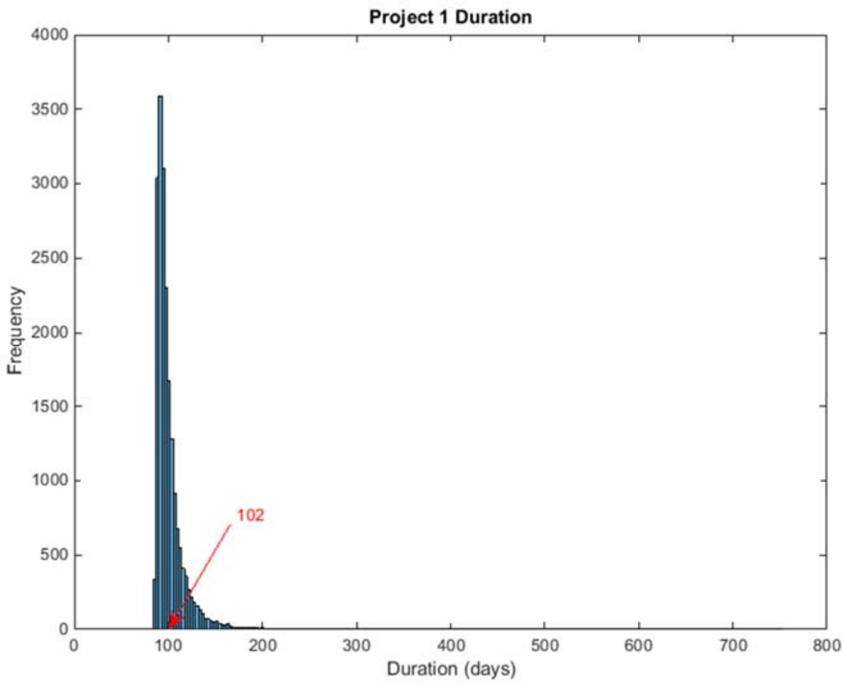
11. The model is instructed to always select the lowest tenderer. Then counts how many times the lowest tenderer turns out to best tender in terms of cost and duration.

APPENDIX 6

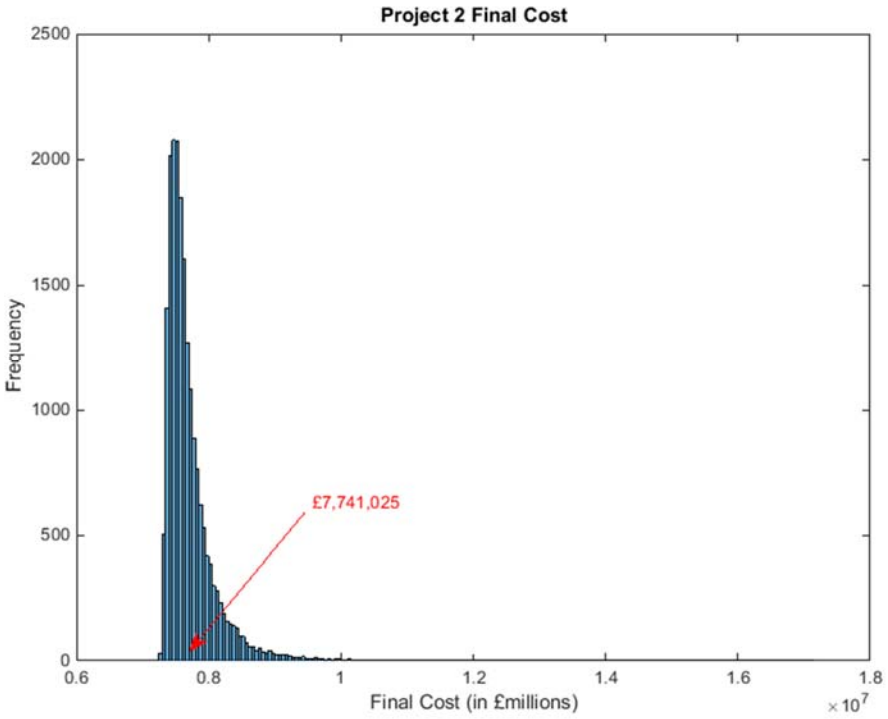
Project 1 Final Cost (Dataset 5)



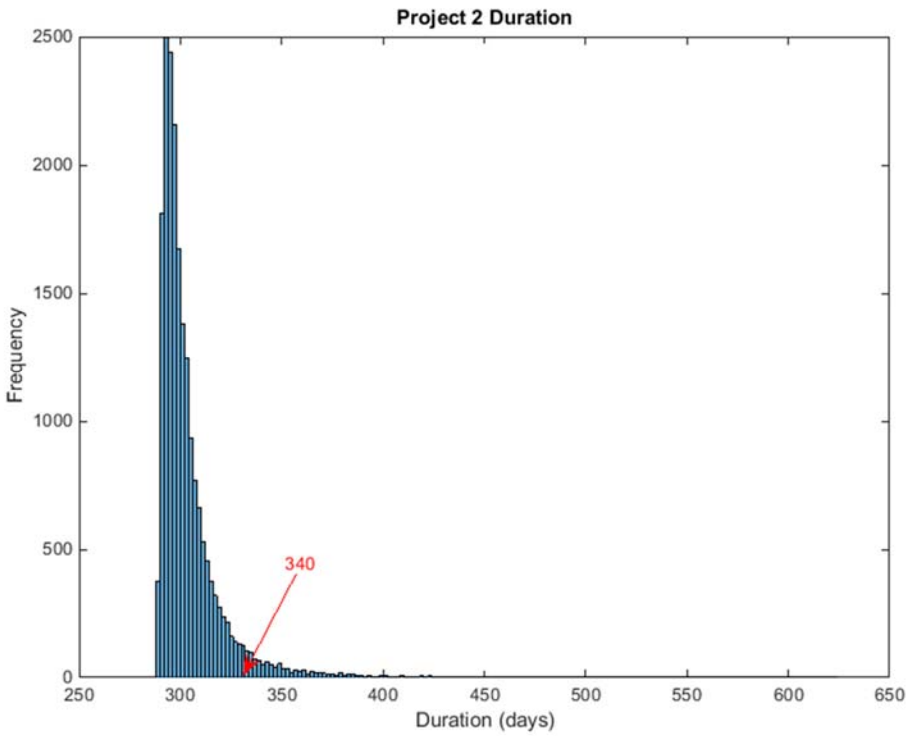
Project 1 Duration (Dataset 5)



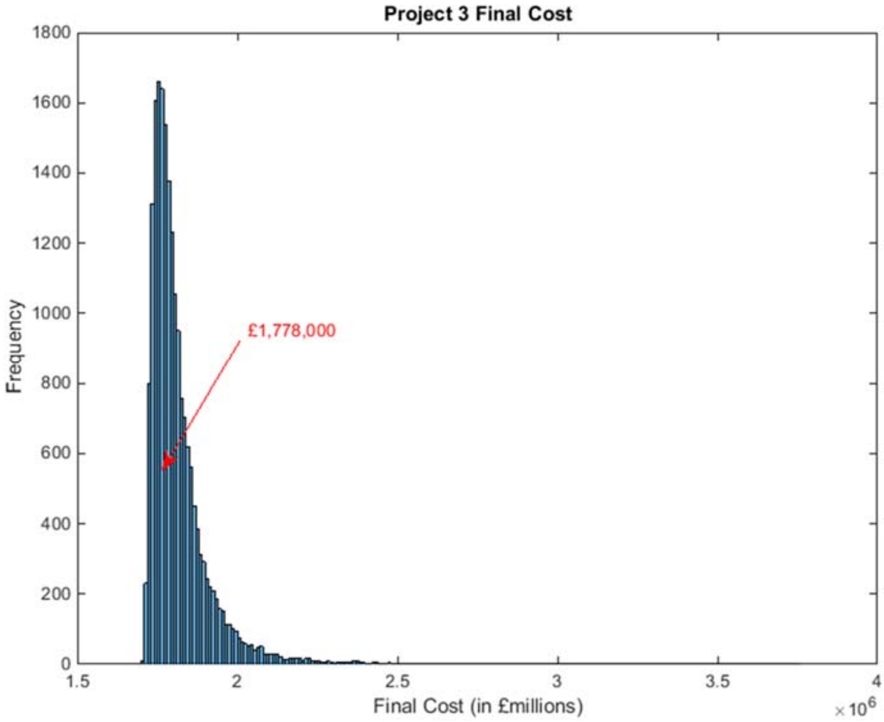
Project 2 Final Cost (Dataset 5)



