May 2016

Causes of Change Orders and Its Impact on Road Maintenance Contracts

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CAUSES OF CHANGE ORDERS AND ITS IMPACT ON ROAD MAINTENANCE CONTRACTS

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A dissertation submitted in partial fulfillment
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Doctor of Philosophy- Civil and Environmental Engineering

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University of Nevada, Las Vegas
May 2016

UNLV | GRADUATE COLLEGE

Dissertation Approval

The Graduate College
The University of Nevada, Las Vegas

March 30, 2016

This dissertation prepared by

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entitled

Causes of Change Orders and Its Impact on Road Maintenance Contracts

is approved in partial fulfillment of the requirements for the degree of

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ABSTRACT

Causes of Change Orders and its Impact on Road Maintenance Contracts

By Kabindra K. Shrestha

Change orders (CO) commonly generate cost-growth, schedule-growth or both, in construction as well as in maintenance contracts. Literature reviews revealed that the causes and impact of CO on new construction contracts had been comprehensively studied, but the causes and impact of CO in maintenance contracts remained neglected. This study collected CO data on road maintenance contracts to determine the amount of CO and the most frequent and high-risk road maintenance activities that had CO. A Delphi study was conducted with 33 maintenance engineers from the state Department of Transportations (DOTs) to identify causes of CO and its impact on cost and schedule of road maintenance contracts. The results showed that the three important reasons of CO on the maintenance contracts were: changes in work scope, errors in the estimate, and failure to verify work site conditions before signing a contract. To reduce these CO, three most important preventive measures agreed by participants were: reviewing specifications, preparing accurate estimates, and reviewing the design drawing before bid solicitation.

In this study, the CO contingency estimation tool was prepared using an artificial neural network (ANN) and a linear regression method. Historical CO data was used to predict the contingency cost for maintenance contracts. In order to reduce the negative impact on the schedule-growth, a schedule-crashing optimization tool was also developed. Hence, the primary contributions of this research to the body of knowledge are the quantification of the CO, the identification of the causes and preventive measures of CO, and the development of the tools to manage cost and schedule growth in road maintenance contracts.

ACKNOWLEDGEMENT

I would like to sincerely thank all personnel who had supported my dissertation: especially faculty, friends, the administrative unit of the department of Civil & Environmental Engineering and Construction, and the administrative unit of the Graduate College in UNLV. I am really indebted to my adviser Dr. Pramen Prasad Shrestha for his support and guidance throughout this study. I should feel ungrateful if I do not express my deep appreciation and thanks to Dr. David R. Shields for his kind guidance and support during my tenure as graduate assistant in UNLV.

I would like to extend gratitude to my dissertation committee member, Dr. Mohamed Kaseko, for his guidance on the optimization of the project schedule crashing. It is unlikely to remain without expressing my gratefulness to Dr. Hualiang Teng for his support to accomplish this dissertation. I would also appreciate and thank Dr. Ashok Singh for his support in teaching me the statistical method in the R-software with the help of which I was able to link the R-software and execute the artificial neural network and the linear regression models.

The credit of my success to prepare this dissertation goes to all state Department of Transportation maintenance engineers who had participated in the Delphi study. Their participation really assisted to gather the required information for this study. Therefore, I am much thankful to their contributions to my study. I am also grateful to the Kenya Rural Road Authority for providing me the maintenance contract data.

Finally, I would like to acknowledge the support and sacrifice made by my family especially by my wife, Gyani, during my Ph.D. study. Her sacrifice weighs as much as my Ph.D. accomplishments. Without the supports from my family, I would not be in the position to complete this dissertation.

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LIST OF ABBREVIATIONS

Abbreviations	Stands For
ANN	Artificial Neural Network
CO	Change Orders
CPM	Critical Path Method
CRAN	Comprehensive R Achieve Network
DLL	Dynamic Linked Library
DOT	Department of Transportation
GA	Genetic Algorithm
ICC	Intra-class Correlation Coefficient
IRR	Inter-Rater Reliability
LRM	Linear Regression Method
MLR	Multi-Linear Regression
MSF	Microsoft Solver Foundation
NIL	Network Interaction Limit
RII	Relative Importance Index
UNLV	University of Nevada, Las Vegas
USA	United States of America
VIF	Variance Inflation Factor

CHAPTER 1: INTRODUCTION

The standard specification document prepared by Texas Department of Transportation (2004), for construction and maintenance of highways, streets, and bridges, states that Change Order is a "written order to the contractor detailing changes to the specified work, item quantities or any other modification to the Contract" (p.5). However, according to Thomas et al. (1991), an oral change order is also valid if the contract meets required criteria that are enough to waive the requirement of written order. Making oral change orders to be valid, the contract should meet the minimum criteria such as 'there are no statutes requiring a written change orders,' 'the owner had knowledge of extra works,' and 'promises to pay for the extra works.'

According to a guide book published by WSDOT (2012), a change order is a part of the contract and should be prepared considering all aspects of the contracts so that any change made to the contract does not generate conflicts with other documents. The guide book mentioned that:

> Changes to the contract may be initiated by the Contracting Agency, the Contractor, or jointly by both parties. In all cases a change order is a legal document and once executed, cannot be un-executed. The only way to make further changes to the contract or correct an error in a change order is by processing another change order (p.1).

Thus, if CO are not planned well, it may generate more CO. The importance level of CO documentation is same as that of the original contract to avoid any kind of misunderstanding with the contractor. To document the CO properly, WSDOT uses a tool called Construction Contract Information System (CCIS) that helps to generate CO documents. In any type of CO, the contract time should be mentioned in a document as its one of the parts.

FHWA (2015) provides a video clip and a companion document on CO. According to the information provided by the FHWA, "a change is any alteration to the original construction contract. And Change orders are negotiated agreements with the contractor that affect the cost, schedule, design details or specification requirements, or any combination of these." Change orders are also referred to as contract change order, work order, supplemental agreement, or contract modification.

In the United States, new highways are constructed by private builders and maintenance of the highways are performed by In-house forces. However, these days, many state DOTs in the United States have already initiated out-sourcing highway maintenance works as well. This fact was supported by responses received from several maintenance engineers working in state DOTs offices. In every contract, there are chances of CO before successful completion of the project. Most of the times, the CO have cost and schedule growth effects in a project. Hence, addressing the CO as anticipated is important to control cost and schedule growth in highway maintenance contracts.

This dissertation tended to focus on four areas of CO. The first is the quantification of CO on road maintenance contracts. For the quantification of CO, the maintenance contract data was collected. The second is the identification of the causes of the CO in road maintenance contracts in the US. The third and the fourth areas are related to the development of a tool to estimate the contingency and optimize the schedule in order to reduce the negative impacts of the CO on road maintenance contracts.

1.1. Change Orders Quantification

As CO may affect the project cost and duration, the CO should be quantified to interpret the intensity of their effects. In studying the CO, normally the effect intensity gets expressed in terms of cost percentage and schedule percentage. If the cost increases more than the original project cost, the effect due to the CO is known as cost overrun or cost growth. Whereas, if the time duration increases more than the original project duration, the effect due to the CO is known as time overrun or schedule growth. Similarly, if the cost decreases more than the original cost, then it is known as cost underrun which stands as a positive effect of the CO for the project. The same concept applies to the time underrun as well.

To study the CO in maintenance contracts, the data on road maintenance contracts performed by Kenya Rural Road Authority (KeRRA) was collected. In Kenya, the CO are referred to as variation orders and ‘rural roads’ referred to as earthen and gravel roads. Only a few roads that had surface dressings, such as bituminous and asphalt concrete surfaces were contracted under the KeRRA. However, both paved and unpaved roads frequently required road maintenances in order to keep them in serviceable conditions. In Kenya, a reasonable amount of these maintenance activities was grouped into a package that was assigned to contractors. Due to the reasons, such as unforeseen conditions and adverse weather conditions, some contracts required the CO. The CO could be either in terms of cost or duration deviation from the original contracts. In this dissertation, only the CO causing the cost alterations were studied.

In Nevada, road maintenance contracts are grouped into three major categories namely: Routine maintenance, Capital improvements, and the Emergency activities. In comparison, Road maintenance contracts in Kenya are categorized as Routine Maintenance (RM), Periodic Maintenance (PM), Rehabilitation and Spot Improvement (Rehab & SI), and Structures (Struc) (MRPWK, 2005). The category ‘RM’ includes recurring maintenance activities that were to be performed frequently throughout the year, such as culvert cleaning, light grading, pothole repairs, and patching works. The category ‘PM’ includes such activities as re-gravelling and structure repair; normally, these were carried out every three to five years. ‘Rehab & SI’ related to improving a short section of road, such as replacing culverts and reconstruction of a complete gravel road section. The main purpose of partial rehabilitation, including spot improvement, was to make the road operable and maintainable. ‘Struc’ contracts included the repair and construction of culverts, drains, and retaining structures along the road.

The quantification of the CO was done at two levels: the first at maintenance activity level and the second at the project level. The activity level CO percentages quantified the cost growth in the frequent road maintenance activities separately. Similarly, the project level quantification identified the cost growth percentage in the original project cost due to the CO. This study also compared the CO percentages among the frequent maintenance activities.

This study was also intended to identify the high frequent maintenance activities and high risk activities. This identification of the high frequent and high risk activities would be helpful for planners who are preparing road maintenance contracts for these activities. One of the objective of this study was to make the road maintenance planners aware of these high frequent and high risk maintenance activities.

1.2. Causes of Change Orders

After a new construction or maintenance contract is awarded to a contractor, any change in the original contract will become CO. The CO having positive impacts on project cost and schedule prove beneficial to both parties: the contractor and the owner. However, the CO could have a negative effect by generating claims and disputes (Alnuaimi et al., 2010). Hence, avoiding or reducing CO lowers the risk of conflicts between the contracting parties. If the causes of the CO and preventive measures to reduce it in the maintenance contracts are known at the time of the contract procurement phase, an engineer can prepare the scope and plan for CO management accordingly. Therefore, this study identified the causes of the CO in highway maintenance contracts and developed tools to minimize the negative impacts on cost and schedule.

The CO in new building construction or maintenance projects incur because of various common reasons such as the unforeseen conditions, errors in estimate or designs, and owner's requirement changes (Shrestha et al., 2013). Most literature identified CO on project level and studied the general causes of the CO. In this study, the causes of the CO are explored in maintenance activity level; providing maintenance engineers and planners with a list of the causes and preventive measures of the CO on specific maintenance activities.

To identify the causes of CO, a Delphi study was conducted with state DOTs maintenance engineers. This study also gathered information on the preventive measures to avoid or reduce CO in maintenance contracts. The main purpose of choosing the Delphi study was to gather consensus on the causes of CO and preventive measures to reduce it. The maintenance activities selected for this study were: chip seal, paint striping, slope repairs, debris removal, and asphalt overlay. These activities were selected because they were the most common road maintenance activities that were outsourced to contractors (NDOT 2013). It was also reported that the total expenditures on these activities were more than $ 1million during 2012/2013 in Nevada (Halcrow 2011).

1.3. Contingency Estimations

A project may require some additional time or cost to complete it successfully. Any extra cost added to the project is known as cost contingency which is provided at the beginning of the project to deal with its uncertainties during construction phase. The method of providing additional costs may vary. For example, according to Lhee et al. (2012), Florida DOT has used two approaches to compensate the uncertain risks and funding required by additional work orders. Both the approaches were in the form of contingency cost; one was the contingency amount item and another was contingency supplementary agreements. After conducting a study on contingency, Ford (2002) and Marco et al. (2015) stated that contingency budget management is very important issue for effective project risk management. Hence, if the contingency could be planned and managed well, it would cover the CO reducing the cost growth problems.

Since the main purpose of the contingency is to cover the unforeseen risk during the construction or maintenance period, the survey participants advocated for a contingency estimation tool, so that the cost of the CO could be managed during the maintenance contracts. Generally, CO appear in a project during construction phase and traditionally, around 10% to 15% of the project cost is allocated for contingencies. Much papers indicated that this deterministic method of contingency allocation as some percentages of the project cost is not an accurate method. If a mathematical model could be developed to predict a contingency cost of the project, CO can be managed more realistically during construction or maintenance phase. Hence, in this study, a mathematical model is proposed to estimate contingency of the maintenance contract. Instead of adopting contingency percentages by traditional methods, a tool developed in this study will assist the planner to design the contingency for a maintenance contract. A neural network or linear regression models were used to forecast the contingency cost of the maintenance project based on historical CO data.

1.4. Schedule Crashing Optimization

A contingency will help to deal with CO during construction or maintenance period. The CO occurring during the construction or maintenance period could delay the works which may need to be accelerated. In such a condition, a schedule crashing may be required to reduce the schedule growth problem. In construction management, schedule crashing refers to a process of shrinking the project duration by reducing activities' durations. Normally, the duration of a project is determined by the critical path method. And, crashing the activities on critical path reduces the project duration. On the other hand, this crashing will lead to increase in the project cost because of the extra overhead costs required in the crashing process. Hence, an optimization should be carried out to determine the most economical project cost at an optimum project duration.

The schedule crashing could be performed manually or with the help of an optimization software; if performed manually, the task becomes very laborious and time-consuming. Whatever the method used, the main goal of the schedule crashing is to minimize the activity crashing cost.

For this study, a tool was developed to automate the schedule crashing optimization process. This tool helps to identify the number of time units for activities to be crashed for the optimum results. The schedule crashing optimization was intended to reduce the negative effect of the schedule growth by reducing the project duration in economical way. In a construction project, CO could appear at the mid-way of the total project duration. Hence, for the schedule crashing purpose, the original schedule has to be broken at that point and the pending works should be integrated into a new activity network. The schedule crashing optimization tool developed in this study assists to identify the optimum project duration for the most economic cost.

1.5. Objectives

The objectives of this research are to:

a) Quantify the amount of CO in road maintenance activities.

b) Identify the causes of CO in road maintenance contracts.

c) List possible preventive measures to avoid or reduce these CO.

d) Develop a contingency estimation tool for maintenance contracts to control cost growth.

e) Develop a project schedule crashing optimization tool to control schedule growth.

CHAPTER 2: LITERATURE REVIEW

Much literature found on Change Orders (CO) stated that CO are common problems in any kind of constructions. However, these papers focused on either new construction of buildings or new construction of highways. There were limited literature on road maintenance contracts and CO in maintenance contracts remained ignored. Whether it is a new construction or maintenance project, CO may appear with positive or negative effects or sometimes with no effects. The positive effects are favorable to the project because that CO will either reduce the project cost or the total project duration or both. On the other hand, the negative effects increase costs or time or both. Empirically, not only new building or highway construction projects are affected by CO, highway maintenance contracts also cannot be ignored for having negative impacts of CO. Therefore, this study focused on CO in maintenance contracts.

The review of past literature is grouped into five sections. The first section covers the literature related to the quantification of CO in building and highway projects. The second section explores the literature about the Delphi method. The third section includes the literature related to the causes of CO in highway construction projects. And the last two sections summarize the literature reviews related to contingency cost estimation and schedule optimization methods.

2.1. Change Orders in Maintenance Contracts

Trombka and Scruggs (2014) published a report for Montgomery County in Maryland State and reported that the average cost growth in 17 county government construction projects was 8% and overall project duration increased by 30.3% (p. 36). Most of the projects considered in the report were building projects. Randa et al. (2009) revealed that the CO were a big problem with lump sum or fixed-priced contracts of building contracts. In cost-plus contracts, the owners handled the CO totally; therefore, CO were not a significant issue. Based on their analysis, the authors noted that most CO for construction projects of large buildings were for structural issues. The authors found that the construction cost growth due to the CO were in the range of 6% to 10% of the original contract cost, and the schedule growth was less than 10% of the original contract duration. The study indicated that CO could increase the cost as well as the duration of the building projects.

Flyvbjerg et al. (2004) conducted a research on the escalation of a project's cost with respect to the project size, the length of the implementation period, and types of ownership for highway projects. Their study indicated that lengthier the duration of the project, the higher the chances of cost escalation. They also reported that the projects, constructed by state-owned enterprises, had 110% cost escalation, on average. In addition that privately owned projects had an average cost escalation of 34%. The authors concluded that the risk of cost escalation was high for all types of projects, and were not necessarily dependent on the size of projects.

According to a study by Ndihokubway and Haupt (2008), there were four types of sources for CO: a) clients; b) consultants; c) contractors; and d) others, such as weather and state regulation statutes. The study indicated that effects of the CO included "cost overruns, time overruns, quality degradations, health and safety problems, and professional relations" (Section 3, para. 1). The authors concluded that whatever the number and the cost value of the CO were for the projects, the CO originated from the agents such as clients, contractors, and consultants. Furthermore, they indicated that a cause of significant amount of CO was design changes.

According to Serag et al. (2010), the timing of the CO could have a significant effect on the increase in the contract price. The outcome of their research, based on 16 heavy construction projects in Florida, was the creation of a tool for the project owners that could help to quantify the cost of CO at various periods during the lifetime of construction. The authors mentioned that the CO in these projects was in range of 0.01% to 15% of the original contract cost. The authors claimed that the tool would be helpful to estimate CO cost before the contract, and would allow the owner to utilize contingencies. The CO model embedded in the tool could be used for forecasting cash flow and confirming that the contingency money was available to cover CO.

Anastasopoulos et al. (2010) found that the frequency of CO was directly correlated with the size of projects. The authors reported that the relationship between the frequency of CO and the project size was significant. In addition, the types of projects had a correlation with the amount of CO. The study found that resurfacing and traffic maintenance projects had fewer CO, because these types of projects did not encounter unforeseen site conditions. The authors found that the longer the project duration, the higher the CO.

Shrestha et al. (2014) identified road maintenance activities that were highly affected by CO. They analyzed road-maintenance contracts under the KeRRA for two consecutive fiscal years, 2011/12 and 2012/13. The authors stated that the three activities that were most affected by the CO were: gravel patching, culvert installation 600 mm diameters with surround, and heavy grading without watering or compaction works.

Choi et al. (2015) studied on 1,372 highway improvement projects handled by California DOT. Those projects were contracted based on accelerated contract provisions (ACPs) such as cost-plus-time (A + B) and incentives/disincentives (I/D). They found that pure A+B projects had the highest schedule change order ratio percentage of 12.7% followed by the I/D combined with A+B having 1.1%. They also found that the cost change order ratio percentage (7.2 %) for the I/D combined with A+B was higher than that in pure A + B (6.6%).

2.2. Delphi Study

The Delphi is a group process that gathers consensus on a problem or solutions through the knowledge of experts without bringing them physically together (Delbecq et al., 1986). Hsu et al. (2007) stated that the Delphi technique is carried to achieve a convergence on opinions provided by experts on specific real world problems. In Delphi studies, experts remain anonymous to each other avoiding chances of influences of one participant to another. Normally, the experts are high level personnel such as decision makers, planners, and professional staff. In Delphi study, the surveys are conducted starting with broad issue questionnaire and continues for several rounds (Delbecq et al. 1986 and Hsu et al. 2007). The survey is terminated only after adequate agreement between the participants is obtained. In their literature review, Hsu et al. (2007) indicated that in most of cases, three iterations in surveys are enough to gather the required information and reach the consensus.

In 1991, Saito and Sinha implemented the Delphi method to study on bridge condition ratings and effects of improvements. Their purpose of using the Delphi method was to allow the bridge site inspectors from Indiana Department of Transportation (INDOT) to participate in the process of the inspection guideline preparation. They conducted the survey consisting of the 14 INDOT employees working in bridge inspection and design. Their survey was completed in two rounds for the Delphi study. The rating used in their study was between 0 and 9 in both of the survey rounds.

Linstone and Turoff (2002), in their book, mentioned that the Delphi method is conducted in the form of either conventional or real-time approach. In the conventional or “Delphi exercise,” the researches work in pencil and paper mode. All the processing is achieved through the writing form. However, in the real-time or “Delphi Conference,” the researcher uses a computer to process and summarize the information from the experts. Whatever approach is selected in Delphi, the participants have flexibility to participate at their own convenient time. This book elaborated on the process of constructing the expert panel. The most promising approach recommended by this book was to start with a small number of participants and inquire for other reliable and possible participants.

Using the Delphi method, Gunhan and Arditi (2005) studied the factors affecting international constructions. The Delphi study was completed in two rounds of surveys. The required information for their study was gathered from 12 international contractors using an eight-page long questionnaire. They combined the Delphi method with the analytic hierarchy process (AHP) to analyze the information received from the survey. They mentioned that the AHP helps decision makers "to identify and set priorities on the basis of their objectives and their knowledge and experience of each problem" (Gunhan and Arditi, 2005, pg. 274).

As per the literature review conducted by Hsu et al. (2007), the number of experts in the survey panel could be variable in normal practice, ranging from 10 to 50. If the number of experts is very few, then it may not represent well the target pool of the experts. On the other hand, if the number of experts is very large, the time required to arrive consensus may extend more than expected. They also reported that the Likert-type scales are greatly in use to allow the experts to rate the items in questionnaire.