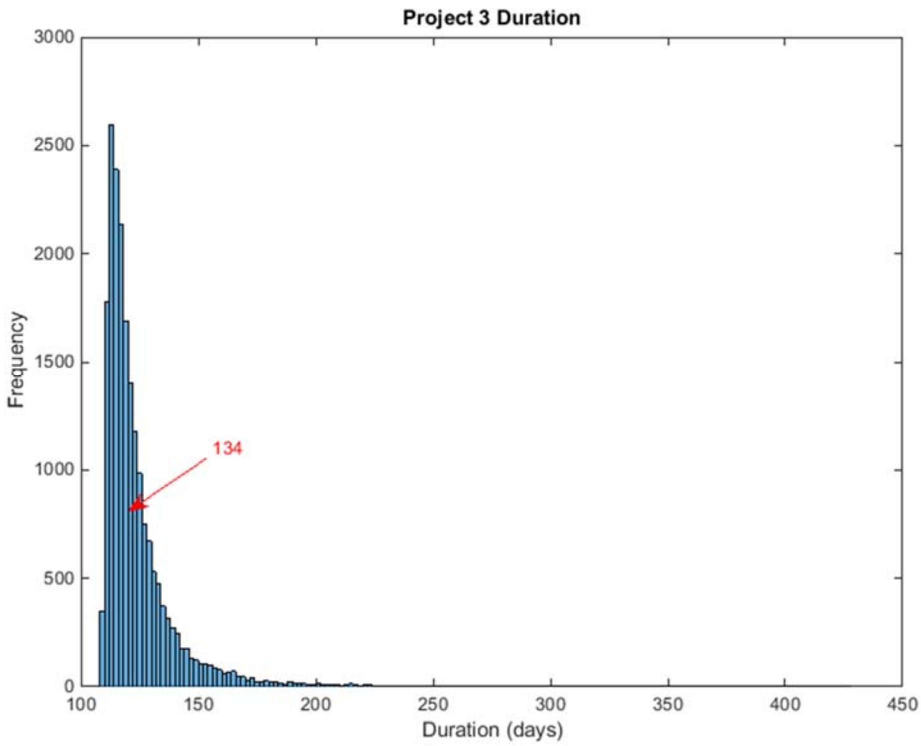
Project 2 Duration (Dataset 5)



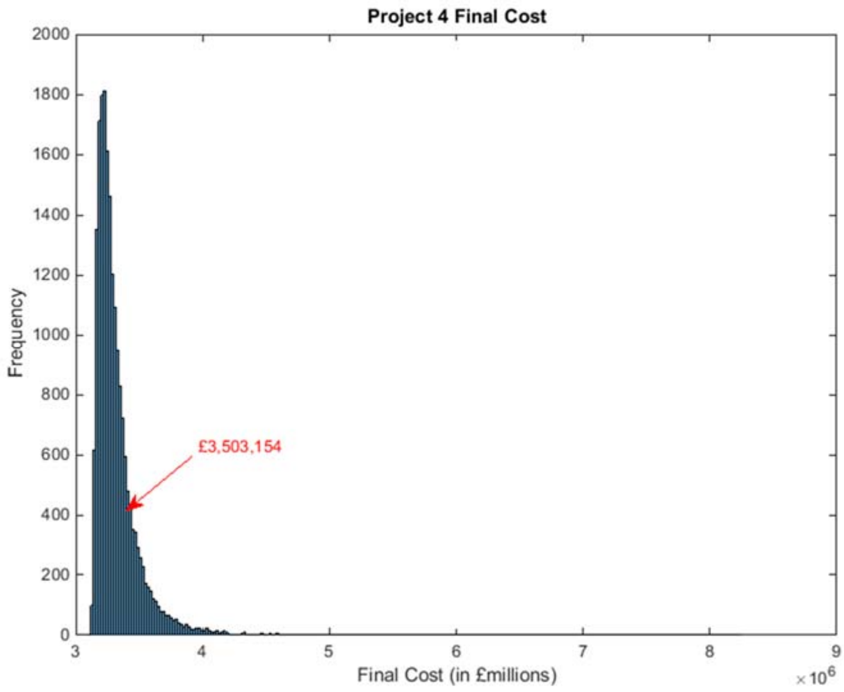
Project 3 Final Cost (Dataset 5)



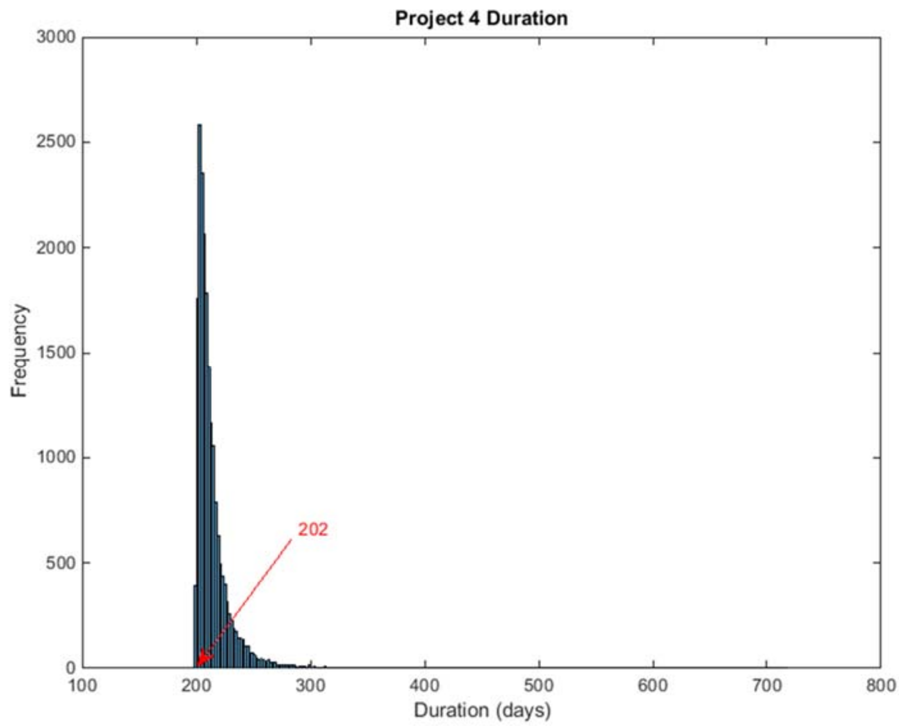
Project 3 Duration (Dataset 5)



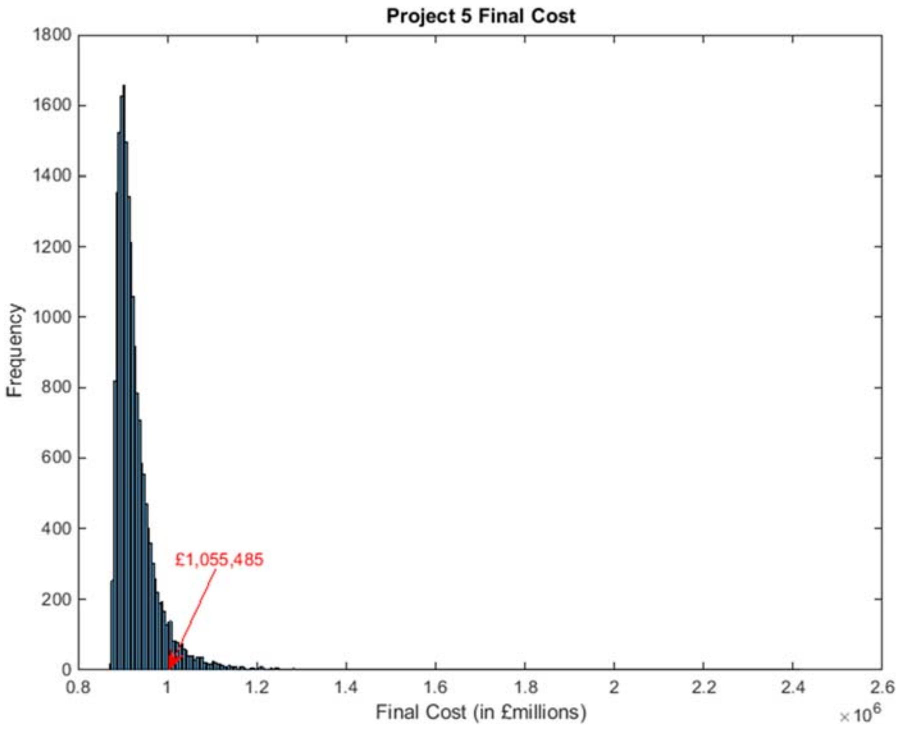
Project 4 Final Cost (Dataset 5)



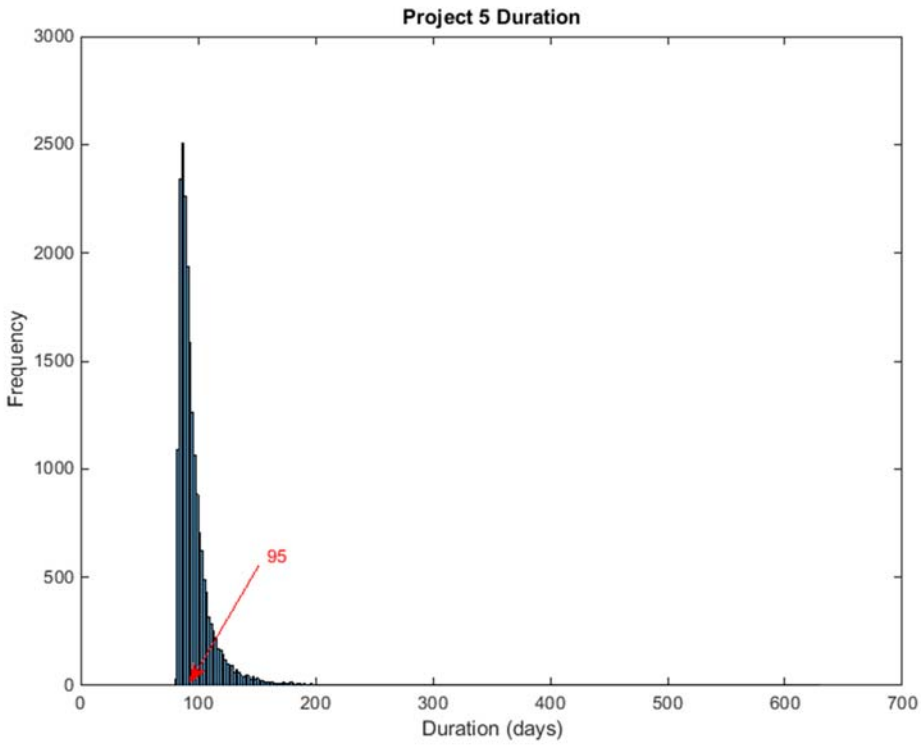
Project 4 Duration (Dataset 5)



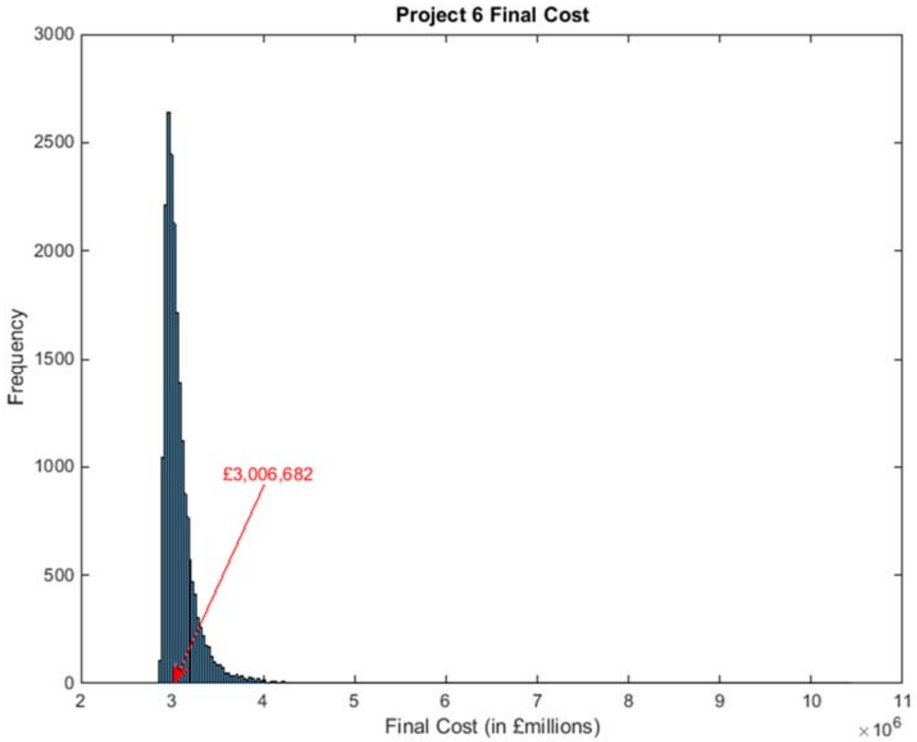
Project 5 Final Cost (Dataset 5)



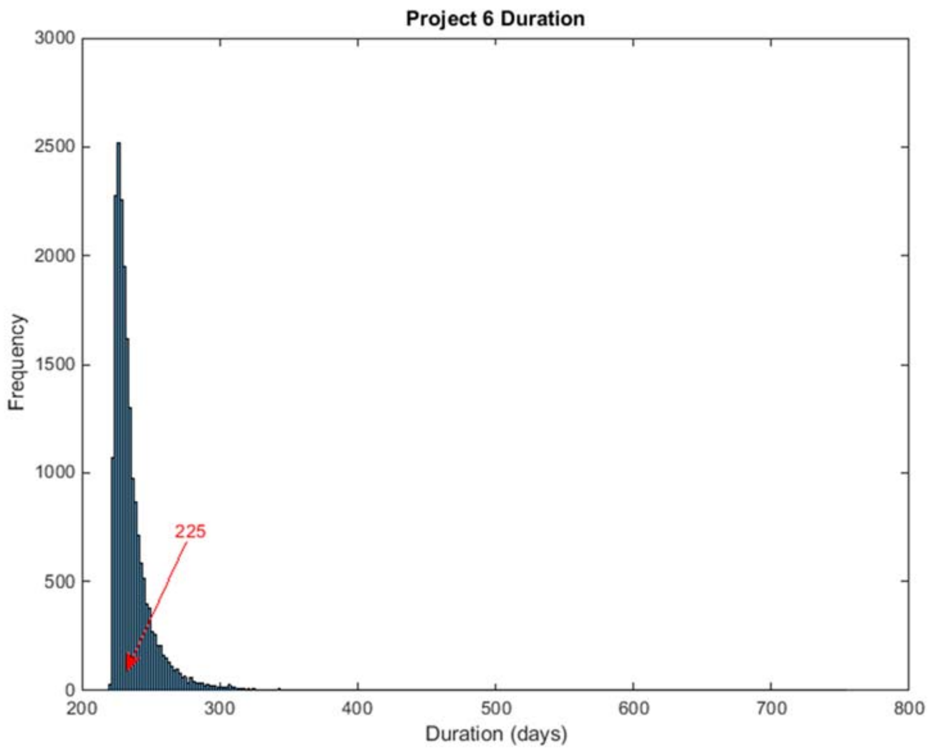
Project 5 Duration (Dataset 5)



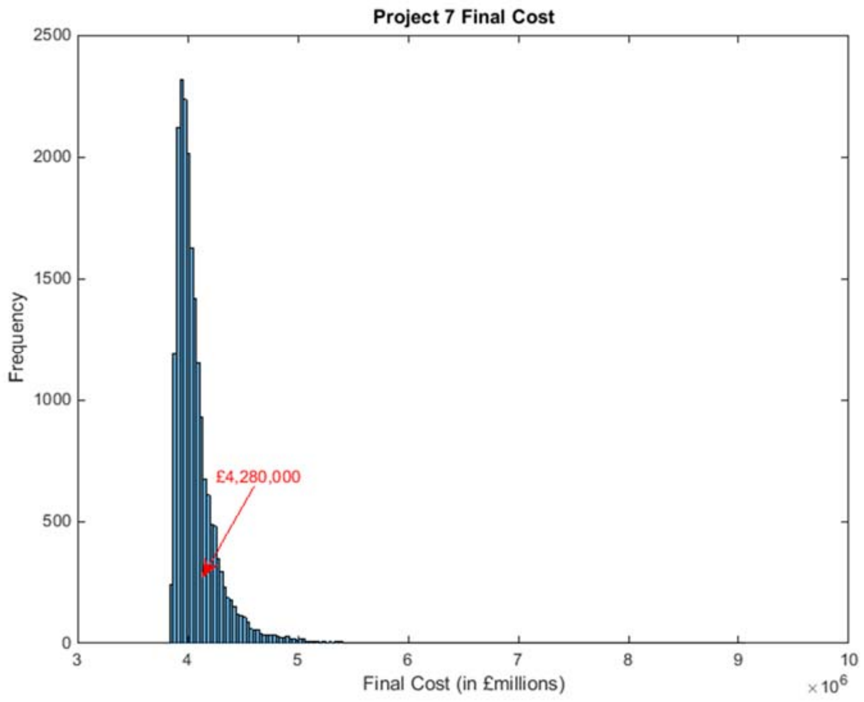
Project 6 Final Cost (Dataset 5)



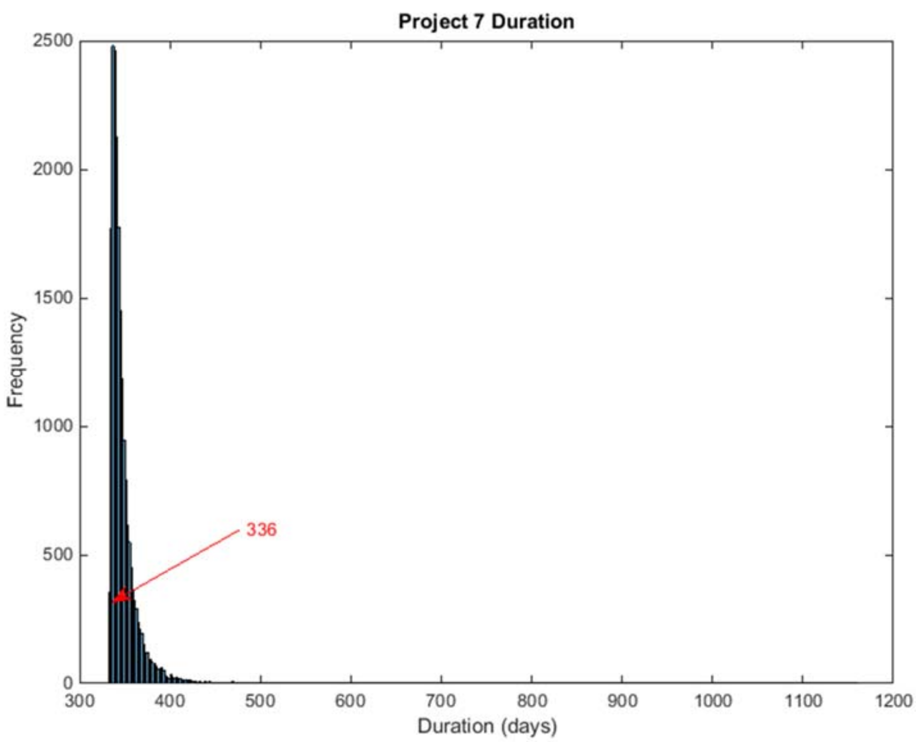
Project 6 Duration (Dataset 5)