Yeung et al. (2009) used the Delphi method to assess the relationship-based contracts in Australia. They referred to partnering, alliancing, joint-venturing, and other collaborative works as relationship contracts that shared risks among the partners. Altogether, they conducted four rounds of surveys. They initiated the Delphi study with 22 Australian construction experts ending the last round of the survey with only 16 participants left. In the first round survey, they identified the key performance indexes (KPI) to assess the success of the relationship-based projects whereas the second round survey allowed the participants to reconsider their opinions. Then, the succeeding rounds were used to gather consensus on the rating for the KPIs. They adopted five point Likert scale for rating these KPIs.

According to Hallowell and Gambatese (2010), the Delphi study allows collection of reliable information from experts through well designed survey questionnaire. They mentioned that for construction engineering and management (CEM) research, the number of panelists should be more than eight and the number of survey rounds could be three. They recommended conducting multiple number of surveys and using the median value instead of mean value to reduce the biased result. They claimed that the Delphi method has strong potentials for its implementation in CEM research for a better result. Hence, in this study, the Delphi method was used to identify the causes and preventive measures of CO in road maintenance contracts.

2.3. Causes of Change Orders

There are many literature exploring the causes of CO in construction projects. In 1990, Yeo conducted a study about literature available on overruns in construction projects. According to his literature review, the causes of the overruns were: changes in scope of works, problems in design, errors in estimate, unforeseen cost inflation, poor project definition, problem in contract administration and policies, and new requirement of government legislation of increased safety.

According to Alnuaimi et al. (2010), the main reasons of the CO were political problems and errors in designs. The authors reported that clients were the number one source of the CO in the public projects such as water transmissions, roads, buildings, and port projects. The main effects of CO were delay in completion date of the project and generation of the claims and disputes. Their survey showed that the party who benefited the most was the contractor. Their study also revealed that consultants were equally benefitted because of getting paid for any kind of time extension or design modification.

In the West Bank in Palestine, the survey data received from consultants and contractors for the projects showed that the average schedule growth for most of the highway construction was between 10 to 30 % of the original project duration (Mahamid et al. 2012). The authors recommended the following control measures to reduce the schedule growth in the highway construction projects:

- Provide training programs related to project control to managers and labors by the client,
- Keep enough oversight by owner during planning and designing phase of the project and document these works, and
- Use sufficient equipment and skilled labors during construction.

Taylor et al. (2012) collected data on 610 roadway construction projects in Kentucky and found that the avoidance of CO due to price escalation in fuels and asphalt were more challenging than earthworks and structure works. They identified that contract omissions, contract item overrun, owner-induced enhancement, and fuel and asphalt adjustments were the most frequent reasons of incurring engineering CO in transportation projects. In their study, they indicated that all these sources, except for fuel and asphalt adjustments, could be avoided by means of front-end planning, which they called "pre-project planning and involves a systematic process to define the project scope prior to construction" (p. 1367).

Similarly, Rosenfeld (2013) studied about the root causes of construction cost growths, and listed the top reasons for the cost growths. According to Rosenfeld, the top three causes were premature tender documents, too many changes in owner's requirements or definitions, and unrealistically low tender winning prices (p. 04013039-6). Upon identifying the causes of construction cost growths, the author implemented a five-step event analysis to find the root causes, which involved understanding the problem, brainstorming, gathering data, data analysis, and identifying the root cause.

Halwatura and Ranasinghe (2013) gathered data on CO for road construction projects in Sri Lanka to determine the main causes of these CO. According to these authors, CO was an official document that addressed the changes made to the original contract. The authors listed 55 causes for the CO. The top five causes identified were poor investigation, political pressure during the construction stage, unforeseen site conditions, poor estimation, and client-initiated variations.

It was Dickson et al. (2014) who did the study of factors behind CO in construction projects in Kenya and identified the top reasons behind the CO in construction projects. Among these reasons, the top five causes were: payment delay for land acquisition, changed site conditions, changes in scope by clients, changes in the schedule by the client, and lack of coordination between contracting parties.

Russel et al. (2014) conducted a study on time buffer required for the variations caused by uncertainties in a project. They found the top 12 causes of the variation in durations and among them, the top five causes were: "Turnaround time from engineers on drawing question, Completion of previous work, Rework required, Waiting for answers about design or drawing, and Quality of documents" (p. 04014016-5). Some other reasons behind the change orders collected from other literature reviews are presented in Table 2.1.

Table 2.1.Some Causes of Change Orders Listed from the Literature Review

Reasons behind the change orders	Project type	Authors
• The change made on plan by owners, • Substitutions of materials and methods, • Errors and omissions in design, • Owners' financial problem, and • The change in design by consultants.	Building projects (Malaysia)	(Randa et al., 2009)
• Error and omissions in design, • Unforeseen work, grade changes, • Alterations in the scope of work changes, and • Deterioration or damage to the project after design.	Highway projects (Florida DOT)	(Serag et al. , 2010)
• Award project to the lowest bid price, • Inconvenient site access, • Poor communication, • Unreasonable project time frame, • Lack of equipment efficiency, • Changes in specifications and material types during construction, • Weather condition, • Inappropriate design, • Rework because of errors during construction, and • Improper construction methods.	Road Construction projects (the West Bank in Palestine)	(Mahamid et al., 2012)

These reasons identified through literature reviews supported this study to prepare the Delphi study. However, all the reasons gathered were for either building projects or new highway construction projects. This study was intended to collect the reasons behind the CO in highway maintenance contracts handled by the state DOTs in the US.

2.4. Estimations of Contingencies

According to Gunhan and Arditi (2007), there were three types of contingencies, namely: designer's contingency, contractor's contingency, and owner's contingency. They put a claim that the best method to predict contingency was to use previous experiences and enumerated that a detailed study of four factors, namely: schedule constraints, site conditions, project scope, and constructability issues, could play an important role either in preventing the CO or reducing the chances of needing contingency.

Smith et al. (1999) was of the view that a rational decision on the amount of contingency used while bidding could have effects on whether one would win the contract. They held interviews to 12 contractors on contingency calculation method, which resulted that none of these contractors was aware of any kind of estimation method for contingency amount. Whenever, these contractors used contingency, they simply followed the traditional approach of adding some percentages to the base cost as contingencies.

Mac and Picken (2000) conducted a study on two types of projects, namely estimating using risk analysis (ERA) and non-ERA projects. They made comparison between 45 ERA projects with 287 non-ERA projects and found that the ERA method helped to reduce unnecessary risk allowances in projects. According to the authors, the Hong Kong government had been implementing this ERA technique in public construction projects. In the ERA method, they described that the cost determined for fixed and variable risks was added to the base estimate cost which was computed considering the project as risk free. They asserted that implementing the ERA method improved accuracy in estimating the contingency amount during pre-tender stages.

Chen and Hartman (2000) studied multiple linear regression (MLR) and artificial neural network (ANN) for prediction of contingency. The authors obtained required data from a large oil and gas company. They got their hand on the fact that the prediction of contingency by the ANN method contained less fallacy than that of the MLR method. Moselhi et al. (2005), after performing an extensive literature review, came to the conclusion that the ANN model had a great potentiality of recognizing the data patterns and data prediction.

Baccarini (2006) scrutinized the methods of estimating contingencies that affect the final cost of a project. They enumerated a number of methods that could be used to determine contingency in a project. The methods commonly used for predictions were: a traditional percentage, Monte Carlo simulations, regression analysis, and artificial neural networks. The author advocated for regression analysis method as a better approach for predicting the final cost of a project.

In 2007, Barraza and Beuno conducted a study on the project management process and reported that contingency management is just as important as contingency estimation during a project execution. They proposed Monte Carlo simulation method for the cost contingency management. Based on Monte Carlo technique, different probabilities of acceptable risk for activities were generated. The total contingency cost required for the project was computed based on cost difference between the planned budget cost that considered the acceptable risk at the final performance and the expected mean budget at completion.

Sonmez et al. (2007) proposed a regression model to predict contingencies required for international projects. The regression model was prepared based on project data collected from Asia, Africa, Europe, and Middle East where Turkish contractors worked for these projects. The regression model showed that contingencies had relationships with the country risk rating

(CRR), the availability of materials in the host country, advance payment amounts, and the project type (which was either a unit price or lump sum contract). According to the author, a lower value of CRR meant less risk in the country and a higher value of CRR indicated a greater level of risk in the country. The authors concluded that the contractors included a 5% extra contingency amount for a lump sum contract as compared to the unit price contract.

Thal et al. (2010) analyzed 203 air force construction projects and used a linear regression model to predict contingency amount for a new project. The contingency amount according to them was “a part of the budget intended to pay for changes initiated by either the client or the contractor after contract award” (p. 1181). They stated that the regression model, they proposed in the study, reduced the error in contingency estimations. The model estimated contingency funds as a function of other parameters such as: estimated/design cost at the awarding time, design duration, contract award month, type of work, and design life were as independent parameters.

According to Barraza (2011), a time contingency was normally calculated as a percentage of the total duration and was allocated to each activity individually. The author defined the time contingency as the total time allowance (TTA), which was “the difference between projects planned duration (PPD) and project target duration (PTD)” (p. 260). In addition, the author proposed a stochastic method to allocate these PPD and PTD where PPD would be always bigger than PDT to have a positive total time allowance.

Lhee et al. (2012) prepared a prediction model based on an artificial neural network (ANN) to estimate contingency cost for transportation projects. They claimed that the model was better than the traditional percentage based approach of allocating the contingencies in a project.

They considered the contingency cost as the expected difference between the original and the final contract cost of the project.

Studying 228 water infrastructure projects, Baccarini and Love (2013) found that the mean contingency percentage allocated to the projects was 8.46%. However, the total contingency cost required was 13.58%. The authors asserted that the deterministic percentage addition as contingencies (normally 10%) to cover the cost growth was not an accurate method.

This literature review section showed that either a regression analysis or an ANN method is appropriate to forecast contingency in a project. Hence, this study selected these methods to predict the contingency amount for a road maintenance contract. The first priority was set for the ANN method because this method eliminates the requirement of knowing the best fit curves or equations suitable for the input dataset. That is why, the users are allowed to choose between the ANN method and linear regression method for prediction purposes.

2.5. Optimizations for Schedule Crashing

There are several optimization software such as Excel solvers, Matlab optimization tools, the Microsoft Solver Foundation, and the LINGO software that can solve the schedule crashing problem with the help of optimization techniques. These tools are standalone tools and can be used to determine an optimal solution for a given problem at a time. If any problem requires multiple iterations to determine the best optimal solution, a customized tool or standalone program needs to be developed. Menesi and Hegazy (2014) used IBM ILOG modeling software to solve multimode resource-constrained scheduling problems. With the help of that software, they were able to determine the near-optimum solutions for the bi-objectives problems (The two objectives were to minimize the project duration and achieve resource leveling).

Wiley et al. (1998) implemented an optimization technique to develop an initial plan for multiple projects. For the optimization procedure, they had taken into account all important factors affecting project cost and duration. They also introduced the optimization model that featured the budget preparation cost such as rewards, overheads, and other activity costs. Then, they prepared a final optimization model to help a contractor understand the most optimal duration after the crashing. However, their study did not consider the liquidated damage costs.

Hegazy (1999) conducted a study on a genetic algorithm (GA) technique for the project management that helps to achieve the near optimum solution for resource allocation and levelling. For optimization purposes, the author gave value to the minimization of double moment criteria; the moment of resources about time axis and the moment of resources about the resource axis. Hegazy also brought into light a macro in the Visual Basic Application (VBA), which was embedded in Microsoft Project and executed the GA technique to perform the schedule optimization. Similarly, El-Rayes and Kandil (2005) also appeared in implementing the GA algorithm to optimize the time-cost tradeoff problems with the minimization of the time and cost while maximizing the quality of the project.

While dealing with time-cost trade-off problem, Chassiakos et al. (2005) studied two methods; one method was the exact method such as linear/integer programming and another method was approximate method such as heuristic algorithms and genetic algorithms. They mentioned the exact method determines the optimum solution at the cost of processing time, whereas the approximate method provides near optimum solutions quickly, though generating less accurate solutions. They included the parameters such as bonuses and penalties while performing the schedule crashing analysis. The activity crashing cost included the activity overhead, but no inclusion of cost saving if the project was completed early.

Yang (2005) proposed a chanced-constrained programming model to study the time-cost tradeoff problems considering the fund variability issues. The author forwarded an optimization model to determine a minimum duration for a project keeping in mind the budget constraints, precedence relationships between the activities, the lower and upper bound of the activity durations, and the initial start time of the dummy start activity. However, the author did not consider crashing cost optimizations.

Ammar (2011) emphasized importance of discounted cash flow (DCF) calculation while performing the time-cost trade off (TCTO) analysis for a project. The discounted cash flow illuminated that the value of the money would decrease as time passes. The author used the LINGO software to find the optimum solution for the TCTO analysis. The analysis of a sample project schedule optimization problem showed the difference in the optimum project duration when the DCF concept was applied and when not applied.

Elmabrouk (2012) developed objective functions and constraints for the project schedule crashing by the linear programming method in his study. The author introduced a prototype for an activity network and put into practice the linear programming technique to solve the schedule-crashing problem. The author did not stay behind to use the LINDO software to find the solution of the linear programming problem. Further than that the author asserted that the sensitivity report obtained from the software could be a great help for a contractor to analyze the schedule crashing issue and determine the most economical project schedule in terms of the cost and time.

Asrul (2013) proposed a model that took into account not only the cost and time for schedule-crashing, but also different methods of activity execution while crashing the schedule. The author determined the activity to be crashed and the method to be used for completion of the project within time and budget constraints. In addition to this, the author developed a generic mathematical model and put into use that model for a case study applying the LINGO 10 software. Similary, El-Kholy (2014) used the LINDO software to address the optimization problem of time-cost tradeoff considering the variability of the funding and the duration of a project.

Georges et al. (2014) designed a tool named CRASH as an attempt to automate the schedule-crashing problem. Their claim was that the tool contained the potency to crash the schedule and lessen 90 to 95% of the calculation time if done manually. They had done remarkable effort to automate a schedule crashing method for a pre-specified duration exposing the fact that the automation process avoids the human errors in the calculations. Their effort to perform schedule crashing from the first principal also could be achieved through a proper optimization technique available in the market.

Kim et al. (2015) initiated the investigation of the Niched Pareto Genetic Algorithm and proposed a new modified model for simultaneous optimization of the project duration, cost, and resource utilizations. Their study did not address the overhead costs, rewards, and liquidated damage costs while solving the optimization problems for the time-cost tradeoff and fluctuations in resources. So, in this study, my effort was to develop a tool based on optimization techniques which would consider all these parameters.

Similarly, in 2015, Al-Haj and El-Sayegh did a study about the time-cost trade-off problem using non-linear integer programing (NLIP) technique. They introduced a concept of the impact of the reduction in total float of the non-critical activities while crashing other activities on the critical path. They reported that the reduction in the total float of the non-critical activities adds restrictions on the resource leveling. The extra cost due to loss in this flexibility was calculated deducting the early finish cost from the late finish cost and dividing it by the total float available. The authors included this effect of losing the total floats in their optimization model. They also made clear that the cost of the project could be more as compared to regular schedule crashing. In addition, the authors found that when the cost of losing the total float was considered in the optimization model, the total project duration increased compared to that without considering the extra cost. Finally, they stated that the extra cost consideration in the optimization process for the loss of flexibility helped to decrease schedule risks.

Even though, there are successful commercial scheduling software such as the Primavera and the Microsoft Project, they do not provide tools for the schedule crashing optimization. Hence, a tool that provides a solution for schedule crashing optimization while assisting the selection of the best project completion period could prove to be useful. This is due to the fact that, while crashing a schedule, the project will have some additional crashing cost. However, crashing the schedule duration shorter than the desired duration could bring some rewards and could reduce the overhead costs. If the reward cost and the overhead cost savings can cover the additional cost of schedule crashing, the schedule crashing will be beneficial to contracting parties especially for the contractor.

As discussed in this literature review section, there was a gap for a study that considers the automation of a project schedule crashing. This study included all parameters such as overhead costs, rewards, and liquidated damages that affect the final construction cost of the project while preparing schedule-crashing tool. This study put forth a tool that would help a contractor to identify the optimal project duration after the schedule crashing. Finally, this automated tool would be a great help in mitigating the schedule growth problem in the project due to the change orders.

CHAPTER 3: METHODOLOGY

The first step in this study was to quantify the CO in road maintenance contracts and also to list the high frequent and high risk maintenance activities. Then for these maintenance activities, another aim of this study was to identify the top most causes and preventive measures of the CO. The final step in this study was to develop tools that help to reduce the cost growth problem and the schedule growth problem that could be caused by the CO.

During this study, the effort put for the data collection of maintenance contracts performed in the USA did not work. The alternative option found was to receive the maintenance contract data from the KeRRA. Because, the KeRRA had well maintained database for their road maintenance management programs. In order to gather causes and preventive measures of CO, the Delphi study was to be conducted with regional managers working for the KeRRA. Unfortunately, this Delphi study in Kenya failed for some reasons such as the regional managers did not show their interest in this study and geographical distance was too far to approach them. That is how, only nine responses were received in the survey with regional managers. That survey data obtained was not enough to make any conclusion. Therefore, the Delphi study was redesigned to conduct with the state DOT engineers in the USA. Before conducting the Delphi study, the frequent maintenance activities for the USA roads were identified from the literature reviews and the survey was prepared for those maintenance activities.

To complete this study successfully, all data and tools were collected at the beginning of this research work. The statistical analyses were performed using the R - program (version 3.2.1). The Qualtrics survey tool (Qualtrics, Provo, Utah) was selected to design the questionnaire for the Delphi study. In order to develop tools required to address the preventive measures of the CO, the Visual C#, the R-program, the LINDO DLL, and the Microsoft Solver

Foundation (MSF) version 3.0.1.10599 were used. The schedule crashing optimization problem was first tested in the Excel using the solver and additionally tested with the spreadsheet version of the LINDO software. However, the MSF was chosen to execute optimization problems because it was as much powerful as the LINDO and it was more compatible with the Microsoft Visual C#.

The research objectives as given in section 1.5 were identified. Exploring the details of the work already done by other researchers in this field, the extensive literature reviews were performed as outlined in Chapter 2. Detailed steps, required to address each of the objectives, are given in succeeding sections: 3.1, 3.2, 3.3, 3.4, and 3.5 in Chapter 3. Section 3.1 covers the steps adopted to perform quantification of the CO. Section 3.2 lists all procedures conducted to identify causes and preventive measures of the CO in maintenance contracts. Other remaining sections describe details of tools development for contingency estimation and project schedule crashing optimization. For modelling purposes, the CO% of the 614 maintenance contracts was used to work on the contingency prediction by the ANN and LRM method. Similarly, some sample activity networks (project schedule data) were used to check the project schedule crashing optimization tool. Figure 3.1 presents the general breakdowns of the dissertation methodology.

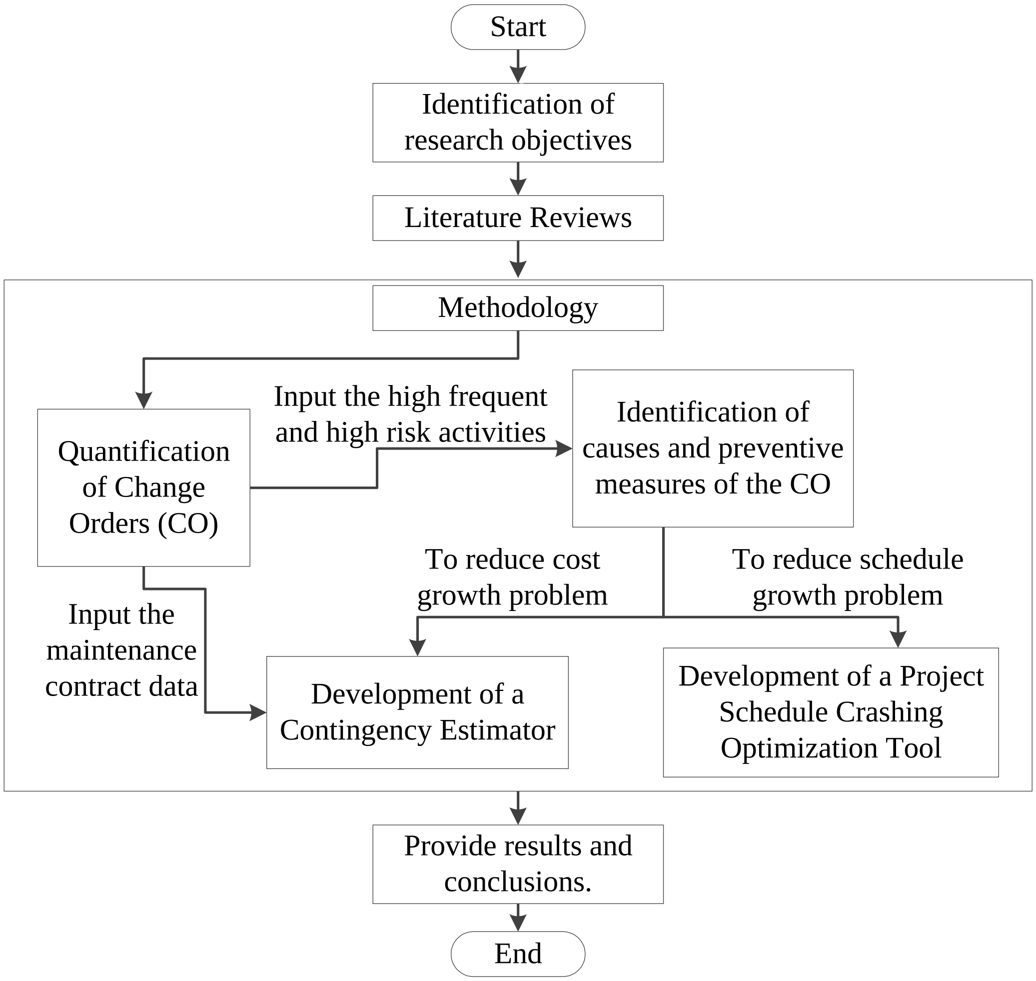


Figure 3.1 Breakdowns of the dissertation methodology.