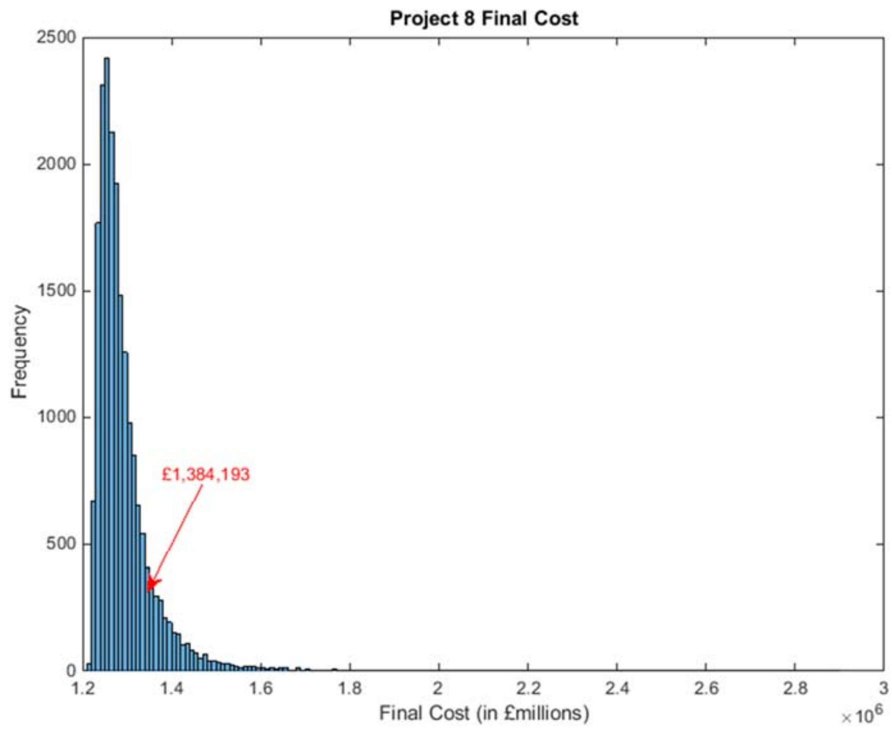
Project 7 Final Cost (Dataset 5)



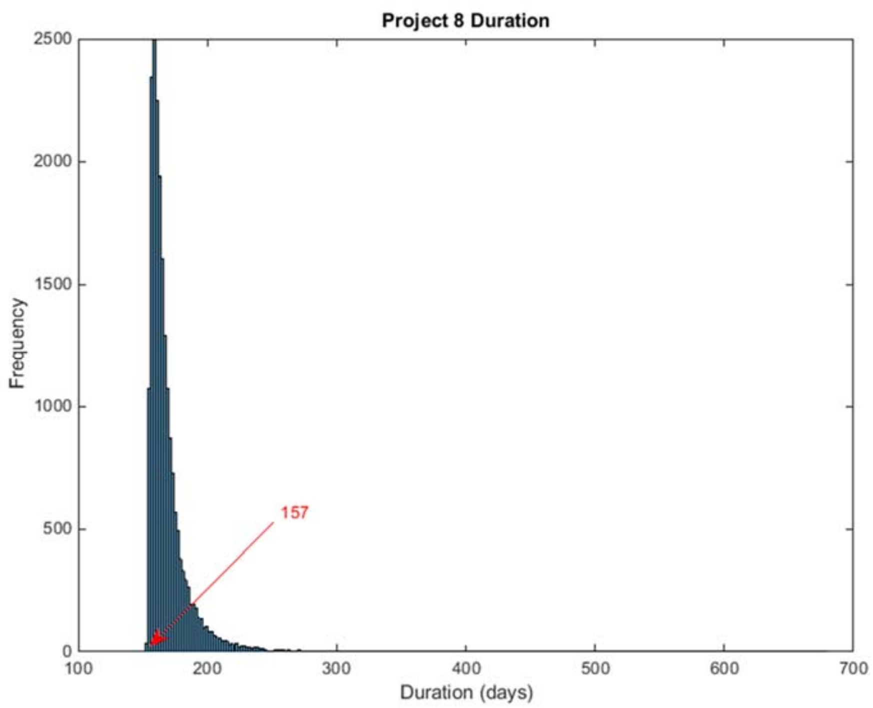
Project 7 Duration (Dataset 5)



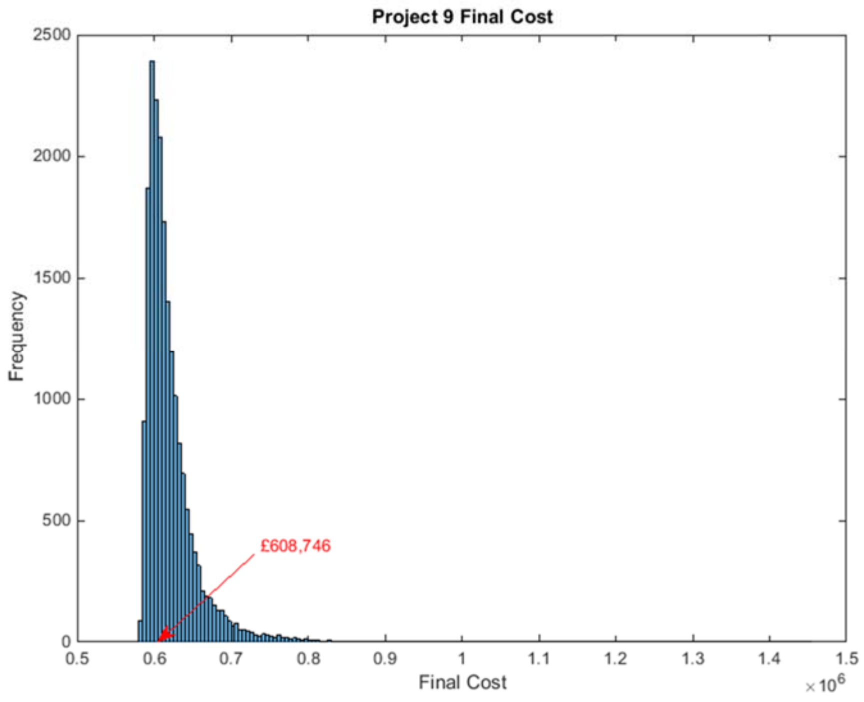
Project 8 Final Cost (Dataset 5)



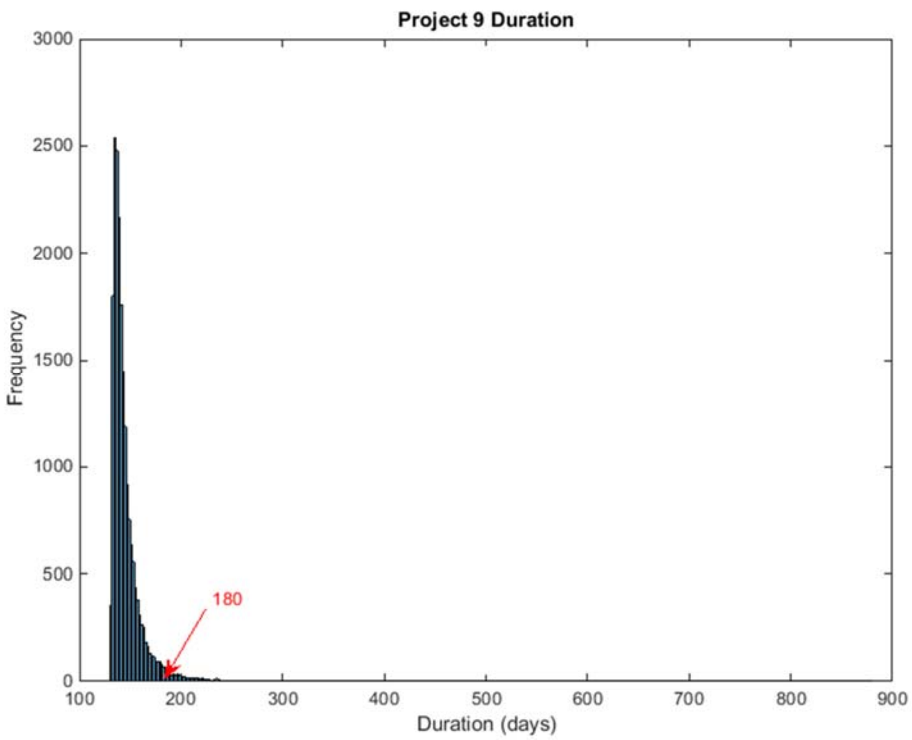
Project 8 Duration (Dataset 5)