3.1. Quantification of the Change Orders

The KeRRA provided CO data for five fiscal years, starting from 2009/2010 to 2013/2014. The projects having contract amount equal to or greater than $10,000 were taken for the data analysis. The cost was calculated by converting Kenya shillings to the dollar amount, using the currency conversion rate for November 15, 2014 (US $1 equivalent to 90 Kenya Shillings). In addition, only projects having the CO amounting to or greater than $200, either negative or positive, were considered in this study. A descriptive analysis was performed to summarize the data. The Kruskal Wallis test was performed to compare the CO in the road maintenance activities. The steps followed for the quantification of the CO are shown in Figure 3.2.

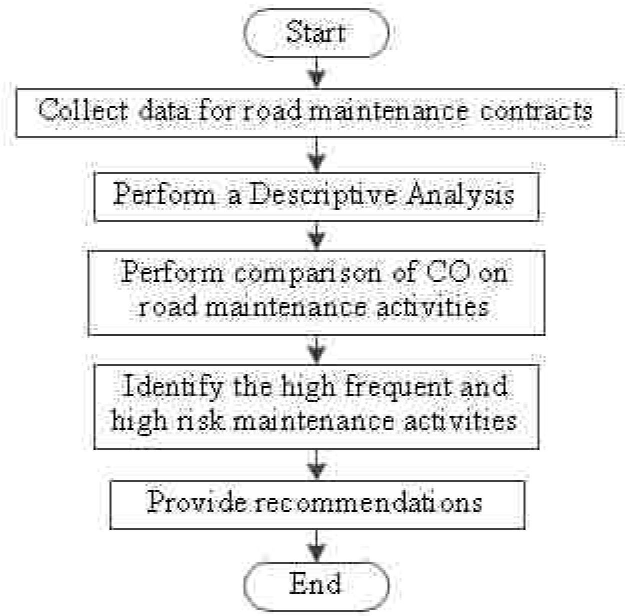


Figure 3.2 A flowchart for analyzing change orders in road maintenance contracts.

Based on the selection criteria, the 614 contracts were sorted out to perform the quantification of the CO. These contracts had CO in at least one of the maintenance activity packaged into them. The CO percentage in an activity was computed using Equation 1.

$$The\ Activity\ Change\ Order\ \% = \frac{Change\ Order\ Cost\ for\ the\ activity}{Original\ bid\ Cost\ of\ the\ activity} * 100\ \% \qquad \dots (1)$$

The contract could have other activities that didn't have any changes, hence the total CO percentage of a contract was computed using Equation 2.

$$The\ Contract\ Change\ Order\ \% = \frac{Change\ Order\ Cost\ of\ the\ contract}{Original\ Contract\ Cost} * 100\ \% \qquad \ldots (2)$$

In order to determine the average CO percentage for each activity and the overall CO percentage among the contracts, a descriptive analysis was performed. The descriptive analysis also became helpful in summarizing the contracts based on the maintenance categories, financial years, cost ranges, and road surface types. The data for the contract packages was divided based on work categories (RM, PM, and Rehab & SI). Another categorization was based on road-surface types. The results obtained from the descriptive analysis are presented in Chapter 4.

3.2. Analysis of Causes and Preventive Measures of Change Orders

The causes and preventive measures of CO in maintenance contracts can be different for different activities. The Delphi technique was adopted to gather the consensus from maintenance engineers working for state DOTs in the USA. In the first round survey, the open-ended questions phone interviews were conducted with road maintenance engineers. The maintenance engineers provided valuable inputs to this study by sharing their experience and enlisting causes and preventive measures of CO in road maintenance contracts.

The information collected through the first round survey was used to prepare a new questionnaire that was designed using the Qualtrics survey tool. The weblink was distributed to the maintenance engineers with a request to rate these causes and preventive measures identified in the first round survey. The data received in the second round survey was analyzed to check agreement between the participants. If adequate agreement was obtained from the second round survey, the survey would be considered final. Otherwise, the important causes and preventive measures would be decided from the second round survey and again a new survey would be designed and distributed as the final round survey. Finally, the top five causes and preventive measures would be determined and reported as a result of this study. Figure 3.3 presents the procedure followed to conduct the Delphi study.

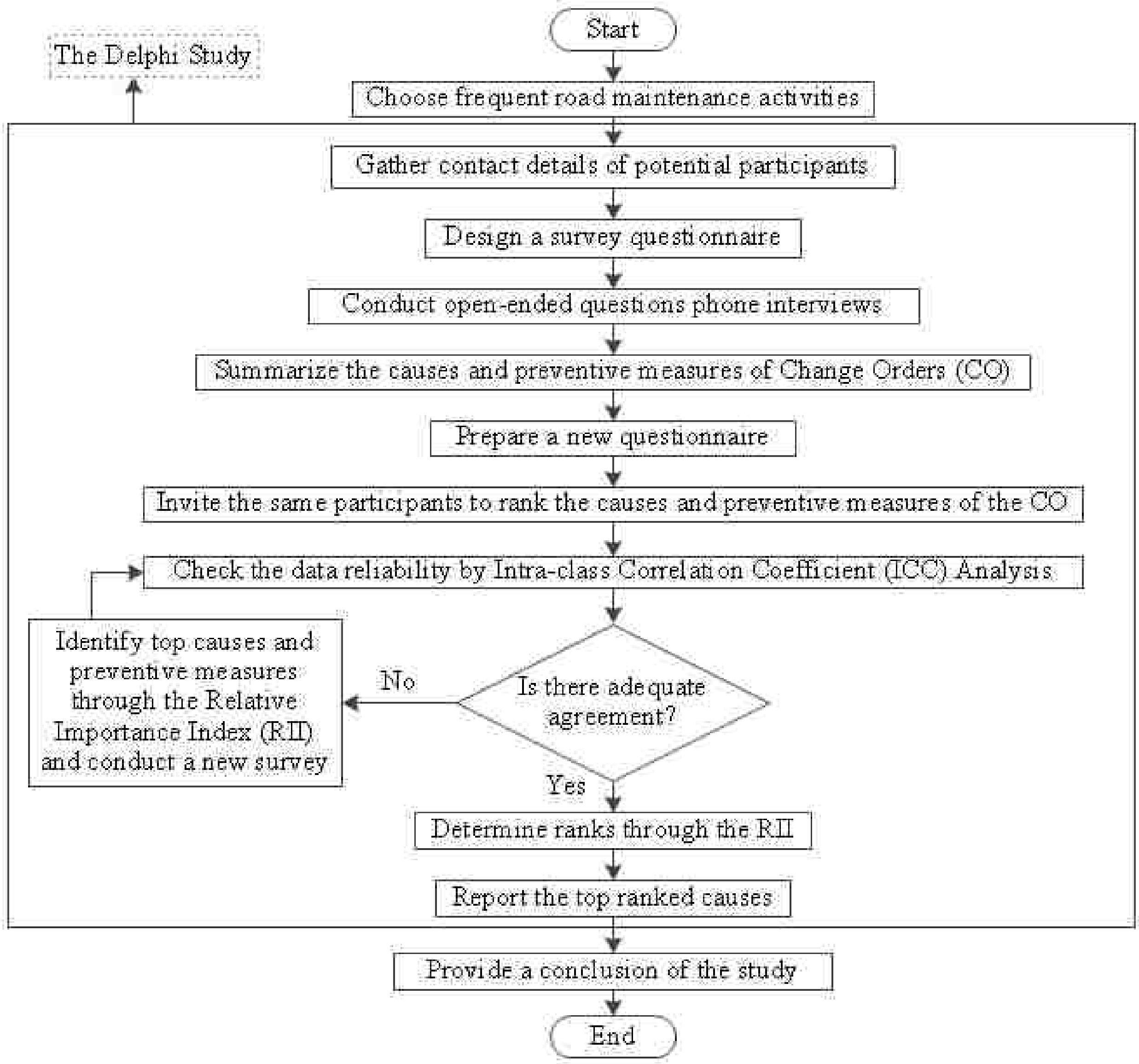


Figure 3.3 A flowchart presenting the steps of the Delphi study on change orders.

During this study, the first round survey gathered the causes of CO and the control measures to reduce or eliminate the CO. The responses from the phone interviews were summarized for each of the road maintenance activities. Based on the summary, a new questionnaire was developed, in which the survey participants were allowed to rate the causes and preventive measures based on their importance level. The rating scale points of one to five was used, where the Likert scale point five indicated very important and the Likert scale point one was very unimportant. In order to conduct online survey, a web-link was distributed to the maintenance engineers who participated in the first round survey.

The data was tested for inter-rater reliability (IRR) using the statistical method called intra-class correlation coefficient (ICC) proposed by Shrout and Fleiss (1979). The function 'ICC' provided by the R-package 'psych' was used to perform this analysis. The method determined how much the multiple raters agreed with each other. Based on the coefficient value obtained from the ICC analysis, the raters' agreement was reported.

This study used the Relative Importance Index (RII) method to rank top causes and preventive measures of the CO. Equation 3 was used to compute the RII value for an item under consideration. This method is similar to the one implemented by Gunduz et al. (2013) in their study. They also adopted the same method to determine the relative importance of the causes of delays in construction projects in Turkey.

$$RII = \frac{\sum_{i=1}^{N} W_i}{(A*N)} \text{.........} (3)$$

Where, W_i = a rank assigned by i^{th} responder,

A = the highest rank,

N = the total number of respondents, and

RII = the relative importance index.

Having results from the ICC and RII analysis, each road maintenance activity was reported for the top five causes and preventive measures of the CO.

3.3. The 'neuralnet' Package in the R-program

There are several software that can be used to implement neural networks. In this study, the R-program particularly the 'neuralnet' (version 1.32) package was used to implement neural networks. The R-program is supported by a Comprehensive R Archive Network (CRAN) repository which provides the necessary routines to be executed in the program. For this study the 'USA (CA 2)' CRAN mirror is used to obtain the necessary packages. The 'neuralnet' package is loaded into the R-library for the required neural network functions. The R-commands as shown in Figure 3.4 provide the steps required to load the package. The figure also presents the necessary commands to create an ANN model and to predict a result for the given input data.

```
install.packages('neuralnet')
library("neuralnet")
#Test 0
#-----------------------------------------------
#Implementation of the 'AND'gate.
#comparing data with 2 hidden layers
(d <- read.csv("E:/Spring 2015/HOA732/Neural Networks/and_gate.csv"))
names(d)
#training the NN model
netsqrt <- neuralnet(O~(X1+X2),d, hidden=2, threshold=0.01)
print(netsqrt)
names(netsqrt)
#Plot the neural network
plot(netsqrt)

#Test the neural network on some training data
a<-matrix(c(1,1),nrow=1,ncol=2)
netresults <- compute(netsqrt, a) #Run them through the neural network

#Lets see what properties netsqrt has
ls(netresults)
#Lets see the results
print(netresults$net.result)
```

Figure 3.4 The steps required to execute and test an ANN model in the R-program.

A sample input data required to train an ANN model for a logical ‘AND’ gate is as given in Table 3.1. Before executing commands in the R-program, the ‘neuralnet’ package is installed. The package is then loaded into the R-program library. The input data either comma-separated values (*.csv) file or text file (*.txt) format is loaded. Using the loaded text file, a data-frame is created to execute the neural network function. A neural network model is generated by passing the data and implementing the function. The function is provided with the required information such as output data, input data, number of hidden neurons, and threshold value for error adjustments. Once the ANN model is successfully generated, the properties of the model can be explored with several built-in commands in the R-program. The graphics of the ANN model can also be checked through the command ‘Plot’ as given in Figure 3.4. Other summary and results also could be checked executing different R-commands.

Table 3.1. A Sample Data for the 'AND' logic gate

Input 1 (*X1*)	Input 2 (*X2*)	Output (*O*)
1	1	1
0	1	0
1	0	0
0	0	0

For the data given in Table 3.1, a neural network model prepared by the 'neuralnet' package is illustrated in Figure 3.5. In the figure, variables *X1* and *X2* represent the input variables, and the *O* represents the output. The model has a hidden layer with two neurons that receives a bias input data with a value of one. This biased input is automatically generated by the neuralnet function. Through the training processes, the ANN model receives the weight adjustment values for input data and the biased data. Based on these weighting values and the inputs, the model determines intermediate output. The intermediate outputs are processed through an activation function. The result obtained from the activation function is multiplied by the corresponding weighting value obtained from the training process. Finally, a single output of the 'AND' gate is reported.

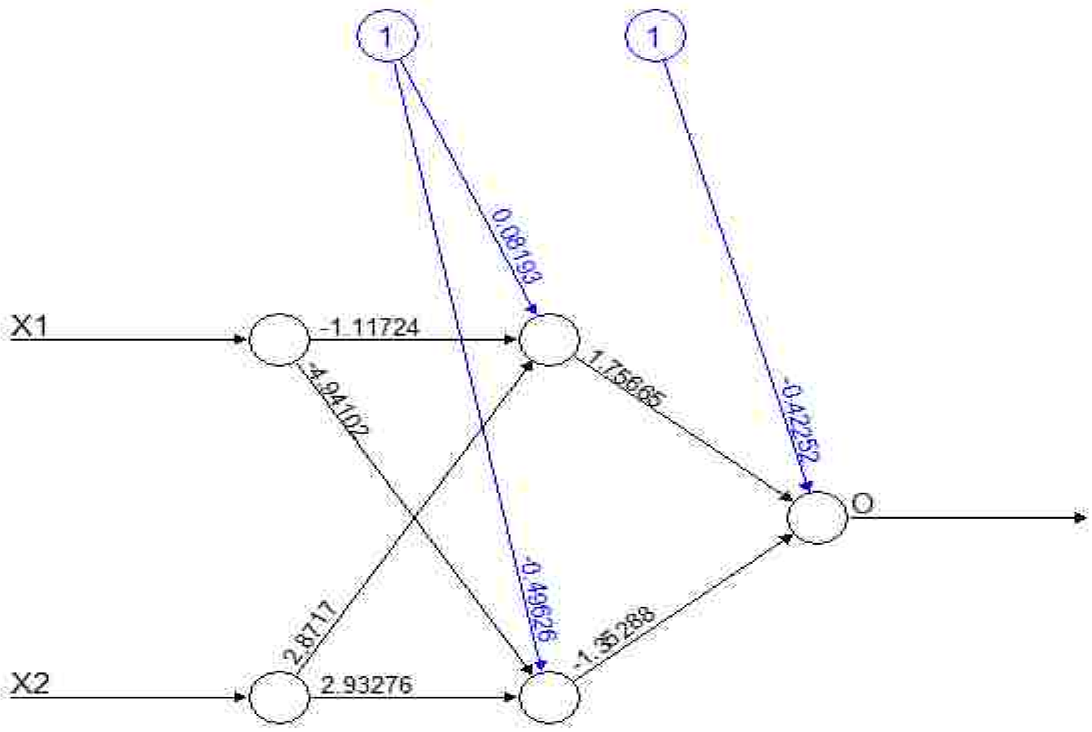


Figure 3.5 A neural network generated by 'neuralnet' package for the logical 'AND' gate.

Some important default settings used by 'neuralnet' package are presented in Table 3.2. Gunther and Fritsch (2010) stated that the default algorithm for the ANN training is the resilient backpropagation with weight backtracking (rprop+). They stated that this algorithm was based on the traditional backpropagation algorithm that modifies the weight of the neural network to determine a local minima of the error function using only one learning rate. However, the resilient backpropagation implements different learning rate at different stages of the training process.

Table 3.2. The Default Setting in neuralnet package (version 1.32)

Parameters	Description	Value
err.fct	Error Function	$E(x, y) = 1/2 * (y - x)^2$
act.fct	Activation Function	$A(x) = 1/(1 + \exp(-x))$
Threshold	Error Threshold	0.01
Algorithm	Resilient backpropagation	rprop+

The default settings for the error function and activation function were identified by using following R-commands as shown in Figure 3.6. The 'netsqrt' is the name of the ANN model prepared using the neuralnet function. The 'names' command provides a list of objects inside the model. Then simply, the issuing print command for these variables displays the information stored in the objects.

```
> names(netsqrt)
 [1] "call"                  "response"
 [5] "err.fct"               "act.fct"
 [9] "net.result"            "weights"
[13] "result.matrix"
> netsqrt$err.fct
function (x, y)
{
    1/2 * (y - x)^2
}
<environment: 0x27e0ba44>
attr(,"type")
[1] "sse"
> netsqrt$act.fct
function (x)
{
    1/(1 + exp(-x))
}
<environment: 0x27e0ba44>
attr(,"type")
[1] "logistic"
```

Figure 3.6 The R-commands used to check the default settings.

Knowing default values for the ANN model parameters allows tracing operations of the ANN model. For example, a step by step sample manual calculation performed during the prediction process by the ANN model shown in Figure 3.5 is presented below.

1. If *X1*=1 and *X2*=1 as given the first row of input data in Table 3.1, then *O*=? Assuming the biased inputs are with a data of value one.

2. Based on the weighting value received through the training process, the intermediate outputs are obtained by Equation 4 and 5.

$x1$ = -1.11724 * $X1$ + 2.8717 * $X2$ + 0.08193 * $b1$ ……… (4)

where, $b1$ is the bias variable.

$x2$ = -4.94102 * $X1$ + 2.93276 * $X2$ + (-0.49626) * $b1$……… (5)

3. Substituting values for the variables, the intermediate outputs are computed as given below.

$x1$ = -1.11724 * 1 + 2.8717 * 1 + 0.08193 * 1 i.e. $x1$ = 1.83639

$x2$ = -4.94102 * 1 + 2.93276 * 1 + (-0.49626) * 1 i.e. $x2$ = -2.50452

4. Processing these outputs through the activation function given by Equation 6, new output data is generated from the hidden layer. The activation function is executed by processing elements in the hidden layer.

$$A(x) = \frac{1}{1+ e^{-x}} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

Hence, $a1 = \frac{1}{1+ e^{-1.83639}}$ i.e. $a1$= 0.862521 and

$a2 = \frac{1}{1+ e^{-(-2.50452)}}$ i.e. $a2$= 0.075542

5. Finally, outputs from the hidden layers are multiplied by the corresponding weight values generated by the ANN model to determine the final output. Equation 7 is used to obtain the final output from the model.

$o1 = 1.75665 * a1 – 1.35288 * a2 – 0.42252 * b2$ ……………….. *(7)*

where *b2* is the bias variable.

Hence, $o1 = 1.75665 * 0.862521 – 1.35288 * 0.075542 – 0.42252 * 1$

i.e. $o1 = 0.99$ (which is almost equal to 1).

These steps were repeated to check for the other data rows in input data of Table 3.1. The results obtained from manual tracing are provided in Table 3.3. The difference between the expected output and predicted output is known as error (E) in the prediction process. The table indicated that the resulting errors were negligible. This manual testing provided a proof of the suitability of the 'neuralnet' package for prediction purposes.

Table 3.3. The Comparison of the ANN Model Output with the Real Output

Input		Expected Output	Predicted Output	Error
X1	*X2*	*O*	*o1*	*E*
1	1	1	0.990	0.010
1	0	0	0.032	-0.032
0	1	0	0.003	-0.003
0	0	0	-0.020	0.020

3.4. Development of a Contingency Estimation Tool

In this study, a tool was developed to estimate contingency cost for a maintenance contract based on historical records of CO on the road maintenance activities. In order to develop the tool, the Visual C# and the R-program were selected as development platforms. A complete list of required software is presented in Appendix B.

For the contingency estimation process, maintenance contract data was collected. A database system was designed and all contract data was imported to the database system for storage. The necessary input and output interfaces were prepared for the estimation system. The contingency percentage is estimated based on the input parameters such as work category, road surface type, road condition, site accessibility, weather condition, location name, and the total activity cost. Among these input data, most of them were coded to have categorical data type and only one item, the activity bid amount was of continuous data type. The steps that were required to develop the contingency estimation tool are outlined in the flowchart presented in Figure 3.7.

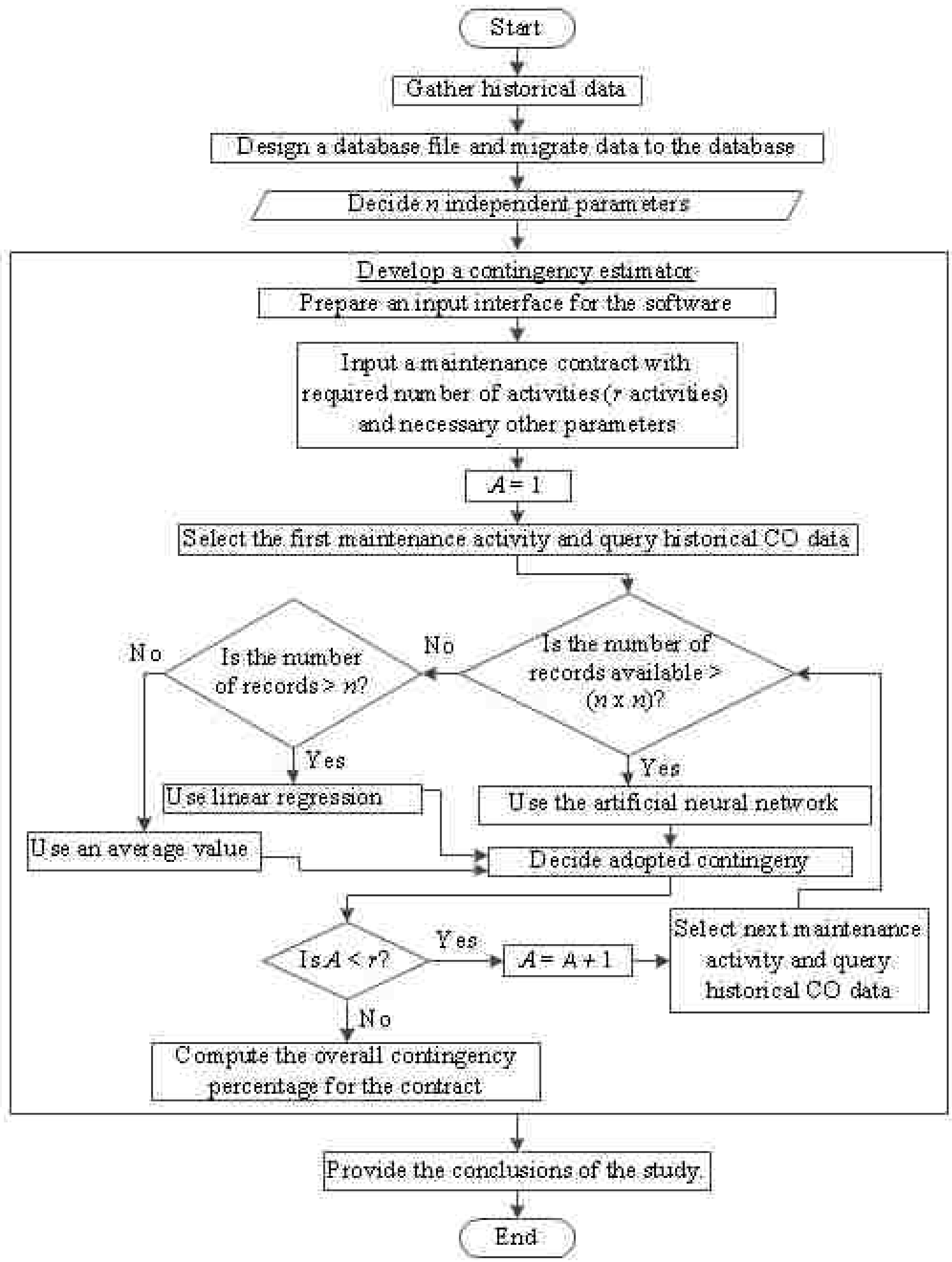


Figure 3.7 A flowchart to develop a contingency estimator for road maintenance contracts.

The prediction process can be achieved in three ways based on the amount of data points available. The number of data points (n) that are retrieved from the database determines what prediction method to choose. The first priority is for the artificial neural network (ANN). If the number of data points is not enough to train the ANN model, then the second priority is for the linear regression model (LRM). Otherwise, if the number of data points is small, then simple average value approach will be used. In this tool, the number of independent parameters was seven (m) and the threshold value was set as m^2 to use the ANN method. Hence, the ANN method will be used only if n is greater than m^2. If n is less than m^2 and greater than m, then the LRM is preferred. As a last option, the average value method will be used if n is less than m. These logical arguments can be presented by conditional statements as outlined below.

If ($n >= m^2$) then

Use the ANN method for data predictions.

Else if ($m^2 > n$ and $n >= m$) then

Use the LRM method to predict contingencies.

Else

Use the average value method.

End if

At the beginning of the prediction, this tool queries the historical data on CO for the activity from the database. Then, based on the number of data points available, a prediction method is chosen. If n exceeds more than 49 data points, this tool prepares an ANN model for the data prediction. These data are used to train the neural network prepared by using the R-program. Then, for a particular activity, the contingency is predicted. If n stands less than 49, but greater than seven, this tool prepares a LRM. The LRM is also developed using the R-program.

The ‘car’ package is used to determine the variance inflation factor (VIF) of predictors from the LRM. The ‘vif’ function built in the package, helps to calculate the VIF values.

The R-program is used to filter out all insignificant predictors in two levels. The First level filtering takes place based on the VIF values. If the VIF value is greater than two, these predictors are considered highly correlated with other predictors. These correlated predictors are eliminated from the model, one at a time starting from the predictor with the largest VIF. After that, a new regression model is prepared and again the VIF values are checked for the predictors in the new model. This process needs to be repeated until, the LRM is set free from the correlated predictors. The second level of filtering is done based on the p-value of the predictors in the LRM. All predictors having p-value greater than 0.05 (which is the default threshold value) are considered insignificant. The iterative loop written for this tool, removes all the insignificant variables from the LRM by eliminating one at a time starting with a predictor having biggest p-value and preparing a new LRM. The final LRM prepared only with the significant variables is used to predict the contingency value of the activity. If *n* is less than seven, then a simple average value method is used to determine the contingency. This process is repeated for each activity and the overall contingency required for the contract is computed based on the cost weighting of the activities.

The tool that was developed during this study, considered the following steps given below to predict contingency of a contract.

1. Provide the contract name and number.
2. Select the region name and the road name that has to be packaged under the maintenance contract.

3. Choose the work category whether it was routine maintenance, periodic maintenance, or spot improvement & rehabilitation work.
4. Provide weather data.
5. Provide information regarding site accessibility.
6. Select activities (*k* activities) to be included in the contract.
7. Provide the desired quantities, *Q* units for each activity.
8. Provide the unit price, $ *P* per unit to perform each activity.
9. Determine the total cost of the contract using equation 8.

$$\text{Total Cost } (TC) = \sum_{i=0}^{k} (P_i * Q_i) \qquad \ldots\ldots\ldots (8)$$

10. Recommend a contingency for each of road activities based on the historical data. If the amount of data available is greater than 49, use the neural network method to find the contingency, otherwise if less than 49 and greater than seven, use a linear regression or if less than seven then use a simple average value.
11. Provide the final contingency percentage *C* % since the suggested value can be modified based on requirements if the planner wishes to.
12. Finally, compute the overall contract contingency based on the cost weighting value for each activity as given by equation 9.

$$\text{Overall contingency } \% = \sum_{i=0}^{k} \left(C_i \ \% * \frac{(P_i * Q_i)}{TC} \right) \ldots\ldots\ldots (9)$$

In order to use the ANN method for the contingency prediction, the supervised training process is considered as opposed to the unsupervised training process which is typically used for pattern recognition. Supervised training is a process where the ANN model is provided with input for training purposes along with the respective output data. This training process adjusts the weighting value while reducing the errors by using the resilient back-propagation method. The resilient back propagation method is very much similar to the back propagation method. The only difference between them is, this method uses different learning rates at different training stages. In contrast, the back propagation uses only one learning rate to adjust the error during training processes. Once, the training process is completed, then the contingency prediction can be implemented using the seven independent input variables to get the contingency as the output dependent variable.

For the ANN model, the input parameters and an output are as shown in Figure 3.8. The input parameters are: the work category, site accessibility, weather condition, road surface type, road condition, location name, and the activity bid amount. This ANN model is capable of predicting a CO percentage for the activity. The ANN model prepared for this study is a three layer model having an input layer, a hidden layer, and an output layer.

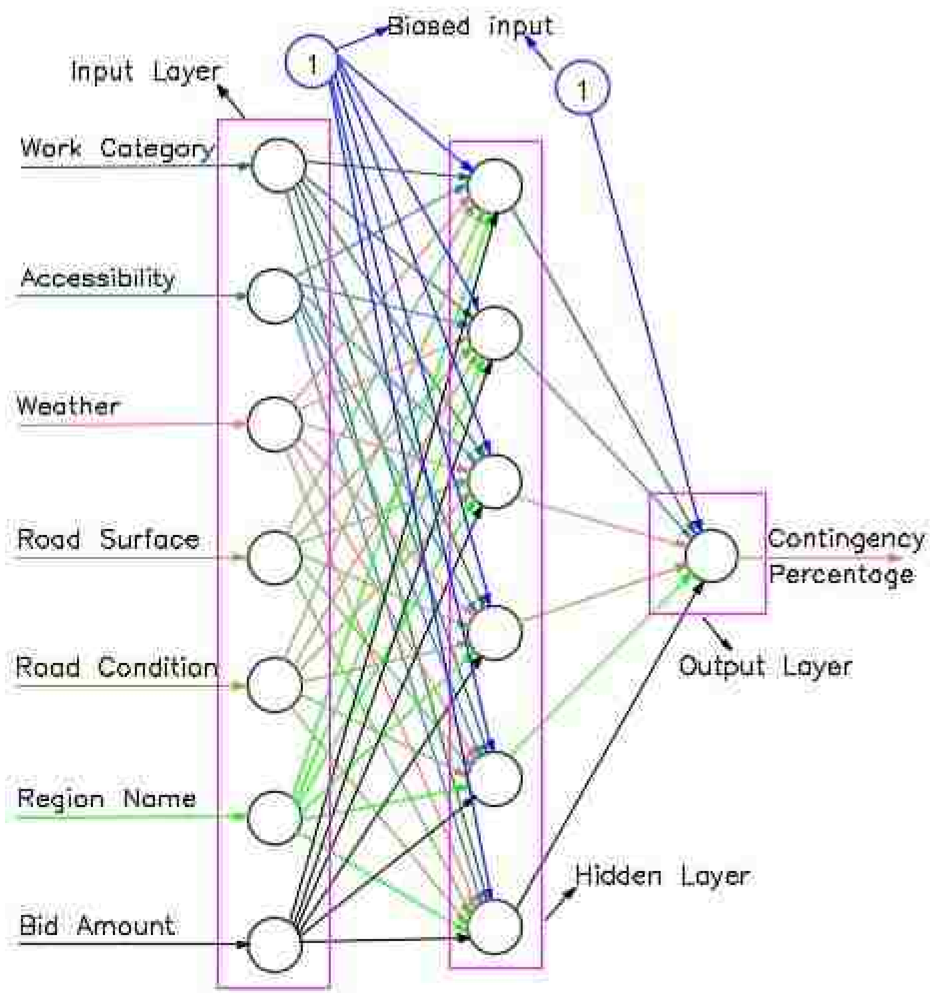


Figure 3.8 A sample artificial neural network used for contingency predictions.

The sample model shown in Figure 3.8 has an input layer with seven neurons, a hidden layer with six neurons, and an output layer with one neuron. Referring a thumb rule, the number of neurons (nodes) in the hidden layer should be in between the number of neurons in the input layer and the number of neurons in the output layer (Heaton, 2008). The number of neurons in the hidden layer is determined as given by Equation 10.

$$N = (m + b + o) * 2/3 \ldots\ldots\ldots (10)$$

Where, N = the number of neurons in hidden layers,

m = the number of neurons in the input layer,

b = the number neurons as biased inputs, and

o = the number of neurons in output layers.

The accuracy of the model depends upon the data available to train the ANN model. For the execution of ANN model, the R-program is used. The tool developed for this study links the R-program, loads necessary packages into the R-library, and makes a prediction through the ANN model. As said earlier, if enough data is not available to train the ANN model, a LRM is used to predict the contingency.

For both methods whether the neural network or the linear regression, the tool executes the R-commands iteratively to predict the required contingency for each activity in the contract. The tool provides a dynamic process and automation for the contingency estimations. In instances where the neural network is selected, this tool prepares a separate neural network model for each activity and uses it to predict the contingency. Similarly, when the linear regression is used, this tool bears all responsibility of running the iterative procedure to remove all insignificant predictors from the regression model. Finally, based on these predictions, this tool provides a contingency estimation for a contract.

3.5. Testing and Validation of Artificial Neural Network

The ‘neuralnet’ package did not provide the validation method for the ANN model, therefore, the testing and validation was traced manually for this study. The ‘neuralnet’ uses the resilient backpropagation method by default and the threshold value of 0.01 for error adjustment. However, the ANN model should be tested for its correctness in the prediction process. Normally, the ANN model preparation consists of following steps.

1. Split the dataset into two sets: training dataset and test dataset.
2. Train the ANN model starting with the random weights and adjusting these weights based on the other data in the dataset until the errors reduce to the smaller value than the threshold value.
3. Test the ANN model using the test dataset and check the error of the ANN model.
4. Repeat the steps from 1 to 3 until the error of the ANN model converges to a small magnitude as much as possible.

In this study, the training dataset and test dataset were obtained by splitting the original dataset into approximately 90% and 10% respectively for each of high frequent maintenance activities in the 614 contracts. After the training process, the ANN models were checked against the test dataset. The testing was performed comparing the average CO% of the test dataset and the average CO% of the corresponding predicted values for the test dataset. The results of the testing and validation is provided in Section 4.3.2.

3.6. Development of a Tool for Schedule Crashing Optimization

Generally, the critical path method (CPM) determines the project completion time and the activities in a critical path. Any duration changes in these critical activities will ultimately affect the final completion time of the project (Feltz, 1970). Feltz was of the view that by reducing (here referred as crashing) the duration of these critical activities might increase the construction cost of the project. Project schedule crashing is a method of reducing the project duration by the desired and possible amount of time. Normally, project schedules are prepared based on the normal productivity rate for project activities. However, if some activities could be performed with their maximum productivity rate, the total project duration might be shortened by a certain amount. Therefore, the project schedule crashing method considers the shortening the duration of activities which are on the critical path by performing at their maximum productivity rate. The final crashed project duration and the total project cost are then reported.

As a manual calculation method to determine the optimized schedule crashing requires extensive calculations and a huge number of steps, the likelihood of introducing errors is high. Therefore, it is recommended to have a tool capable of finding the crashed schedule. In order to develop such a tool, Visual C# was selected as development platforms. Initially, the LINGO software was selected as the first choice as the optimization tool. However, the Microsoft Solver Foundation (MSF) using the Gurobi optimization tool was found having similar capabilities as of the LINDO and was of more compatible to the Visual C# environment. That is why, the MSF was selected to execute the optimization problem. This study was intended to develop the tool to reduce the time-growth problem in construction contracts. The flow chart in Figure 3.9 describes steps required for the development of the tool for the project schedule crashing optimization.

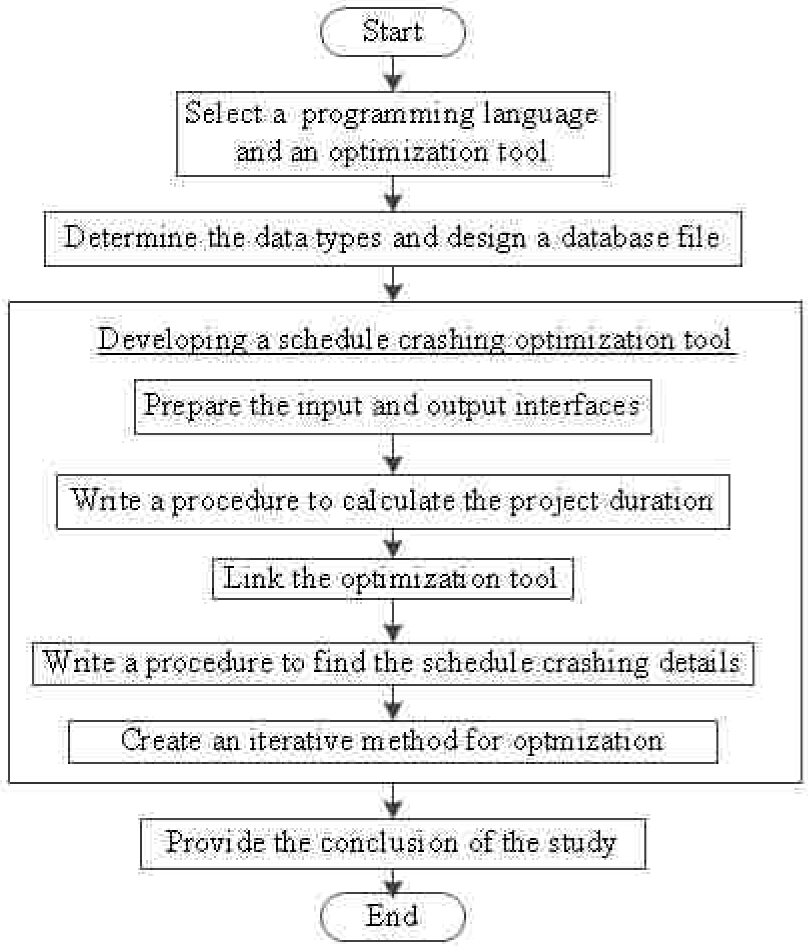


Figure 3.9 A flowchart for development of a project schedule crashing optimization tool.

For this tool to execute the optimization command successfully, there requires a complete activity network for a construction project. In addition, the schedule crashing information such as crashing cost per day and total available number of crashing days are also required. To save and retrieve these information, a database file was designed and necessary table relationships were established in the database. This study considered the 'finish to start' relationship between the activities. For the optimization effort, the rewards/penalty per day and the overhead cost per day should be known. Figure 3.10 presents these parameters graphically and illustrates how they affect the construction cost for a contractor. Considering these parameters, the schedule crashing is done in such a way that the final project duration and the construction cost will be optimum. The optimization process is achieved through the function provided by the Microsoft Solver Foundation (MSF). The MSF, by default, uses the Gurobi-Solver and executes the mixed integer linear programming (MILP) to solve the optimization problem.

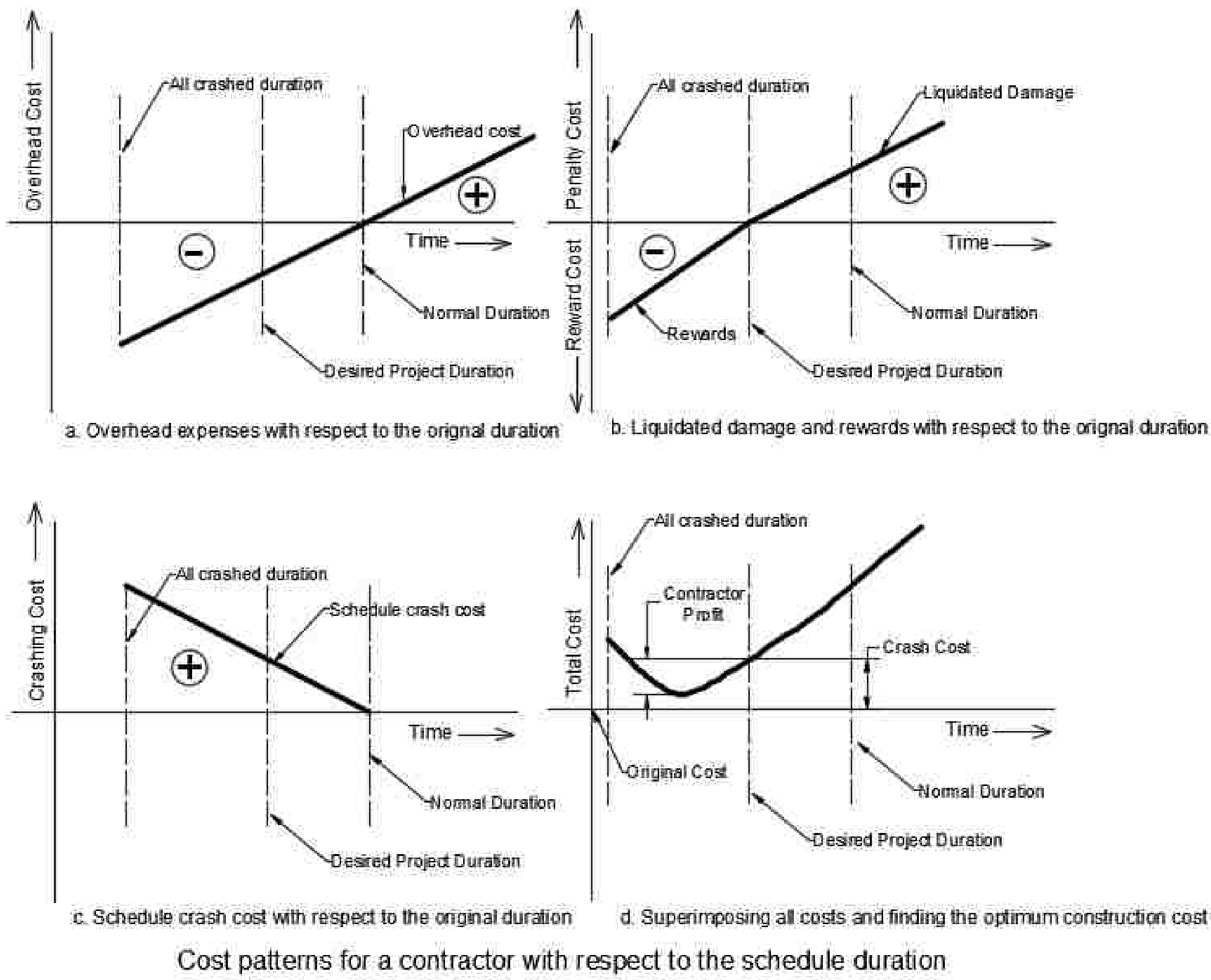


Figure 3.10 The parameters involved in the construction cost for contractors.