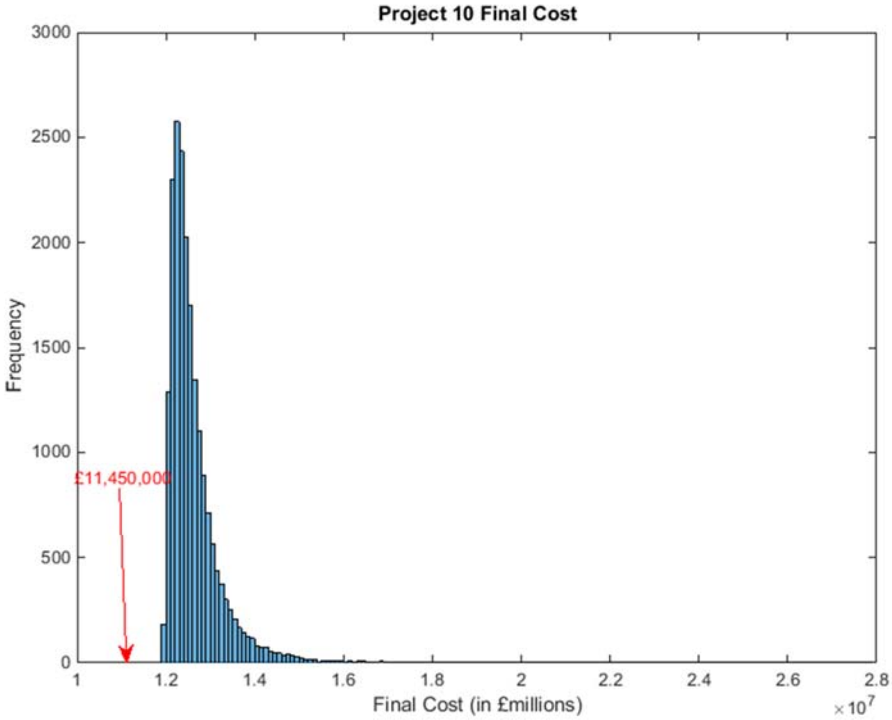
Project 9 Final Cost (Dataset 5)



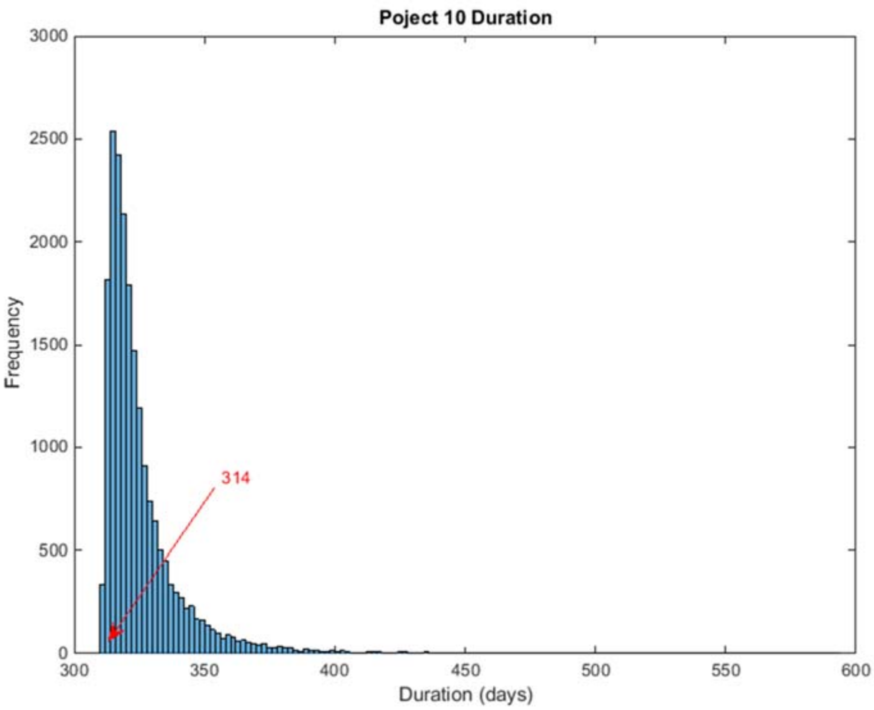
Project 9 Duration (Dataset 5)



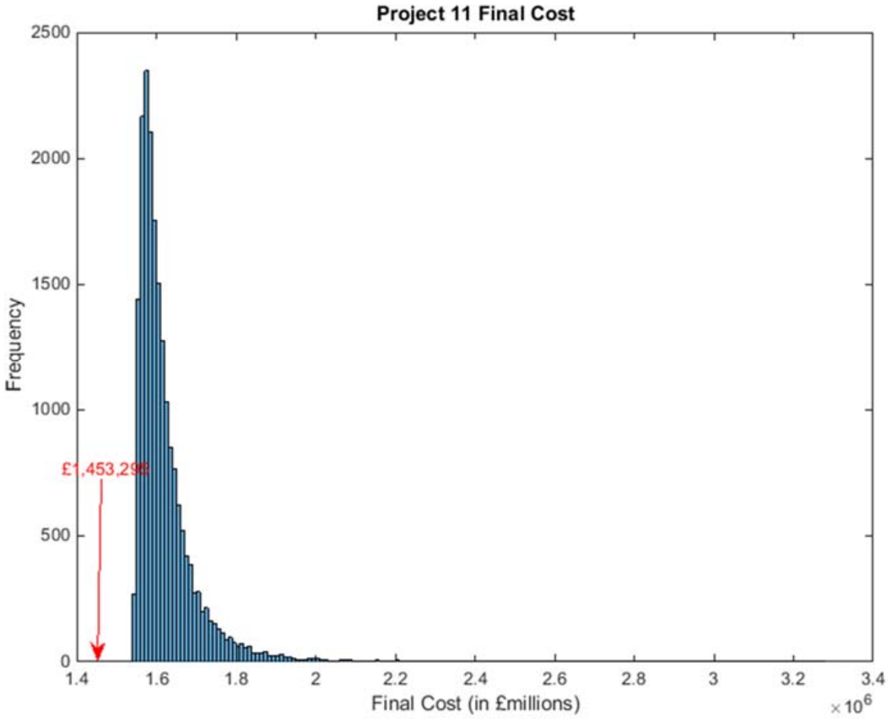
Project 10 Final Cost (Dataset 5)



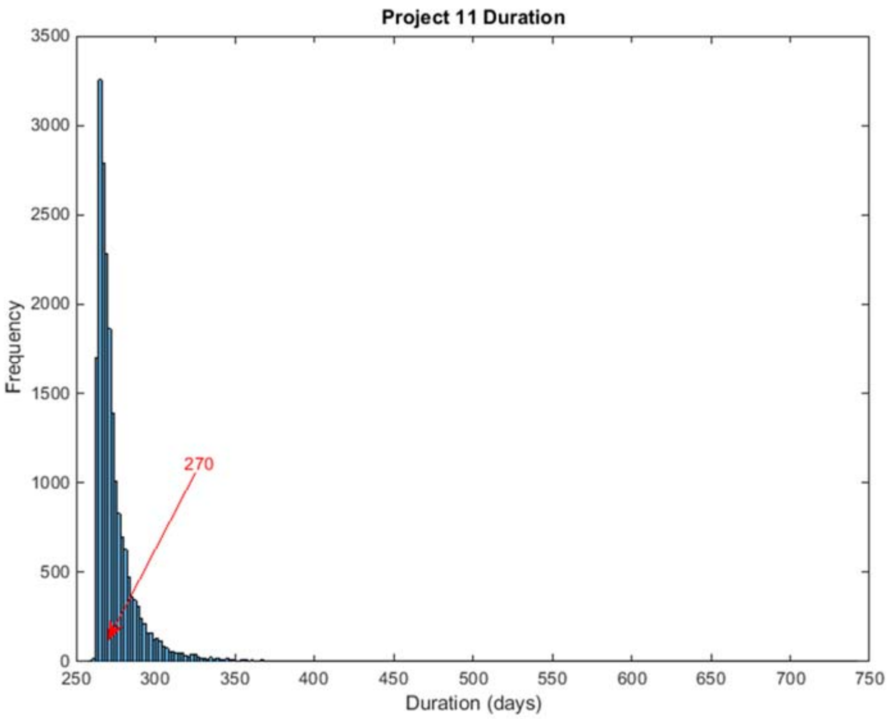
Project 10 Duration (Dataset 5)