As shown in Figure 3.10, for optimization purposes, this study considered several variable costs. Normally, there are three types of durations for a schedule crashing problem: the normal project duration, all crashed project duration, and the desired project duration. If the final project duration is smaller than the normal duration, there will be some overhead cost savings and if not some extra overhead costs. Similarly, if the final project duration is smaller than normal project duration, there will some extra cost for the activity crashing. If the final project duration is smaller than the desired project duration, the contractor will receive some rewards, if not, the contractor has to pay for liquidated damages. When all these variable costs are combined, the optimum cost and duration will be as shown in Chart d of Figure 3.10. The main objective of the optimization process is to minimize the crashing cost and to find the optimum duration that provides the most economical project cost. In order to achieve the minimum crashing cost, following points are considered while performing the schedule crashing.

1. Schedule crashing is performed for the activities on the critical path.
2. The activity, having the least cost per unit-time, is identified and the crashing limit for the activity is checked. The link-lag values for the succeeding activities are also determined. Based on the lag values, the minimum lag value also known as network interaction limit (NIL) value is calculated. The selected activity duration is reduced by the lesser time unit amount defined by comparing the crashing time limit and the NIL value. If more than one critical path are identified and crashing is to be done on more than one activity, the same time-unit reduction is applied to these activities.
3. The new total cost and total duration of the schedule are determined.
4. The steps 2 and 3 are repeated until each activity or combinations of activities attain its crashing limits.

3.7. An Algorithm for a Project Schedule Crashing Optimization:

The steps for a project schedule crashing optimization are listed as given below.

1. Consider an activity network with n activities.
2. Provide the activity network details along with crashing information for each of the activities as input data. The crashing cost per time-unit and the number of allowable crashing time units (L_i) are also required. The time-unit could be a day, week, or month.
3. Find the CPM duration, N_d, for the network.
4. Determine the all crashed CPM duration, C_d, for the network.
5. Identify the most desired project duration, D_d.
6. Provide the reward cost, \$$R$ per unit-time.
7. Provide the liquidated damage cost, \$$Lc$ per unit-time.
8. Provide the overhead cost, \$$Ov$ per unit-time.
9. Initialize the variable for duration iteration, $X_d = C_d$.
10. Assign the longest duration that has to be studied. Let's assume E_d time units which should be greater than value of N_d.
11. Calculate the normal cost of the project, \$$PC$, determining the summation of each activity cost.
12. Perform crashing for all project durations between C_d and N_d.

    k=0; //counter for the number of iterations.

Do while $X_d \leq E_d$

Decision variables:

Z_{ki}

Where Z_{ki} = Number of crashed time units for i^{th} activity.

Objective:

min $(\sum_{i=0}^{n}(Z_{ki} * C_i))$ //the minimization objective

Where C_i = Crash cost for i^{th} activity per time-unit.

Constraints:

$Z_{kj} \leq L_j$

Integer Z_{ki}

$Z_{kj} \geq 0$ //Non-negative constraints.

$\sum_{i=0}^{n} Z_{ki} \geq (N_d - X_d)$

$Y_j \geq Yi + D_j - Z_{kj}$

$X_d \geq Y_j$

Where,

Y_i = the finish time of i^{th} activity (predecessor of j^{th} activity).

Y_j = the finish time of j^{th} activity (successor of i^{th} activity).

D_j = the duration of j^{th} activity.

Z_{kj} = Number of crashed units for j^{th} activity in k^{th} iteration.

L_j = Allowable number of crashing time units for j^{th} activity.

Output:

Values for all Z_{ki} decision variables for each activity.

Record the output for Z_{ki} after the schedule crashing to the specified project duration.

$X_d = X_d + 1$

$k = k + 1$

End loop

13. Compute the cost of the project for all durations.

$X_d = C_d$

$PC_d = PC$ + additional crash cost at desired duration

k=0 //to record the kth crashed cost. //Initialize the variables.

Do while ($X_d \leq E_d$)

$PC_k = 0$ // Project Cost at k^{th} iteration.

$CC_k = 0$ // Crash Cost at k^{th} iteration.

$RC_k = 0$ // Reward Cost at k^{th} iteration.

$LC_k = 0$ // Liquidated damage or penalty cost at k^{th} iteration.

$OC_k = 0$ // Overhead Cost at k^{th} iteration.

If ($D_d > X_d$) //include crashing costs, overheads, and rewards.

{

$CC_k = \sum_{i=0}^{n}(Z_{ki} * C_i)$

$RC_k = - R * (D_d - X_d)$

$OC_k = - Ov * (N_d - X_d)$

}

Else if ($X_d < N_d$) //include crash costs, overheads, and penalties.

{

$CC_k = \sum_{i=0}^{n}(Z_{ki} * C_i)$

$LC_k = Lc * (X_d - D_d)$

$OC_k = - Ov * (N_d - X_d)$

}

Else //include liquidated damage and overhead cost.

{

$LC_k = Lc * (X_d - D_d)$

$OC_k = Ov * (X_d - N_d)$

}

$PC_k = PC + CC_k + RC_k + LC_k + OC_k$

Record this project cost at k^{th} iteration.

$X_d = X_d + 1$

$k=k+1$

End loop

14. Now identify the most optimal project duration.

$X_d = C_d + 1$

k=1 //to record the k^{th} crashed cost.

$C = PC_0$ //record first cost as desired cost.

$d = X_d$

Do while $X_d \leq E_d$

If ($C > PC_k$) then //Record the lowest cost and the project duration.

$d = X_d$

$C = PC_k$

End if

$X_d = X_d + 1$

$k=k+1$

End loop

15. Finally report the optimal project cost C and the optimal project duration d.

CHAPTER 4: ANALYSIS AND RESULTS

The initial data analysis for quantification of CO was performed. Results are presented in the subsequent section 4.1. Similarly, the Delphi study was conducted and its results are reported in Section 4.2. The information received from the maintenance engineers in the state DOTs indicated that a well prepared estimate and well planned schedule are important to avoid the CO. Hence, the contingency estimation and the project schedule crashing optimization tools were developed. These tools will assist to reduce some negative effects of the CO.

4.1. Change Orders in Road Maintenance Contracts

Based on the criteria set for the selection of the maintenance contracts, 614 road maintenance contracts were selected. The costs of these contracts were equal to or greater than $10,000 and had the CO amounting equal to or greater than $200, either negative or positive. Table 4.1 presents the number of contracts conducted during three financial years 2011/12, 2012/13, and 2013/14. As shown in Table 4.1, all together 575 contracts had positive change-orders (indicating cost growths); and the average percentage of the CO among these contracts was 14.34%. On the other hand, 39 contracts had negative change-orders (indicating cost under budget), and the average percentage was -5.64%. The overall average percentage of the CO among all contracts was 13.07%.

Table 4.1. Road Maintenance Contracts having Costs Equal to or Greater than $10,000

Description	Financial Years			Total Count	Change-orders (%)
	2011/12	2012/13	2013/14		
Contracts count with positive change-orders	231	221	123	575	14.34
Contracts count with negative change-orders	19	15	5	39	-5.64
Total number of contracts	253	242	131	614	13.07

Table 4.2 lists the number of contracts categorized based on the contracted cost range and the average percentage of the CO among the contracts. This table showed that the contracts having a cost range from $10,000 to $50,000 were significantly higher in number. In addition, the average percentage of the CO among these contracts was higher than that of the contracts in other cost ranges. These values showed that the number of contracts decreased as the contract amount increased. These values also indicated that as the contract cost increased, the CO percent decreased. More to the point, the average CO percent was 15.28% for the contracts having cost the range $10,000 to $50,000 whereas the average CO percent was 8.39% for the contracts costing more than $150,000.

Table 4.2. Average Percentage of Change-orders Based on Cost Ranges

Contract Cost Range (KES in 1,000)	Contract Cost Range	Number of Contracts	Average Change-Order (%)
900 to 4,500	10 to 50	424	15.28
4,500 to 9,000	50 to 100	122	9.38
9,000 to 13,500	100 to 150	45	6.16
Greater than 13,500	Greater than 150	33	8.39

The contracts were grouped based on the work categories (RM, PM, Struc, and Rehab & SI), as shown in Table 4.3. A contract could have either a single road-maintenance activity or multiple road-maintenance activities. Table 4.3 shows that RM was the most frequently performed road maintenance by the KeRRA, followed by Rehab & SI. The contracts with the positive CO were comparatively higher in number than the contracts with the negative CO. PM and Struc had no contracts that had the negative CO.

Table 4.3. Number of Contracts Based on Work Categories

Contract count \ Work category	RM	PM	Rehab. & SI	Struc
Contracts with negative change-orders	34	0	5	0
Contracts with positive change-orders	405	30	133	7
Total contract count	439	30	138	7
Percentages distribution by the count	71.50%	4.89%	22.48%	1.14%

Figure 4.1 gives an overall idea of how the contracts were distributed during the three consecutive financial years: 2011/12, 2012/13, and 2013/2014. RM had 71.50% of the contracts, Rehab and SI had 22.48%. However, the number of contracts for PM and Struc appeared negligible; PM had only 4.89% and Struc had 1.14%.

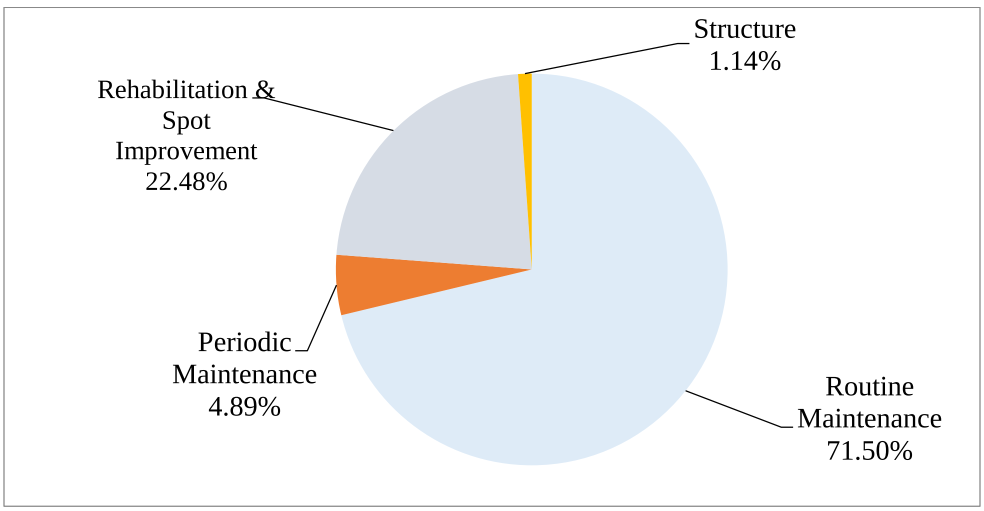


Figure 4.1 Distribution of Contracts based on work categories.

The contracts were also categorized based on the different type of road surfaces, such as earthen, gravel, paved surface, and mixed surfaces (for a road having earthen, gravel, and paved surfaces). Most of the maintenance projects were contracted for the earthen roads as indicated in Table 4.4. The second most commonly contracted projects were for gravel surface roads, followed by mixed surface roads. The maintenance contracts for the paved road were very few. Table 4.4 presents the respective percentages of the contracts.

Table 4.4. Grouping of Contracts Based on Road Surface Types

Contract Count \ Road Surface Type	Earthen	Gravel	Paved	Mixed
Contracts with negative change-orders	28	10	0	1
Contracts with positive change-orders	277	154	20	124
Total contract count	305	164	20	125
Percentage	49.67%	26.71%	3.26%	20.36%

Figure 4.2 shows the percentage distribution of contracts for different type of road surfaces. In this figure, 49.67% of the projects were contracted for earthen roads, followed by 26.71% for gravel roads, and mixed-surface roads for 20.36%. Other contracts were for paved roads that was just 3.26% of the total number of contracts.

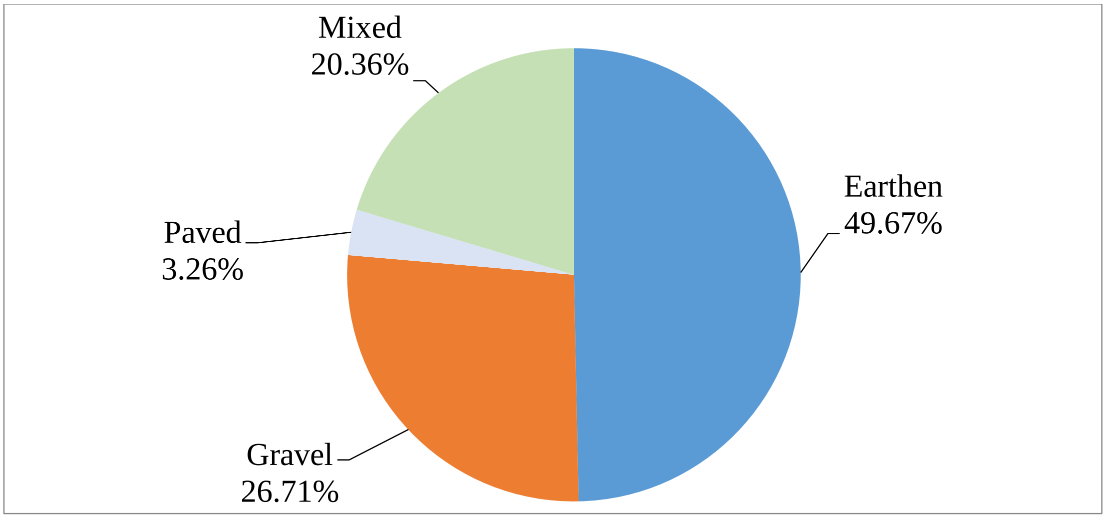


Figure 4.2 Distribution of contracts based on the road surface types.

In this study, the data analysis showed that the CO percentages varied in these projects with variation in their spatial locations. This result indicated that the CO value was also affected by the spatial location of the project. Hence, if a contingency had to be predicted based on the CO, the location of the project should also be considered.

A descriptive analysis was conducted to identify the most frequent road maintenance activities that were subjected to CO. These activities are presented in Table 4.5. ‘Gravel patching’ was highly affected by the CO, followed by ‘heavy grading without watering’ and ‘provide gravel wearing course’. ‘Culvert installation 600 mm with surrounds’ was fourth most frequently affected by the CO. Additionally, Table 4.5 shows the average percentages of the CO for road maintenance activities.

Table 4.5. The Top Road Maintenance Activities that have Most Frequent Change-orders

Activity Code	Activity Description	Unit	Contract Count	Average Change-Order (%)
10-60-003	Gravel patching	M^3	115	17.88
10-50-001	Heavy grading without watering or compaction as instructed by the engineer (Heavy grading)	M^2	76	11.54
10-60-001	Provide gravel wearing course-excavation, free haul, spread, water, and compact gravel to specifications. (Provide gravel wearing coarse)	M^3	68	19.36
08-60-025	Culvert installation 600 mm with surround (600 mm culvert installation)	M	58	27.32
04-50-003	Heavy bush clearing	M^2	38	12.27
10-50-003	Light grading as instructed by the engineer (Light grading)	M^2	28	20.28
08-50-005	Drain (ditch/ mitre drain / catch water) excavation	M^3	17	13.24
08-60-027	Culvert installation 900 mm with surround	M	14	17.73
04-50-004	Light bush clearing	M^2	13	20.38

Figure 4.3 presents the CO percentages versus the frequency of the CO. The activities to right of the average number of contracts were high-frequency activities, and the activities above the average percentages were high-risk activities. Hence, ‘600 mm Culvert installation’ and ‘Provide gravel wearing course’ were the top two high risk and high frequent maintenance activities. ‘Gravel patching’ was the most frequent maintenance activity.

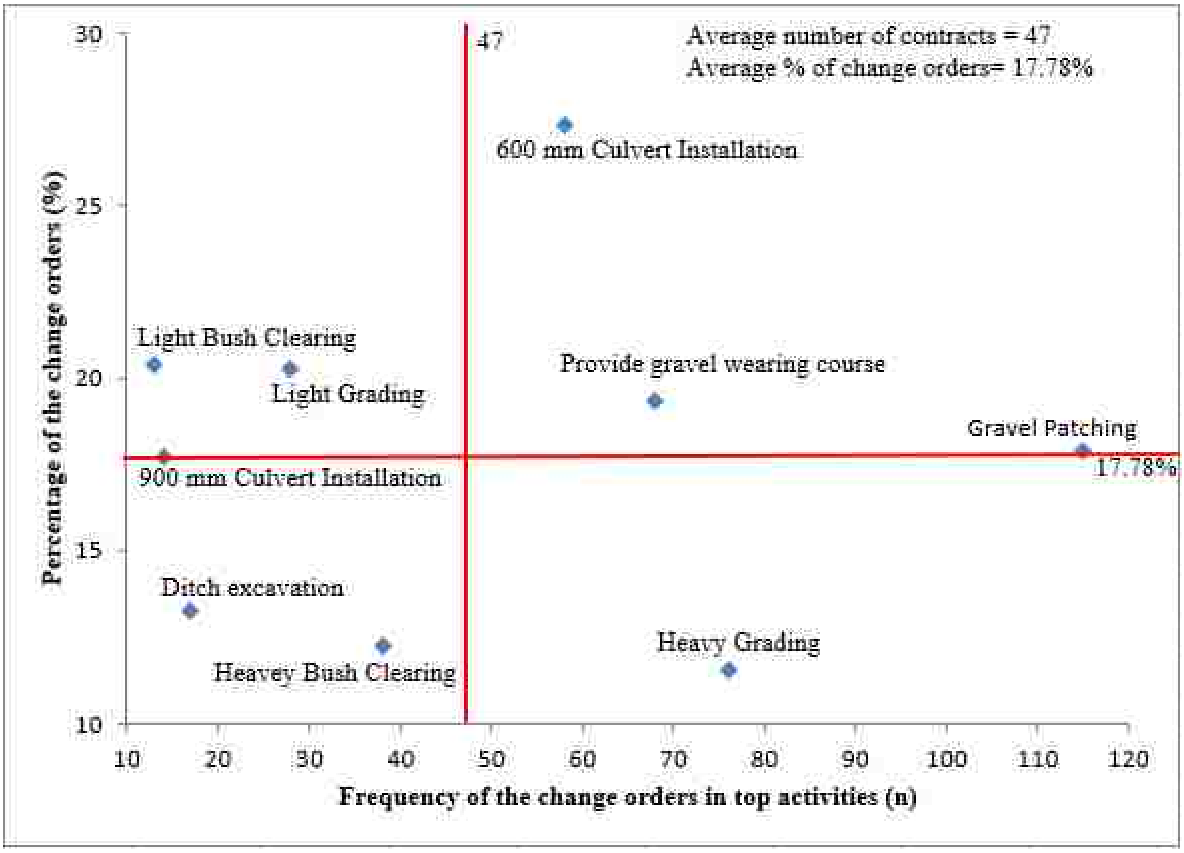


Figure 4.3 Change Orders percentages versus the frequency maintenance activities.

To compare the CO percentages between maintenance activities, the data was tested against several criteria to determine an appropriate statistical method. The Shapiro-Wilk normality test indicated that the CO percentages for these frequent maintenance activities were not normally distributed. Additionally, the dataset was found to be from random and independent sources. The Bartlett test of homogeneity of variances was performed to compare the variances of the data among different activities. A p-value less than 0.05 was obtained suggesting that the variances for the CO on these activities were significantly different from each other. The R-software was used to conduct these tests. The non-parametric data comparison test was chosen to compare the CO percentages on these activities.

The non-parametric Kruskal-Wallis test – which does not require checking the normal distribution of the dataset – was performed to compare the CO percentages. Before performing this test, following requirements should be checked:

- The dependent variable should be interval or ratio data.
- The independent variable should consist of two or more independent groups.
- The data should be from independent observations, and
- The distributions of data groups should be of similar patterns.

The test result indicated that the data satisfied these requirements.

In this study, an alternative hypothesis was set for the Kruskal-Wallis test. This hypothesis contemplated that the median CO percentages in road maintenance activities were significantly different from each other. On the other hand, the null hypothesis was set to test that the median CO percentages of road maintenance activities were not significantly different to each other. The p-value obtained from the Kruskal-Wallis test was less than 0.05 indicating that at least one pair of the road maintenance activities had the CO, which were not identical. Hence, the post-hoc test for the Kruskal-Wallis test was executed. Table 4.6 presents the results of that test on the road maintenance activities with maintenance frequencies higher than 30. The test results reflected that the most of the median CO of maintenance activities were not significantly different to each other. However, the median value of the CO percentages in activity '600 mm culvert installation' was significantly higher and different than that of the activities 'Heavy grading' and 'Heavy bush clearing.' The reason behind the difference could be: unpredictable site conditions and requiring extra works for culvert installation. Because, before the culvert installation, some protection works may be required and that could change during the construction.

Table 4.6. Results of the Post-hoc Test for the Change-Orders of Maintenance Activities

S.N.	Road Maintenance Activities	No. of samples	Median Change-orders (%)	p-value
1	Gravel patching	115	17.38	0.99
	Provide gravel wearing course	68	13.12	
2	Gravel patching	115	17.38	0.16
	Heavy grading	76	8.79	
3	Gravel patching	115	17.38	0.08
	600 mm culvert installation	58	26.57	
4	Gravel patching	115	17.38	0.25
	Heavy bush clearing	38	6.88	
5	Provide gravel wearing course	68	13.12	0.12
	Heavy grading	76	8.79	
6	Provide gravel wearing course	68	13.12	0.29
	600 mm culvert installation	58	26.57	
7	Provide gravel wearing course	68	13.12	0.18
	Heavy bush clearing	38	6.88	
8	Heavy grading	76	8.79	**<0.01****
	600 mm culvert installation	58	26.57	
9	Heavy grading	76	8.79	0.99
	Heavy bush clearing	38	6.88	
10	600 mm culvert installation	58	26.57	**<0.01****
	Heavy bush clearing	38	6.88	

Note: * Significant at alpha level 0.05
** Significant at alpha level 0.01

4.2. Causes of Change Orders in Road Maintenance Contracts

Based on the information obtained in the data analysis, some regional engineers in Kenya were asked to identify the causes of the change orders in road maintenance activities. They were of the opinion that the unforeseen conditions, the inclement weather, awarding contracts to the lowest bidder, and quantity under-estimation were the main causes of CO. With reference to their feedbacks and the literature reviews, the Delphi study was designed to explore causes of the change orders in the road maintenance contracts in the US.

Though, a lot of effort was put to request participation of the maintenance engineers in this study, some state DOTs maintenance engineers did not respond to the emails and the phone calls. Few state DOT representatives declined to participate in this study. Some DOT engineers such as from Kansas, Minnesota, Nevada, New Hampshire, New York, Oregon, Pennsylvania, and Washington State reported that there was no documentations on change orders in their states for maintenance contracts. Most of them mentioned that all the maintenance works were performed through their own state forces and all kinds of changes handled through their in-house maintenance crews without issuing any kind of change orders. Some maintenance engineers responded that they had unit-price contracts. If any kind of changes occurred, that would be for quantity variations or overruns that were addressed by paying an extra costs for the additional work quantities performed.

The phone-interviews were conducted from June 01 through Aug 15, 2015. The questionnaire used for phone interviews is shown in Appendix A. During the two and half-month period, altogether, 29 phone interviews were successfully conducted. The phone interviews were conducted with the maintenance engineers from the following state DOTs: Alabama, Arkansas, Arizona, California, Delaware, District of Columbia, Florida, Georgia, Illinois, Iowa, Maryland, Mississippi, Missouri, Montana, New-Jersey, New-Mexico, North-Carolina, Ohio, Utah, Vermont, Virginia, Wisconsin, and Wyoming. Some maintenance engineers from the DOTs such as Colorado, Kentucky, Maine, and Idaho sent their responses through the emails. The spatial distribution of survey participants is presented in Figure 4.4. They provided many reasons and control measures for the CO in road maintenance activities. A summary of the responses received are given in Appendix C.

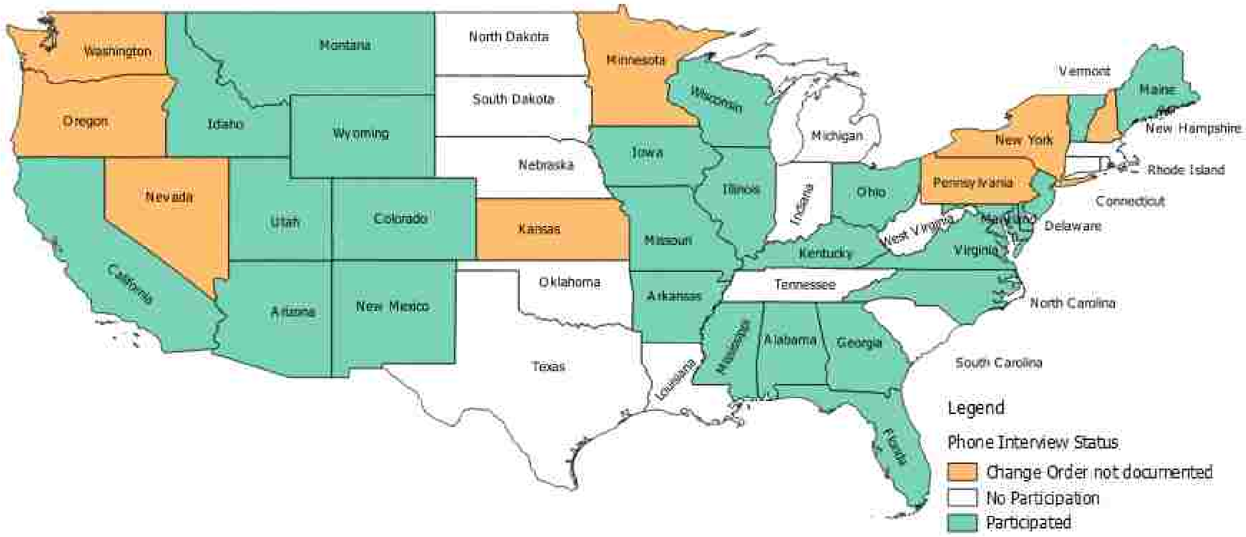


Figure 4.4 The spatial distribution of the survey participants.

Based on the unique causes of the CO and their preventive measures for each activity, received through the first round survey, a questionnaire was prepared in the Qualtrics for the second round survey. The questionnaire used in the second round survey is provided in Appendix D. The second round survey was distributed to all the responders participated in the first round survey. The survey was sent to the participants on October 30, 2015 and was closed on December 24, 2015. Participants were asked to rate the causes and the preventive measures of the CO drawing from their experience with activities in the question. After gathering the rating data, the reliability of data was tested using the ICC method proposed by Shrout and Fleiss in 1979. To determine the top critical causes and preventive measures of CO, the RII method was used.

4.2.1 Intra-class Correlation Coefficient (ICC) Analysis

Hallgren (2012) stated that higher ICC value indicates greater inter-rater reliability (IRR). If the value of the ICC is '1,' then there is perfect agreement between the raters; if value zero, then there is no agreement at all or agreement is by chance. Hence, the higher ICC value means the better and reliable survey data. Cicchetti (1994) referring his co-authored previous publication provided four common categories of the ICC values. According to that publication, the reliability of data is: 'poor'– if the value of the coefficient is in-between 0 to 0.4; 'fair' – if in-between 0.4 and 0.59; 'good' – if in-between 0.6 to 0.74; and excellent – if in-between 0.75 to 1.0. Similarly, according to Graham et al. (2012), even though the desirable value of ICC ranges in-between 0.8 to 0.9, for research purposes, the ICC value above 0.7 is sufficient or acceptable. Therefore, in this study, all survey data having ICC value greater than 0.7 are counted reliable.

In order to determine the inter-rater reliability, the ICC analysis proposed by Shrout and Fleiss in 1979 and implemented by the R-package, 'psych,' was used. The reliability of the survey data was analyzed using following methods: a) two-way ANOVA model because of the multiple raters randomly selected from the population of maintenance engineers in state DOTs, b) the absolute agreement rather than consistency because the Likert scale was used based on importance ratings from 1 to 5, and c) quantification of the reliability based on the average rating value because raters were random experts rating the same number of items. Therefore, among the six ICC values obtained from the analysis, the ICC value for the average random raters (ICC2k) was taken into account for the agreement between the raters.

Out of 33 participants from the first round survey, 31 participants provided the ratings for the causes and preventive measures of CO. Most of the participants filled out the survey completely, however, some participants did only partially. Because of that reason, some questions were answered by 29 participants and some questions only by 26 participants. The summary of the ICC analysis performed in the R-program is presented in Table 4.7 as given below. The confidence level used for the analysis was 95% (i.e. level of significance was 0.05). Hence, the ICC values – obtained from the analysis for about 95% of sample cases – would be within the given confidence intervals in Table 4.7. The details of the analysis along with the R-script file is provided in Appendix E.

Table 4.7 indicated that there were impressive agreements between the ratings provided by the participants. Out of 10 question groups on the CO, nine groups received 'excellent' agreement on the ratings. Only one question group received 'good' agreement. Since, the threshold value set for the ICC coefficient in this study was 0.7, all survey data were considered acceptable and reliable. Even though the item 'Causes of CO on the Chip-Seal' had the ICC value of 0.63 indicating good agreement by the raters, it was considered satisfactory.

Table 4.7. Intra-class Correlation Coefficient (ICC) Analysis

SN	Question groups on CO	Number of experts	ICC			95 % Confidence Interval of ICC	
			value	Status	p-Value	Lower bound	Upper bound
1	Causes of the Change Order on the Chip Seal	26	0.63	Good	<0.001	0.35	0.84
2	Preventive measures to reduce the Change Order on the Chip Seal	26	0.88	Excellent	<0.001	0.75	0.96
3	Causes of the Change Order on the Paint Striping	29	0.75	Excellent	<0.001	0.55	0.91
4	Preventive measures to reduce the Change Order on the Paint Striping	29	0.82	Excellent	<0.001	0.65	0.94
5	Causes of the Change Order on the Asphalt Overlay	29	0.75	Excellent	<0.001	0.53	0.91
6	Preventive measures to reduce the Change Order on the Asphalt Overlay	29	0.86	Excellent	<0.001	0.73	0.95
7	Causes of the Change Order on the Slope Repair	26	0.84	Excellent	<0.001	0.66	0.95
8	Preventive measures to reduce the Change Order on the Slope Repair	26	0.83	Excellent	<0.001	0.69	0.93
9	Causes of the Change Order on the Remove Debris	26	0.85	Excellent	<0.001	0.66	0.97
10	Preventive measures to reduce the Change Order on the Remove Debris	26	0.83	Excellent	<0.001	0.62	0.96

For ranking purposes, the ratings obtained from participants were analyzed by using the RII method as described in the methodology section. The causes and preventive measures of CO on five maintenance activities were analyzed separately in following sections.

4.2.2 The Causes of CO on Chip-Seal

The number of those participants who provided responses to the question about the causes of CO on chip-seal was 26 participants. The outcome of the RII analysis for this question was that the top five causes were: 'change in length of road sections (addition or deletion),' 'change in materials' specifications,' 'error in estimate due to lack of site verification,' 'calculation error in estimates,' and 'error in estimating quantity of oil and chips.' However, the reason 'awarding the contract to the lowest bidder' was at the lowest rank among all other reasons. It put forth the idea that awarding to the lowest bidder is not main cause that generates the CO. The ranks received by the causes of CO on chip-seal is listed in Table 4.8.

Table 4.8. The Ranking of Causes of CO on Chip-Seal

SN	Causes of Change Orders on Chip-Seal	Relative Importance Index (RII)	Ranks
1	Change in length of road sections (addition or deletion)	0.88	1
2	Change in materials' specifications	0.83	2
3	Error in estimate due to lack of site verification	0.82	3
4	Calculation error in estimates	0.81	4
5	Error in estimating quantity of oil and chips	0.81	4
6	Incorrect estimate of oil application rate	0.79	6
7	Change in traffic management plan	0.78	7
8	Additional traffic control measures required than stated in a contract	0.77	8
9	Unforeseen site conditions	0.77	8
10	Road section not ready for chip seal	0.76	10
11	Delay in the contract awarding	0.75	11
12	Material cost escalation	0.74	12
13	Different equipment required than stated in the contract	0.71	13
14	Adverse weather condition	0.70	14
15	Awarding the contract to the lowest bidder	0.60	15

4.2.3 The Preventive Measures of CO on Chip-Seal

Based on the rating data provided by 26 participants, the RII value was computed for the preventive measures to reduce CO on chip-seal maintenance activity. The result as presented in Table 4.9 showed that the top five preventive measures were: 'define scope of work correctly,' 'prepare accurate estimates,' 'design chip seal correctly,' 'review the specification before bid solicitation,' and 'prepare road sections for chip-seal before the contract.' The ranks received by different preventive measures are presented in Table 4.9. The results indicated that estimating and defining the work scope correctly helps to reduce CO on chip-seal maintenance activity.

Table 4.9. The Ranking of Preventive Measures of CO on Chip-Seal

SN	Preventive Measures to reduce CO on Chip-Seal	Relative Importance Index (RII)	Ranks
1	Define scope of work correctly	0.98	1
2	Prepare accurate estimates	0.92	2
3	Design chip seal correctly	0.91	3
4	Review the specifications before bid solicitation	0.89	4
5	Prepare road sections for chip seal before the contract	0.83	5
6	Ensure that the contractor is aware of materials' specification	0.81	6
7	Perform contract with the contractor regarding oil grade and its application	0.78	7
8	Approve contractors' work method before starting chip seal	0.76	8
9	Allocate contingency for unforeseen site conditions	0.75	9
10	Plan and prepare up-to-date schedules	0.68	10
11	Revisit the road section before signing the contract	0.65	11

4.2.4 The Causes of CO on Striping

The causes of CO on striping accumulated through the survey were rated by 29 participants. The ranks assigned to the causes are presented in Table 4.10. The top five causes were: 'error in quantity estimate of paint striping,' 'calculation error in estimate,' 'changes in length of road sections (addition or deletion),' 'error in estimating temporary striping,' and 'changes in materials' specification.' The rankings for these causes provided the evidence that the error in calculation and estimates were the main reason of the CO in striping maintenance activities. Hence, an estimate should be prepared very carefully.

Table 4.10. The Ranking of Causes of CO on Striping

SN	Causes of CO on Striping	Relative Importance Index (RII)	Ranks
1	Error in quantity estimate of paint striping	0.87	1
2	Calculation error in estimate	0.86	2
3	Change in length of road sections (addition or deletion)	0.84	3
4	Error in estimating temporary striping	0.81	4
5	Change in materials' specification	0.79	5
6	Change in traffic management plan	0.75	6
7	Additional traffic control measures required than stated in a contract	0.74	7
8	Timing of paint striping (peak traffic vs. off-peak traffic)	0.74	7
9	Unavailability of materials	0.72	9
10	Unforeseen site conditions	0.70	10
11	Adverse weather condition	0.68	11
12	Rework of paint striping because of time gaps	0.66	12
13	Different equipment required than stated in the contract	0.65	13

4.2.5 The Preventive Measures of CO on Striping

In response to the question about the ratings of the preventative measures in lessening CO on striping, 29 participants sent their answers. Based on the ratings received for the question, the ranks assigned to each preventive measure are presented on Table 4.11. The top five preventive measures were: ‘define scope of work correctly,’ ‘prepare accurate estimates,’ ‘review the design drawing properly,’ ‘measure the work done with the contractor,’ and ‘ensure the contractor is aware of materials’ specification.’ The table turned to the result that defining the work scope and preparing accurate estimate were the most important issues to be considered in order to reduce CO on striping maintenance work.

Table 4.11. The Ranking of Preventive Measures of CO on Striping

SN	Preventive Measures of CO on Striping	Relative Importance Index (RII)	Ranks
1	Define scope of work correctly	0.93	1
2	Prepare accurate estimates	0.90	2
3	Review the design drawing properly	0.83	3
4	Measure the work done with the contractor	0.83	3
5	Ensure that the contractor is aware of materials’ specification	0.81	5
6	Check the weather before performing striping	0.80	6
7	State in the contact what to do during inclement weather	0.77	7
8	Prepare traffic control plan	0.73	8
9	Plan for possible additional work	0.71	9
10	Mention equipment requirement in the contract	0.66	10
11	Revisit the road section before signing the contract	0.66	10

4.2.6 The Causes of CO on Asphalt Overlay

Out of 31 participants, 29 participants responded to the question on rating the causes of CO on asphalt overlay. After performing the RII analysis, the rankings received by individual causes are presented in Table 4.12. The top five causes of the CO on asphalt overlay were: 'encountered more deterioration than at the time of contract,' 'inaccurate planning during contract procurement due to poor site condition survey,' 'changes in the patching plan after the milling work is done,' 'error in quantity estimate of milling works,' and 'change in materials' specification.' Therefore, some preparations such as site verification of the plan and cross-checking the estimate against current site condition before assigning a contract could help reduce the possible CO on asphalt overlay.

Table 4.12. The Ranking of Causes of CO on Asphalt Overlay

SN	Causes of CO on Asphalt Overlay	Relative Importance Index (RII)	Ranks
1	Encountered more deterioration than at the time of contract	0.88	1
2	Inaccurate planning during contract procurement due to poor site condition survey	0.85	2
3	Changes in the patching plan after the milling work is done	0.83	3
4	Error in quantity estimate of milling works	0.81	4
5	Change in materials' specification	0.75	5
6	Material cost escalation	0.74	6
7	Change in mix design	0.72	7
8	Change in traffic management plan	0.71	8
9	Additional traffic control measures required than mentioned in a contract	0.70	9
10	Unavailability of materials	0.66	10
11	Adverse weather condition	0.61	11

4.2.7 The Preventive Measures of CO on Asphalt-Overlay

The preventive measures to reduce CO on asphalt overlay were rated by 29 participants. Based on the RII analysis, the ranks assigned to each preventive measure are presented in Table 4.13. The top five important preventive measures to reduce the CO on asphalt overlay were: 'estimate surface area accurately,' 'measure the work done with the contractor,' 'provide sufficient contract duration,' 'spend enough time during planning phase,' and 'conduct the meeting with contractor before the work.' Referring to the table, the best strategy to avoid or reduce the CO on asphalt overlay was to plan and estimate the work accurately assuring the duration of the work was enough to achieve it.

Table 4.13. The Ranking of Preventive Measures of CO on Asphalt Overlay

SN	Preventive Measures of CO on Asphalt Overlay	Relative Importance Index (RII)	Ranks
1	Estimate surface area accurately	0.93	1
2	Measure the work done with the contractor	0.86	2
3	Provide sufficient contract duration	0.85	3
4	Spend enough time during planning phase	0.83	4
5	Conduct the meeting with the contractor before asphalt overlay	0.82	5
6	Ensure that the contractor is aware of materials' specification	0.81	6
7	Use better estimating tools	0.77	7
8	Ensure that the materials are available in the market	0.74	8
9	Set incentive and disincentive for contract modifications	0.74	8
10	Provide sufficient contingency costs	0.71	10
11	Revisit the road section before signing the contract	0.66	11
12	Plan for possible additional weather delays	0.64	12
13	Solicit the bid only in summer	0.59	13

4.2.8 The Causes of CO on Slope Repairs

All together 26 participants filled out the survey for rating of the causes of CO on slope repairs. Results of the RII analysis are presented in Table 4.14. The top five causes of the CO on slope repairs were: 'extent of slope failure is different than that mentioned in the contract,' 'error in quantity estimate of drainage and shoulder work,' 'encountered more deterioration than at the time of contract,' 'new damages detected where the initial work order had been done,' and 'inaccurate planning during contract procurement due to the poor site condition survey.' These issues indicated that unpredictable site conditions were the main reasons behind the CO on slope repairs.

Table 4.14. The Ranking of Causes of CO on Slope Repairs

SN	Causes of CO on Slope Repairs	Relative Importance Index (RII)	Ranks
1	Extent of slope failure is different than that mentioned in the contract	0.92	1
2	Error in quantity estimate of drainage and shoulder work	0.89	2
3	Encountered more deterioration than at the time of contract	0.88	3
4	New damages detected where the initial work order had been done	0.85	4
5	Inaccurate planning during contract procurement due to poor site condition survey	0.83	5
6	Unforeseen site conditions such as wet lands, storm water effects	0.80	6
7	Bid solicitation without obtaining wetland storm water permit	0.78	7
8	Adverse weather condition	0.66	8
9	Different equipment required than mentioned in the contract	0.65	9

4.2.9 The Preventive Measures of CO on Slope Repairs

Altogether, 26 participants responded to the question asked on rating of the preventive measures of CO on slope repairs. Based on the RII analysis of the ratings, results are presented in Table 4.15. The top five preventive measures of the CO on slope repairs were: ‘visit the site before designing,’ ‘define scope of work correctly,’ ‘conduct geo-technical investigation before designing,’ ‘define the acceptable slope treatments,’ and ‘spend enough time during the planning phase.’ These preventive measures indicated that the work site should be judged accurately. In addition, work planning time should be sufficient so that the scope of the work could be estimated correctly.