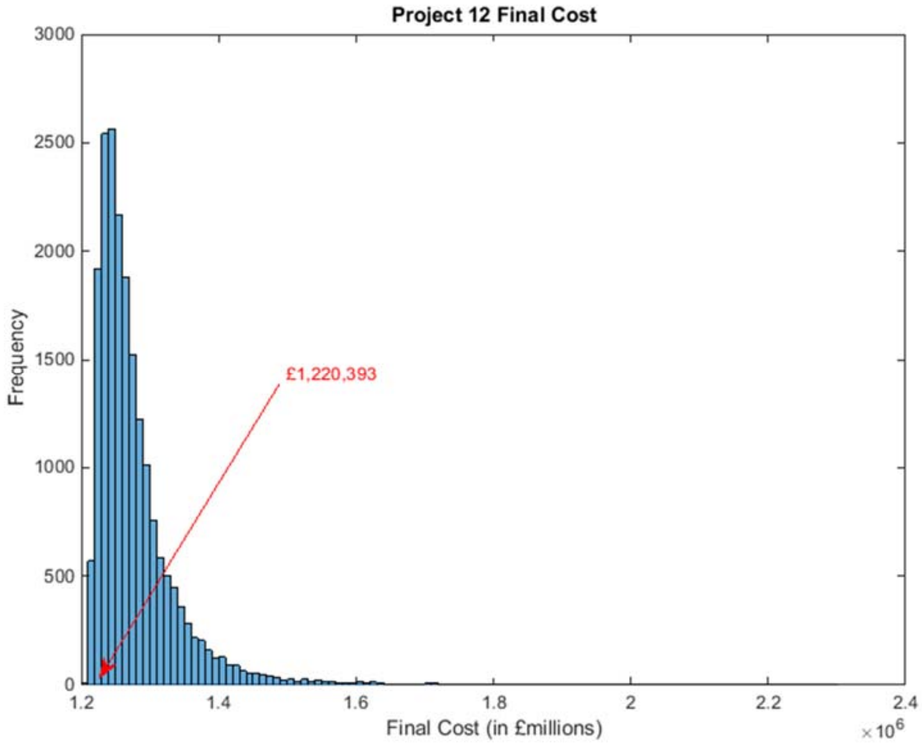
Project 11 Final Cost (Dataset 5)



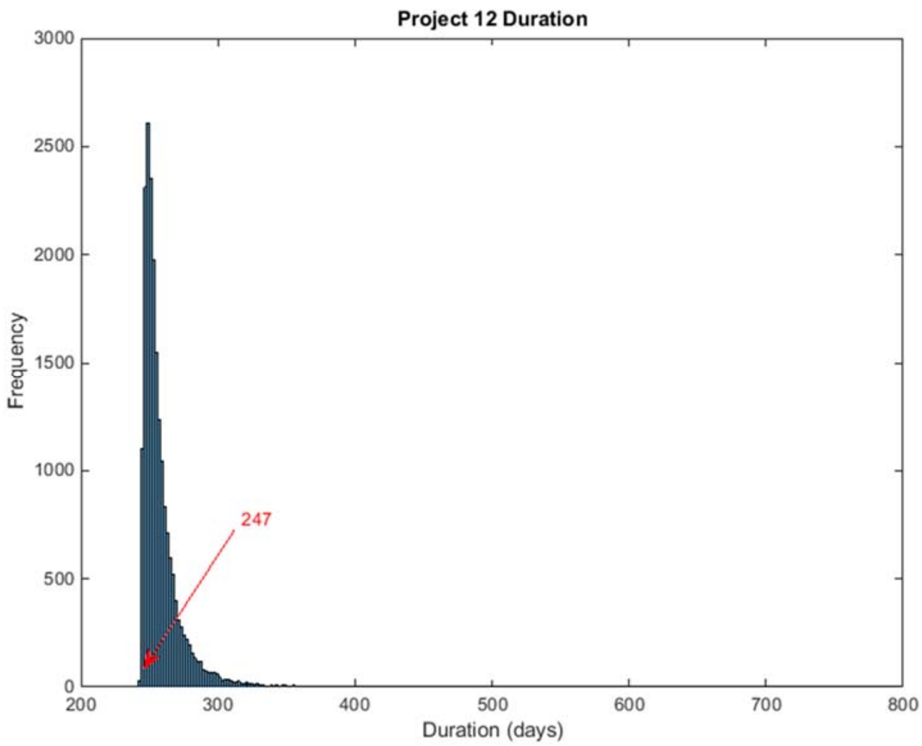
Project 11 Duration (Dataset 5)



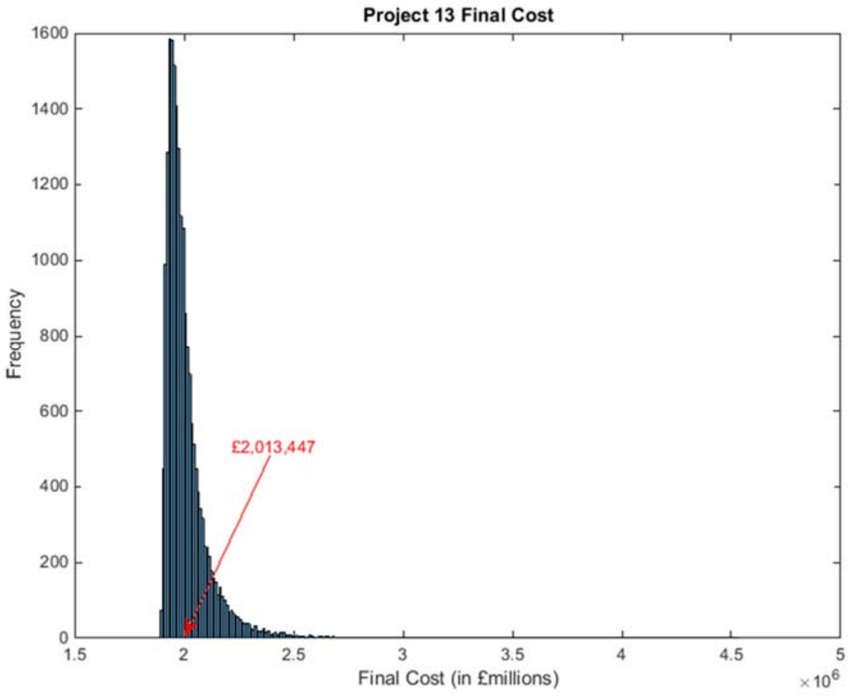
Project 12 Final Cost (Dataset 5)



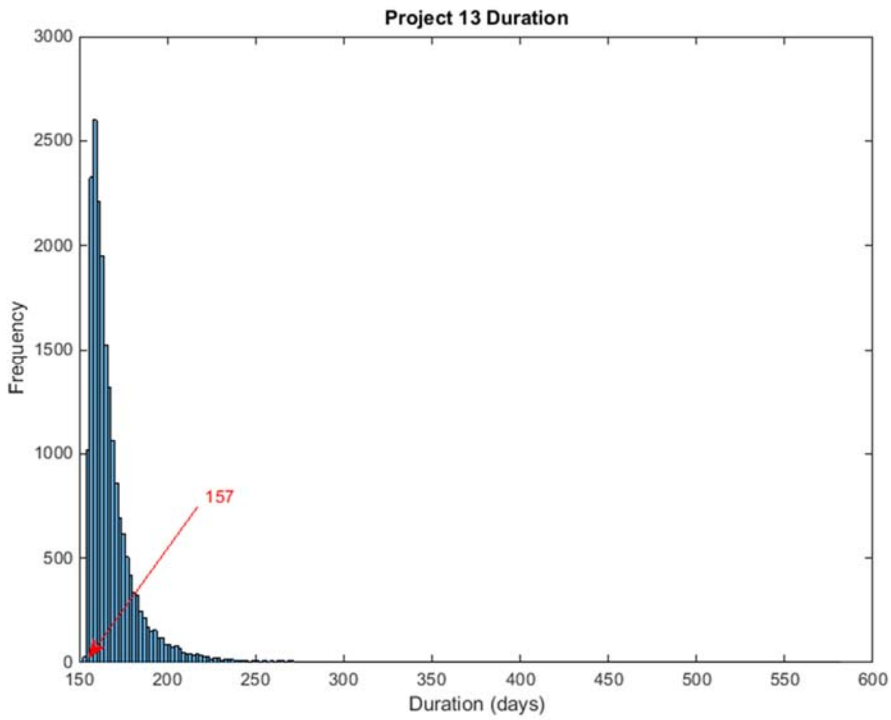
Project 12 Duration (Dataset 5)