Table 4.15. The Ranking of Preventive Measures of CO on Slope Repairs

SN	Preventive Measures of CO on Slope Repairs	Relative Importance Index (RII)	Ranks
1	Visit the site before designing	0.93	1
2	Define scope of work correctly	0.91	2
3	Conduct geo-technical investigation before designing	0.87	3
4	Define the acceptable slope treatments	0.86	4
5	Spend enough time during the planning phase	0.85	5
6	Review the design drawing properly	0.83	6
7	Obtain the required permits before the contract	0.83	6
8	Prepare the estimate with the help of experience person	0.79	8
9	Use better estimating tools	0.76	9
10	Identify the temporary construction required to fix the slope	0.76	9
11	Provide sufficient contingency costs	0.75	11
12	Obtain accurate meteorological data	0.70	12
13	Mention equipment requirement in the contract	0.62	13
14	Use performance-based contract rather than lump-sum	0.62	14

4.2.10 The Causes of CO on Debris Removal

Based on the responses from 26 survey participants for the causes of CO on debris removal, a ranking analysis was performed using the RII method. Results of the analysis are presented in Table 4.16. The top five causes of CO on debris removal were: 'encountered hazardous materials,' 'error on quantity estimate,' 'new safety requirement,' 'unforeseen site conditions,' and 'inappropriate hauling method chosen.' The causes of the CO on debris removal, listed in the table, figures out for the requirement of a proper pre-planning before signing a contract.

Table 4.16. The Ranking of Causes of CO on debris removal

SN	Causes of CO on Debris Removal	Relative Importance Index (RII)	Ranks
1	Encountered hazardous materials	0.88	1
2	Error on quantity estimate	0.83	2
3	New safety requirements	0.75	3
4	Unforeseen site conditions	0.74	4
5	Inappropriate hauling method chosen	0.73	5
6	Different equipment required than mentioned in the contract	0.68	6
7	Adverse weather condition	0.59	7

4.2.11 The Preventive Measures of CO on Debris Removal

Table 4.17 shows the ranks received by the preventive measures to reduce or avoid CO on debris removal. The number of responses for this question was also 26 responses. The RII analysis was performed to find the ranks of these measures. The top five preventive measures were: 'define scope of work correctly,' 'prepare better estimate,' 'planning and estimating with the help of experience person,' 'provide sufficient contingency costs,' and 'plan for possible additional work.' These listing indicated that the work plan should be prepared accurately and better estimated. If these measures could be adopted during the planning phase, there would be less CO on debris removal activity.

Table 4.17. The Ranking of Preventive Measures of CO on Debris Removal

SN	Preventive Measures of CO on Debris Removal	Relative Importance Index (RII %)	Ranks
1	Define scope of work correctly	0.89	1
2	Prepare better estimate	0.83	2
3	Planning and estimating with the help of experience person	0.81	3
4	Provide sufficient contingency costs	0.73	4
5	Plan for possible additional work	0.70	5
6	Revisit the road section before signing the contract	0.67	6
7	Use performance-based contract rather than lump-sum	0.62	7

4.3. A Contingency Estimator

All the interfaces required for developing a contingency estimator were designed with the Microsoft Visual Studio Professional 2012 environment (version 11.0.50727.1 RTMREL © 2012 Microsoft Corporation). All of the required methods were coded in Visual C# platform. For data storage and retrieval processes, a database was designed using Microsoft Access program. The details of the database are presented in the next section.

In this study, the predictor parameters adopted for the contingency prediction were: the road condition, road surface type, weather condition, site accessibility, work category, region-name, and the contract award cost. Based on the value of these predictor parameters, a proper prediction method, as described in the methodology section, is used to determine the contingency for the activity. However, if the historical data is not readily available for a road maintenance activity, the tool will simply yield a zero value instead of a predicted value. Iteratively, all the activities are assigned respective contingencies based on the prediction process. For flexibility, an appropriate contingency should be provided based on the predicted value for each activity. Finally, based on the weight assigned to the cost of each road maintenance activity, this tool computes the overall contingency for the contract.

The tool developed in this study, is potential enough to display the neural network model and to generate an R-script file having all R-commands executed during the analysis. Similarly, if the LRM is used, another script file containing all iterative processes executed in the R-program for each of the activities is also generated. For the linear regression model, the final output for the regression models is also presented.

4.3.1 Database System for the Contingency Estimator

The database system provides all kinds of required data management features such as insert, delete, update, and read options. The database system also provides useful aggregate functions such as ‘sum,’ ‘count,’ and ‘average.’ For the contingency estimation tool, the Microsoft Access database system was used. The database system was designed with many tables as shown in Figure 4.5 that illustrates the relationship between the tables. These relationships hold the necessary control over the data duplication problem and prevents saving redundant data. Once the database was ready, all the existing dataset received for 614 contracts was imported to the database.

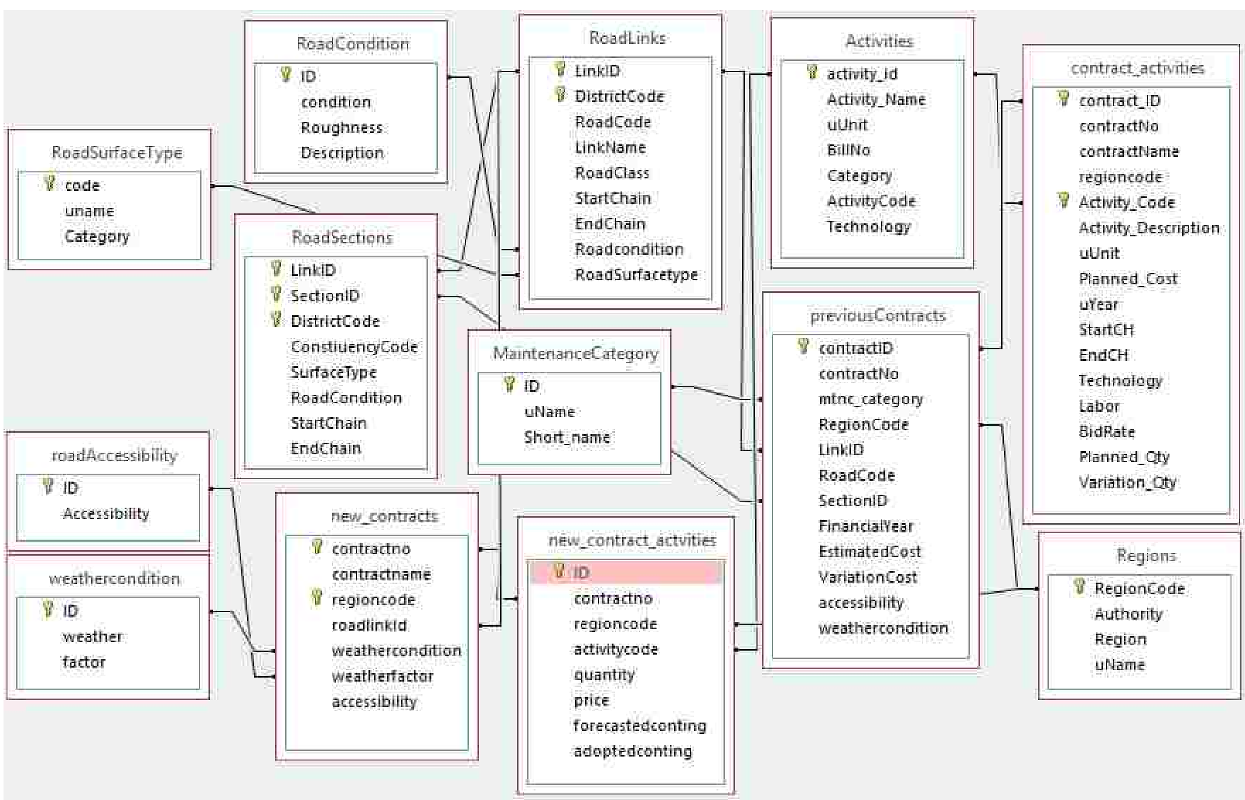


Figure 4.5 The relationship diagram of the database used for the contingency estimation tool.

The database was designed in such a way that all historical data on change orders of the existing contracts and the new contracts prepared are stored in the same file. All activities that are packaged under a contract are saved in the same database so that these records could be traced at any moment necessary. This way, the database system helps store and retrieve historic data as well as newly saved data on maintenance contracts. The primary keys set for each table and the relationships between the tables maintain the associations between these tables. The keys and relationships between the tables organize data and provide a way to query data systematically.

4.3.2 Test results of the Artificial Neural Network

In this study, the R-Program generates separate ANN model for each of the activities under the prediction process. The training and test dataset used for the ANN was obtained by querying the database prepared for the quantification of CO. As the ANN model generation process in this study is a dynamic process and the 'neuralnet' does not require any validation dataset, all data obtained from query were used to train the ANN model. However, in order to check the correctness of the model, the static ANN models were prepared and the testing process was performed to validate the prediction process.

The ANN models were generated using approximately 90% data and then verified against the remaining data, considering them as the test dataset. The result of the testing is presented in Table 4.18. This table presents the average CO% of the test dataset and respective average CO% of predicted values in different maintenance activities. The positive percentage difference indicated the underestimating of the contingency cost for the activity and the negative percentage difference pointed the overestimating of the contingency cost through the ANN model. However, the difference between the predicted and real contingency cost percentage for the maintenance activities was less than 20%. Hence, the errors in the prediction process by these ANN models could vary approximately in between +20% underestimating to -20% overestimating.

Table 4.18. Summary of the ANN model testing

Activity Code	Activity Description	Unit	Average Change % for test data	Average Change-Order % Predicted	% diff.
10-60-003	Gravel patching	M^3	5.98	6.98	-16.72
10-50-001	Heavy grading without watering or compaction as instructed by the engineer	M^2	-4.89	-4.08	16.57
10-60-001	Provide gravel wearing course-excavation, free haul, spread, water, and compact gravel to specifications. (Provide gravel	M^3	19.28	17.57	8.90
08-60-025	Culvert installation 600 mm with surround (600 mm culvert	M	-10.43	-9.9	5.08
04-50-003	Heavy bush clearing	M^2	-7.25	-8.67	-16.10
10-50-003	Light grading as instructed by the engineer (Light grading)	M^2	6.99	8.32	-19.10

4.3.3 How to use the Contingency Estimator

A deployment system was prepared to install this tool in any computer having windows operating system. Once the system is installed, a standalone tool named "CO_UNLV" appears under the "UNLV" menu inside the Window startup menu. The contingency estimator can be launched by running this "CO_UNLV" tool. This tool has two parts: the first part for contingency estimation and the second part for the schedule crashing optimization. This tool has very simple interface as shown in Figure 4.6.

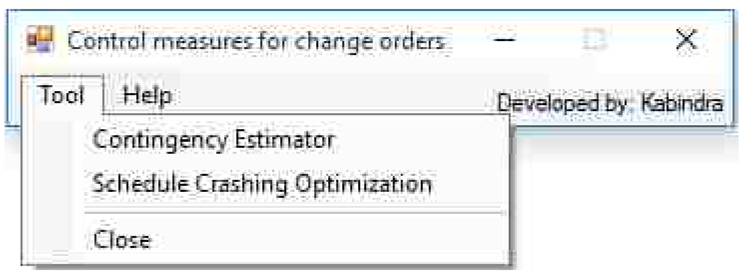


Figure 4.6 A screenshot of the control measure tool for change-orders.

Upon the execution of the command 'Contingency Estimator,' an interface appears as shown in Figure 4.7. The contingency estimator has only one interface where all necessary input data such as contract details and the list of the maintenance activities that have to be packaged under the contract are entered. This contingency estimator tool uses the RDotNet tool, a dynamic linked library (DLL) available for free online, to connect the R-program which is also a free software. Then the R-program handles the ANN and the linear regression models and avoids the burden of writing again the procedures for statistical analysis. In this way, this contingency estimator executes all the statistical methods to prepare the contingency cost estimate for a road maintenance contract.

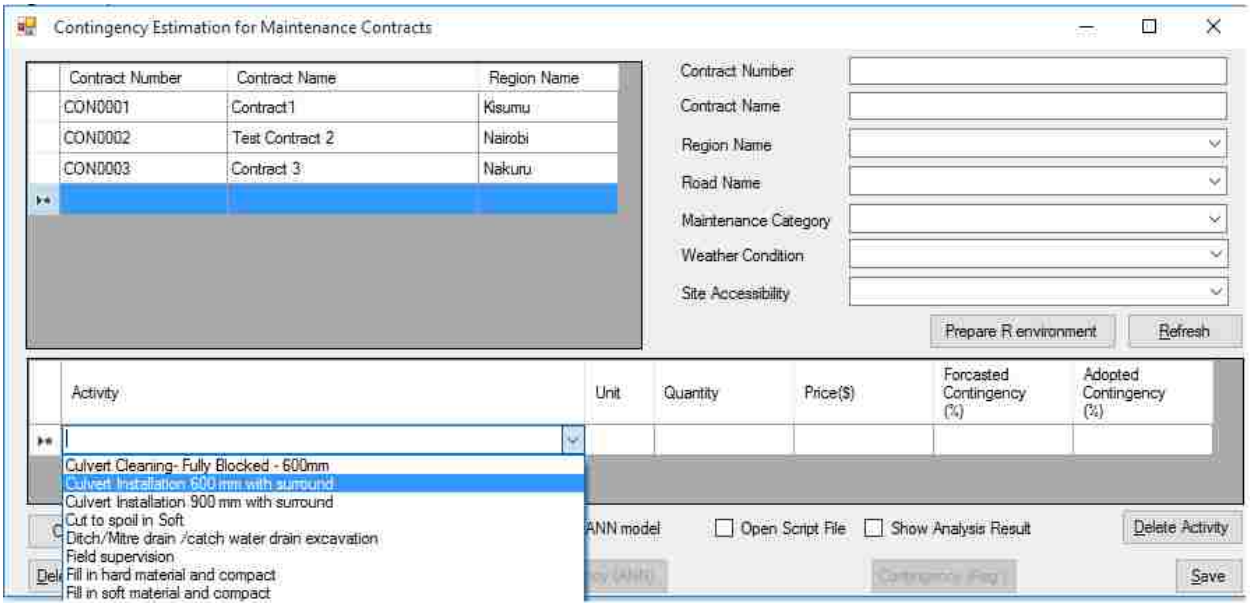


Figure 4.7 The Contingency Estimation Tool.

As shown in Figure 4.7, all necessary parameters should be provided. Some fields are to be typed and some fields entered using the drop box options provided by the system. For example, the data such as the maintenance work category, weather condition, site accessibility, region name, and road names are entered by using the dropdown options. The maintenance category should be selected from the list of items such as RM, PM, Struct., and Rehab. & SI. Then, weather condition could be any one of: 'Favorable,' 'Good,' 'Fair,' 'Bad,' or 'Worst.' The site accessibility could be any one among: 'Easy,' 'Difficult,' 'Very difficult,' or 'Not accessible.'

Similarly, all required road maintenance activities are listed in a table from the list provided by the dropdown option as shown in Figure 4.7. If maintenance activities are not included in the dropdown list, then those activities do not have the historic change order information. To setup a new activity, first of all, the database has to be prepared importing the historic change order information for that particular activity. The activity then appears in the dropdown list automatically. Once, the required maintenance activities are listed in the activity table, the work quantities and unit price for each activity should be provided. After having all required information, the button ‘Prepare R environment’ should be executed. This command prompts for CRAN selection and choose ‘USA (CA 2)’ CRAN as shown in Figure 4.8.

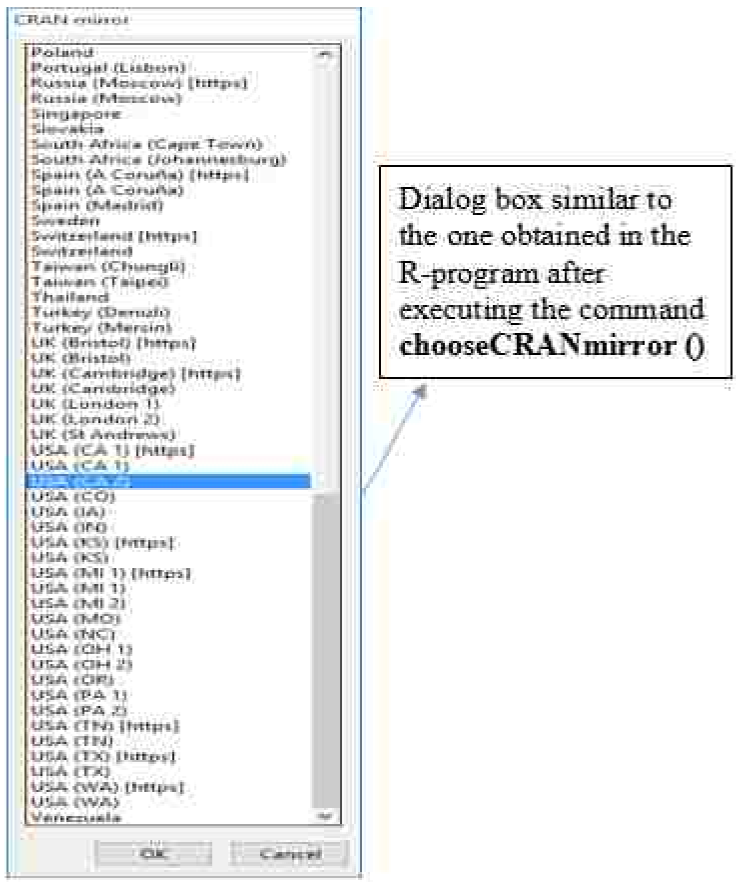


Figure 4.8 The CRAN selection dialogue box.

If everything proceeds successfully, a message reflecting R-program readiness for operation will be displayed as shown in Figure 4.9. This refers the readiness of the tool to execute the statistical methods such as neural networks and regressions. The command to prepare the R environment is one time process. After that, R-commands required by the tool are executed without interruptions.

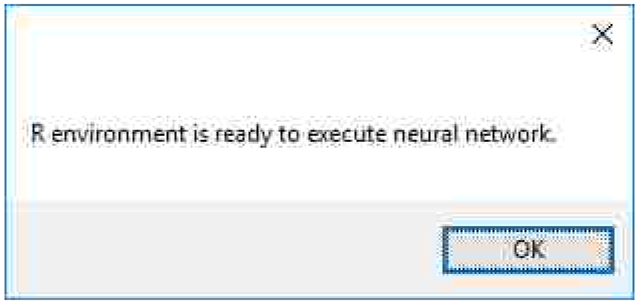


Figure 4.9 The confirmation message indicating the R-program environment ready.

Once, all input data has been provided and the R-program is ready to be executed, the button ‘Contingency (ANN)’ is executed. This command will process all road maintenance activities in the activity table, one at a time. First, the historical data for change orders on the selected activities are retrieved from the database. As explained earlier, if there are enough data points to train a neural network, it will execute the ANN method and predict a contingency for the activity. If not, then based on the number of data points, either linear regression or the average value method is used. Using this command, the first priority was to use the ANN method for the estimation. If the linear regression method is to be used as the first priority, there is another button ‘Contingency (Reg)’ that executes the linear regression analysis directly.

A sample calculation is illustrated in Figure 4.10. The overall contingency is computed based on the cost weighting of each maintenance activity for the contract. The R-program helps forecast the contingency required for each maintenance activity based on the historical CO data. For flexibility in the contingency estimation, this tool allows user to provide an adopted contingency value. Hence, before computing the overall contingency of the contract, the adopted contingency value should be provided from the last column of the activity table. Then, the button

'Overall Cont.' calculates the contingency required for the contract. Figure 4.10 provides details of a sample contingency estimation for a contract.