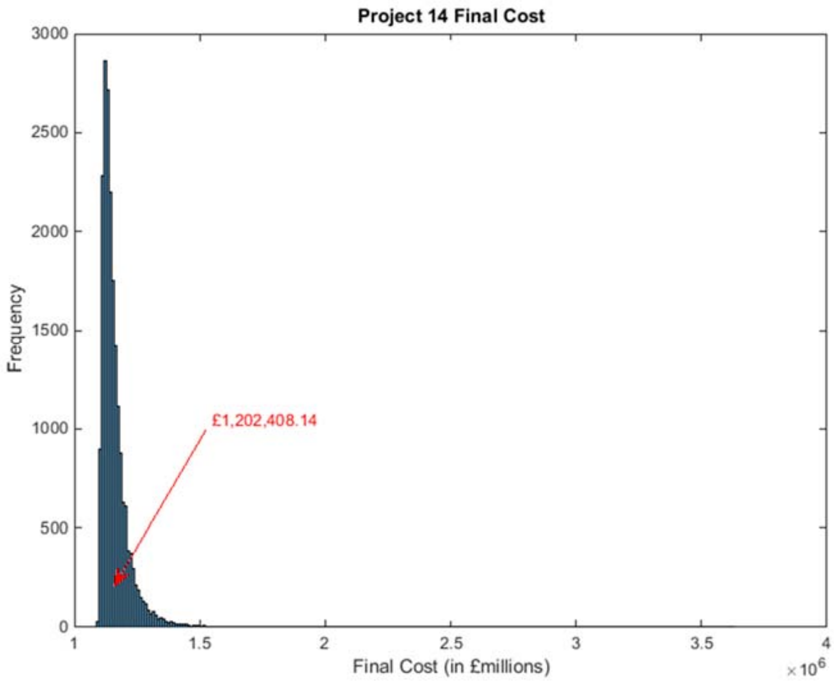
Project 13 Final Cost (Dataset 5)



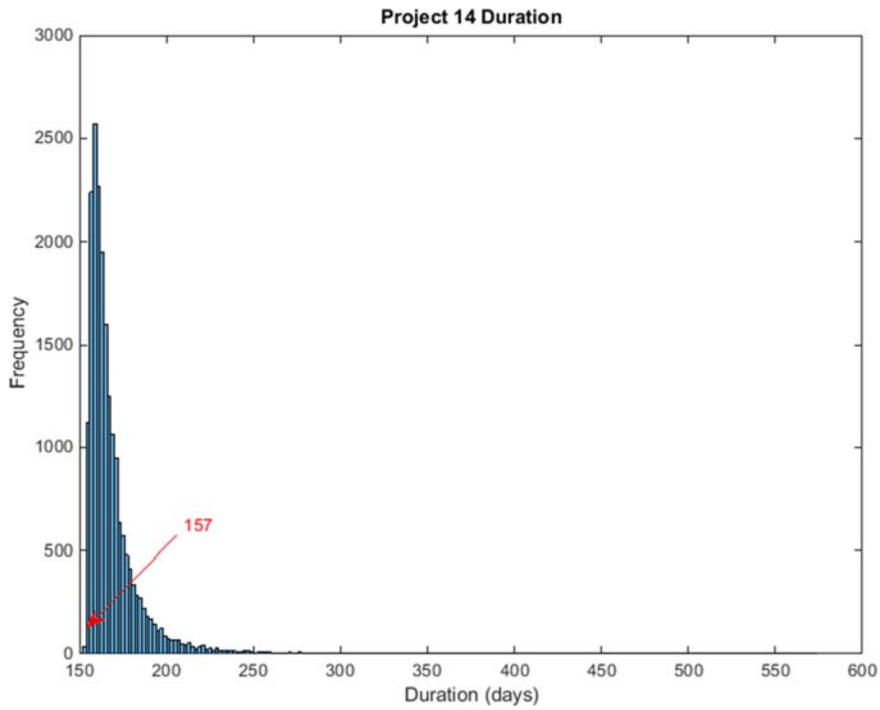
Project 13 Duration (Dataset 5)



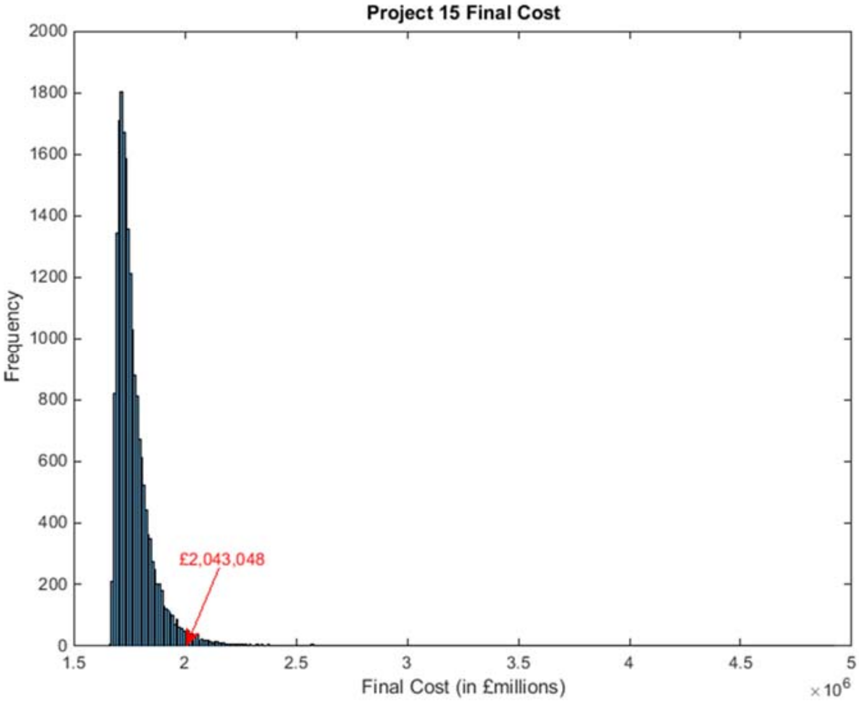
Project 14 Final Cost (Dataset 5)



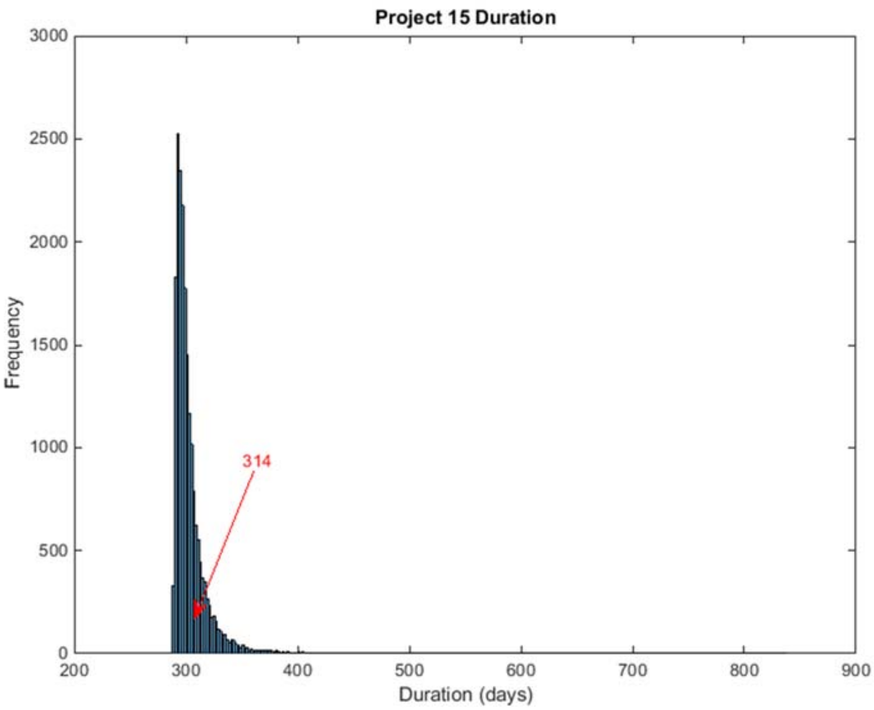
Project 14 Duration (Dataset 5)



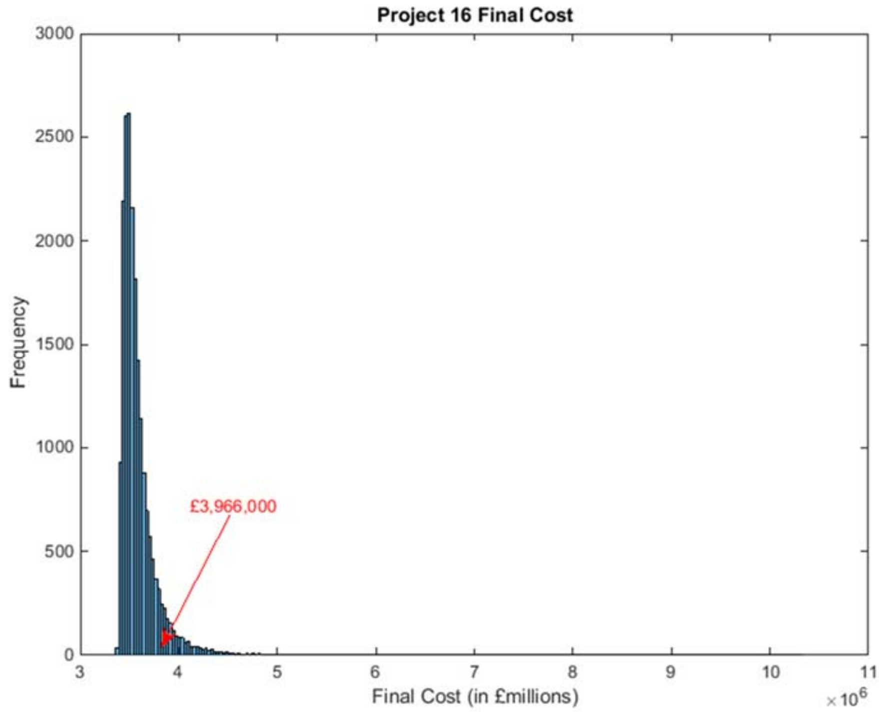
Project 15 Final Cost (Dataset 5)



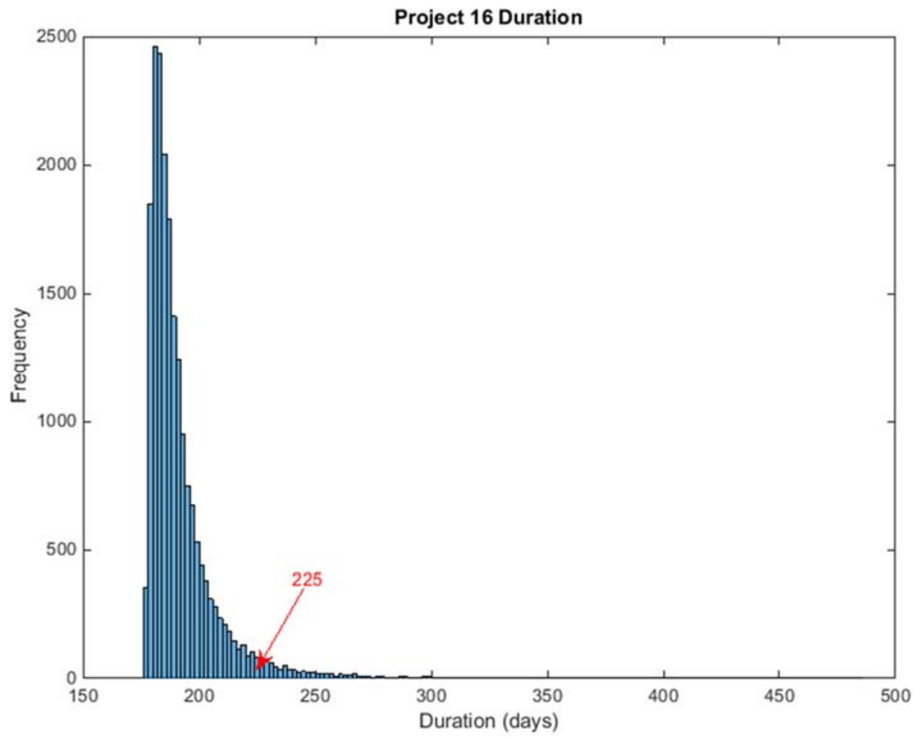
Project 15 Duration (Dataset 5)



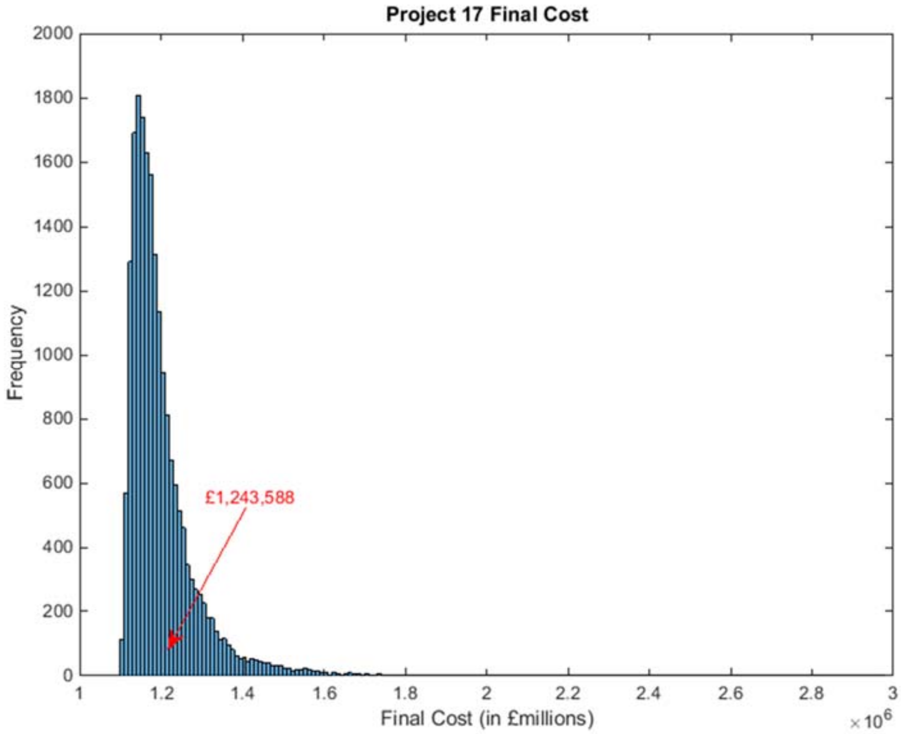
Project 16 Final Cost (Dataset 5)



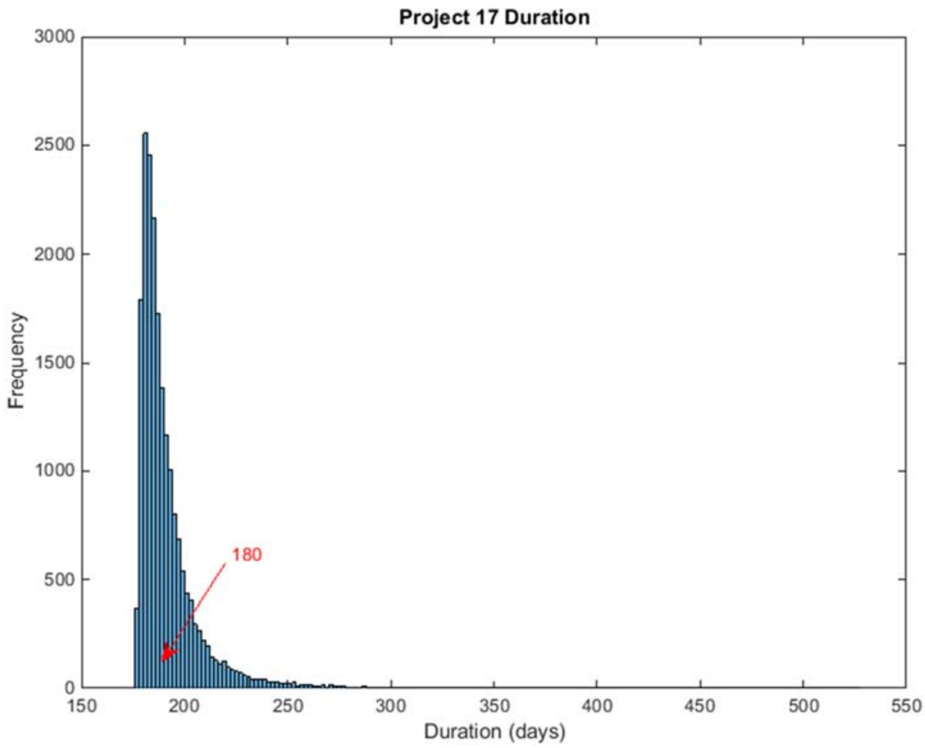
Project 16 Duration (Dataset 5)



Project 17 Final Cost (Dataset 5)



Project 17 Duration (Dataset 5)



APPENDIX 7

1. Derive correlations between the criteria in Table 4.3.18 to 4.3.20; see pg. 133-134.

2. Calculate the mean and standard deviation of overrun cost and delay time to expect from the best value tenderer from Dataset 3.

3. Load the proposed tender of the project: identify all the bid prices, the lowest tender price, and the expected duration of the project.

4. Calculate the mean and standard deviation of the proposed tender prices identified in Step 3 and input.

5. Calculate the mean and standard deviation of overrun cost and delay time to expect of the best value tenderer by multiplying the mean and standard deviation in Step 3 to the mean of tender prices in Step 4; input.

6. Input the weights of the criteria.

7. Input the correlations calculated in Step 1. Then instruct the model to generate 5,000 random distributed numbers given the correlation inputted $\mathbf{x} = \mathbf{A}\boldsymbol{\eta}$; see section 4.3 pg. 81. Make sure correlations are consistent; see pg. 143-144.

8. The 1st variable are tender prices. Scale by multiplying the variable by the standard deviation of tender prices and adding it to the mean of tender prices; see Step 4. The 2nd variable are overrun costs to expect for the project. Scale by multiplying the variable by the standard deviation of overrun costs and adding it to the mean of overrun costs; see Step 5. The 3rd variable are delay times to expect for the project. Scale by multiplying the variable by the standard deviation of delay times and adding it to the mean of delay times; see Step 5.

9. Calculate the total cost to expect by adding the 1st and 2nd variable. Calculate the duration time to expect by adding the client's expected duration identified in Step 4, to the 3rd variable.

10. Contractors are not allowed to score less than 40%. Flag when contractor scores less than 50%; see pg. 148. Identify the lowest tenderer and calculate best value score. Then calculate the best value score of all the other contractors.

11. By doing Step 10, the model finds who the lowest tenderer is, and who the best value tenderer is (or if the lowest tenderer is the best value tender) for each realisation.