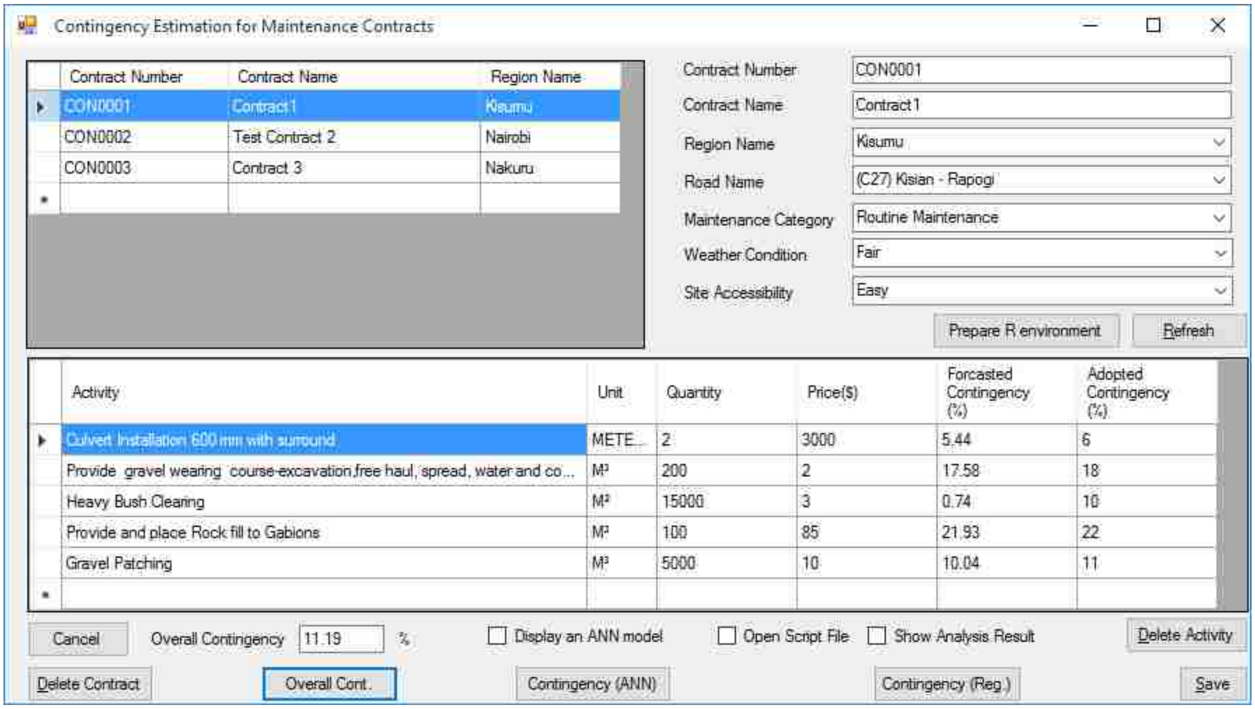


Figure 4.10 A sample contingency estimation for a contract.

There are three optional check boxes in the interface as shown in Figure 4.10. The first left most check box displays the ANN model prepared by the R-program for each maintenance activity if the ANN method is chosen as the computation method. A sample of the ANN model has been already presented in Figure 3.8 in Section 3.4 of the methodology Chapter. The second check box is to show the R-script file that was prepared during the analysis by the R-program. This script file contains all R-commands executed for these maintenance activities for the contingency estimation. The last check box is for displaying the result of linear regression analysis for the activities if any as shown in Figure 4.11. Some functions developed for the tool and a sample R-script file generated by the tool are provided in Appendix-E section.

Culvert Installation 900 mm with surround

Parameters	Coefficients	p-value	Significance
(Intercept)	-30.522	0.079	No
rsurface	5.013	0.032	Yes
cregion	0.775	0.067	No
bidamount	0	0.072	No

Adjusted R-square =0.18

Figure 4.11 A sample regression model generated for the contingency prediction.

Figure 4.11 indicates that out of the seven independent parameters, only three predictors were used for the contingency prediction of the activity in that figure. Though the default significance level was 0.05, for prediction purposes, the significance threshold value was increased to 0.1.

This tool is also equipped with the necessary commands to save and retrieve data from the database. When launched, this tool shows up with a contract list. That is why, at the startup of this tool, it reads contracts already saved in the database and loads to the contract list table. By default, it also displays the attributes of the first contract in the list. The activity table, text boxes, and dropdown boxes are filled with the details of the contract currently selected in the list. In this way, whenever a contract is selected from the contract list table, the contingency estimator tool retrieves details of the contract from the database and fills relevant fields in the interface.

In order to save a contract into database, all details required to prepare the contract should be provided through their respective fields. All maintenance activities should be supplied with unit prices and work quantities. The contingencies are then calculated by executing the R-command to use the ANN method or LRM method. After that the adopted contingency should be provided for each activity. Based on the adopted contingencies and the cost weight of the activity, the overall contingency of the contract should be computed. Finally, the contract data is saved to the database. Once, the contract has been saved to the database, this tool can retrieve the details of the contract anytime when required. If the details of the contract need to be modified, it could be simply edited through the same interface presented in Figure 4.10 and re-saved into the database again. Similarly, to delete a contract, this tool has ‘Delete Contract’ button. Upon executing this command, this tool removes all records related to the selected contract from the database. This type of data deletion is permanent in nature. Once, data are deleted from the database, there is no way to undo it. If only an activity is to be deleted, the button ‘Delete Activity’ should be executed. For undo or backup purposes, a copy of the main database file could be secured with the help of ‘Windows Explorer.’

4.4. A Schedule Crashing Optimization Tool

The schedule crashing optimization tool was designed in the Microsoft Visual C# platform. For optimization purposes, the LINGO DLL file was selected as the initial choice. To use the DLL, a LINGO model was prepared and executed to run the optimization process. However, the Microsoft Solver Foundation (MSF) came up with the same output in a conducive environment for the schedule crashing. Hence, the schedule crashing process was performed with the help of the MSF program.

4.4.1 Database System for the Schedule Crashing Optimization Tool

To store and retrieve data systematically, two database tables were prepared and linked with each other as shown in Figure 4.12. The ‘prj_id’ addresses the uniqueness among the record. Each project is assigned a unique project ID in the table ‘prj_schedules.’ The activity details for each project are then stored in the table “prj_activity_network.’ This activity detail table has two primary keys to allow only unique activities preventing data redundancy. Whenever queries are made against these tables, the primary keys are used to retrieve respective data.

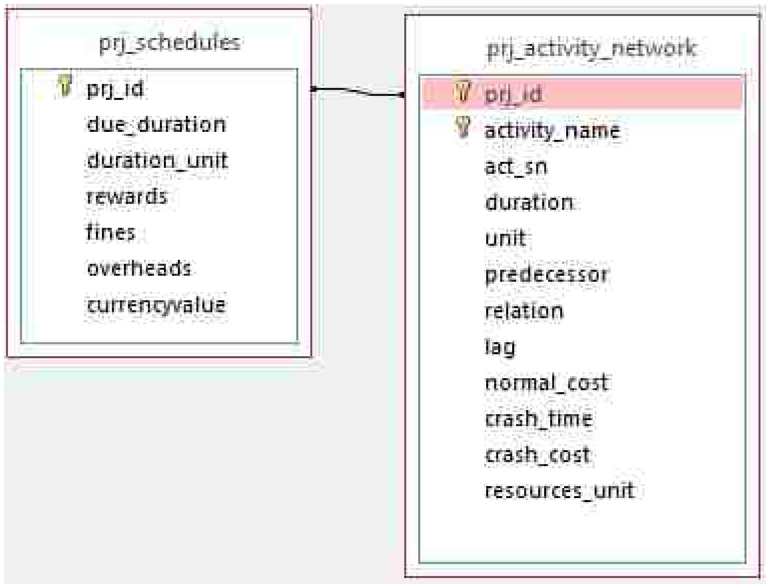
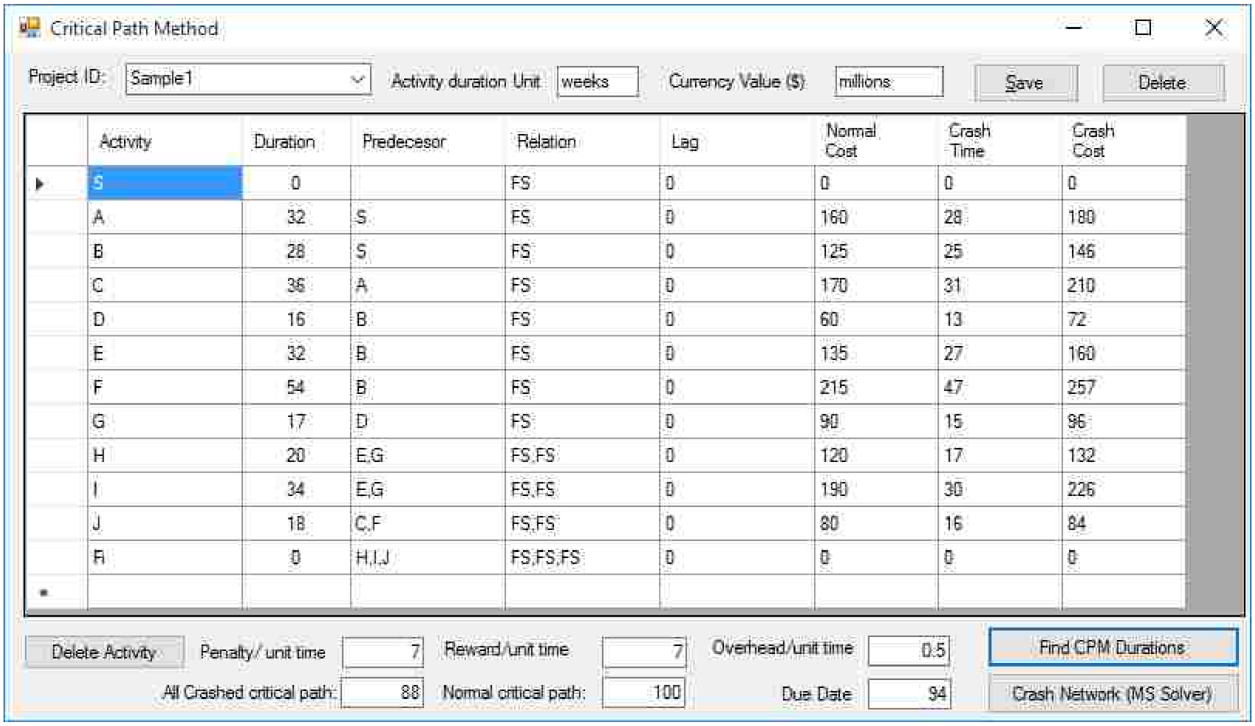


Figure 4.12 The relationship diagram of tables for project activity networks.

4.4.2 How to use the Schedule Crashing Optimization Tool

The schedule crashing optimization tool was designed with an input interface and an output interface. The input interface provides all necessary fields to enter the schedule of a project. An example of an activity network is given in Figure 4.13. The relevant data should be entered into the table to prepare the schedule of a project. Similarly, for crashing purposes, the variable costs such as liquidated damages, rewards, and overheads also should be provided through the respective fields in the input interface. As additional information, the unit of the activity duration and the currency value should be also provided.



Activity	Duration	Predecesor	Relation	Lag	Normal Cost	Crash Time	Crash Cost
S	0		FS	0	0	0	0
A	32	S	FS	0	160	28	180
B	28	S	FS	0	125	25	146
C	36	A	FS	0	170	31	210
D	16	B	FS	0	60	13	72
E	32	B	FS	0	135	27	160
F	54	B	FS	0	215	47	257
G	17	D	FS	0	90	15	96
H	20	E,G	FS,FS	0	120	17	132
I	34	E,G	FS,FS	0	190	30	226
J	18	C,F	FS,FS	0	80	16	84
R	0	H,I,J	FS,FS,FS	0	0	0	0

Figure 4.13 The input screen for an activity network with crashing details.

The table in Figure 4.13 captures all required information for building an activity network and performing a schedule crashing. All information such as activity name, duration, predecessors, relationship, lag, normal cost, crash time, crash cost are provided through this interface. For simplicity, this tool considers all activities in the network have ‘Finish to Start (FS)’ relationship. Another simplification in this model is for lead/lag value. In this study, these lead and lag values are considered zero. For the lead/lag data and other type of relationships, such as ‘Start to Finish (SF),’ ‘Start to Start (SS),’ and ‘Finish to Finish (FF),’ the constraint parts in the optimization model have to be modified accordingly. Then based on the information, the project duration is computed. The button ‘Find CPM Durations’ in this tool calculates the normal project duration and the all crashed project duration by using CPM.

A project's details are saved into database by using the button 'Save.' To save the project data properly, a unique project ID, activity duration unit, currency value, penalty/unit-time, reward/unit-time, overhead/unit-time, and the details of the activity network should be provided. After providing the information correctly, the button 'Save' is clicked to store the schedule into the database. To retrieve the schedule data, simply the desired project ID is selected from drop-down box as shown in Figure 4.14.

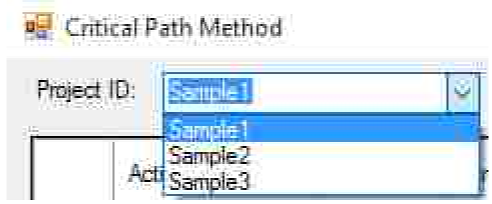


Figure 4.14 The drop-down list for selecting a desired schedule.

If required, the activity network could be edited directly from the activity table and any activity could be deleted by using 'Delete Activity' button. To delete an activity, the activity should first be selected and then the 'Delete Activity' button should be executed. Multiple activities selection is not allowed in the system, which requires selecting activities one by one and deleting then. If many activities have to be deleted together, it is better to delete the entire schedule. To delete the schedule completely, the button 'Delete' should be executed. This command deletes the schedule selected in the project ID drop-down box along with its all activities.

Figure 4.15 presents a sample activity network for a project schedule. The activity network was taken from the book written by Hillier and Lieberman (2010), and modified to present graphically. The alphabet character in a link represents the activity name and the number enclosed in a bracket represents the activity duration in a time unit of weeks. The number inside circle represents a node number.

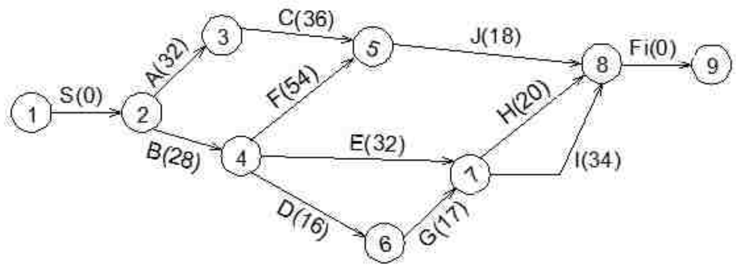


Figure 4.15 A sample activity network diagram.

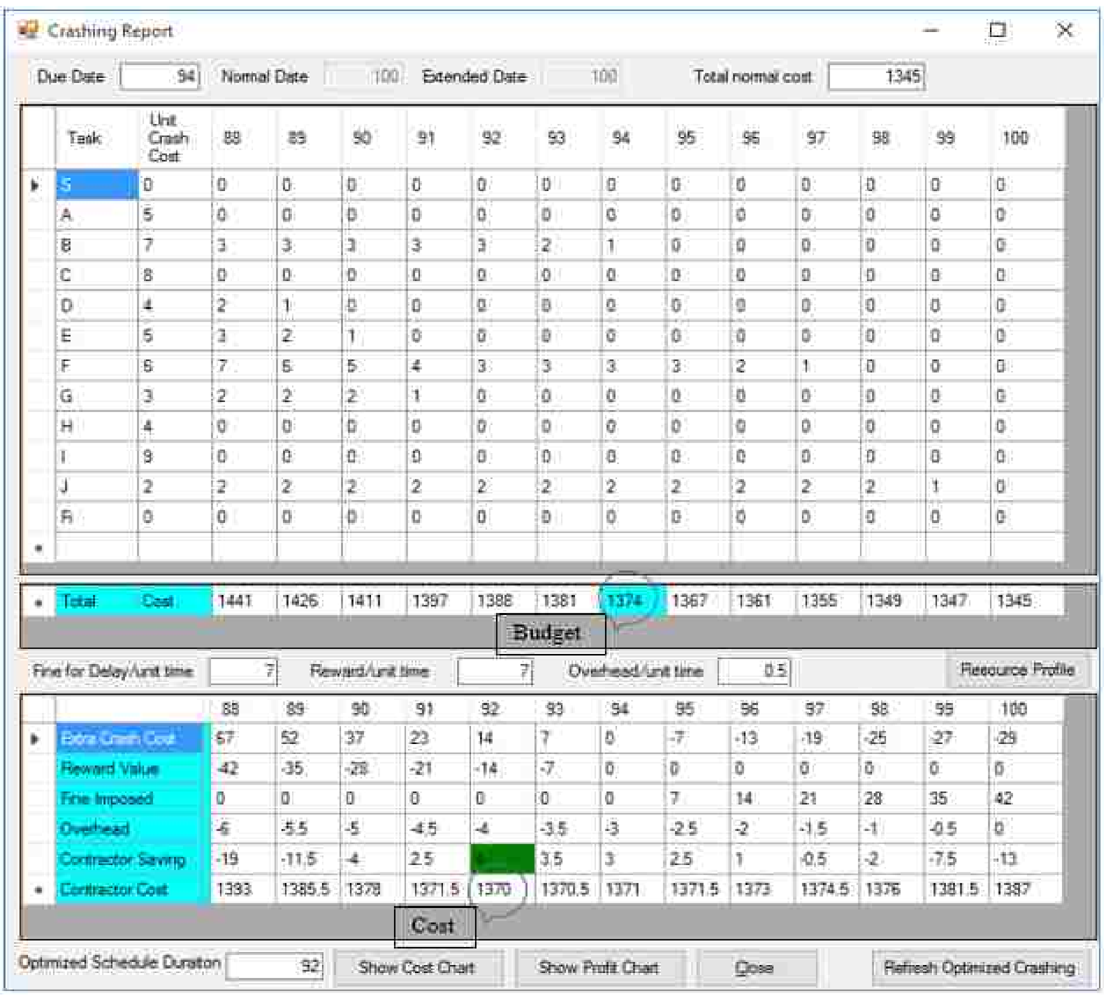
For an activity network as illustrated in Figure 4.15, an activity S (a dummy activity with zero duration) should be provided to initiate multiple activity at the beginning of the project. Similarly, an activity Fi, another dummy activity, should be provided to end multiple activities at the project's completion. Predecessors and activity relationships with proper lags should be clearly defined. All crashing information – such as the normal activity cost, the activity duration, the maximum allowable crashing duration, and the crash cost per time unit – should be provided as well. Before executing the optimization command, the project desired duration should be provided. For example, to complete the project by 94 weeks, the tool prepares optimization model as given in Figure 4.16.

```
!objective is to minimize the crash cost to finish the project in scheduled time
Min = 5*Ca + 7*Cb + 8*Cc + 4*Cd + 5*Ce + 6*Cf + 3*Cg + 4*Ch + 9*Ci + 2*Cj;
!subjected to;
!Final activity;
Ffi <= 94;
Ca+Cb+Cc+Cd+Ce+Cf+Cg+Ch+Ci+Cj>=6;
Ca<=4;          Cf<=7;          Cd<=3;          Ci<=4;
Cb<=3;          Cg<=2;          Ce<=5;          Cj<=2;
Cc<=5;          Ch<=3;
Ffi >= Fj;                Ffi >= Fh;                Ffi >= Fi;
!Activity F;              !Activity C;
Fj >= Fc + 18 - Cj;       Fc >= Fa + 36 - Cc;
Fj >= Ff + 18 - Cj;       !Activity F;
!Activity H;              Ff >= Fb + 54 - Cf;
Fh >= Fe + 20 - Ch;       !Activity E;
Fh >= Fg + 20 - Ch;       Fe >= Fb + 32 - Ce;
!Activity I;              !Activity G;
Fi >= Fg + 34 - Ci;       Fg >= Fd + 17 - Cg;
Fi >= Fe + 34 - Ci;       !Activity D;
                          Fd >= Fb + 16 - Cd;
                          !Activity B;
                          Fb >= 28 - Cb;
                          !Activity A;
                          Fa >= 32 - Ca;
```

Figure 4.16 A sample optimization model required for the activity network in Figure 4.15.

The objective of the optimization model is to minimize the crashing cost of the project, which is the sum of the products of activity crash unit costs and the number of crash time units. In this optimization model, the crashing time units are the decision variables. The constraint parts in this optimization model enforces all relationships between the activities. If lead and lag data are also provided, the constraint parts should include them too along with the decision variables. A constraint is also provided for the target project duration.

Executing the command ‘Crash Network (MS Solver),’ will bring out a new interface to show the result of the schedule crashing process as shown in Figure 4.17. This tool generates the optimization model dynamically based on the information provided for the activity network. The table in this figure presents all crashing details for the selected project durations. More to the point, each project duration ranging from the 'all crashed duration' to the 'normal duration' is provided with the number of days to be crashed for each activity to complete the project by that duration. For example, to complete the project schedule given in Figure 4.15 by 94 weeks, the activity B has to be crashed by one week, the activity F has to be crashed by 3 weeks, and the activity J has to be crashed by 2 weeks. After crashing these activities, the total project cost is estimated $1,374 million.



Task	Unit Crash Cost	88	89	90	91	92	93	94	95	96	97	98	99	100
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	5	0	0	0	0	0	0	0	0	0	0	0	0	0
B	7	3	3	3	3	3	2	1	0	0	0	0	0	0
C	8	0	0	0	0	0	0	0	0	0	0	0	0	0
D	4	2	1	0	0	0	0	0	0	0	0	0	0	0
E	5	3	2	1	0	0	0	0	0	0	0	0	0	0
F	6	7	6	5	4	3	3	3	3	2	1	0	0	0
G	3	2	2	2	1	0	0	0	0	0	0	0	0	0
H	4	0	0	0	0	0	0	0	0	0	0	0	0	0
I	9	0	0	0	0	0	0	0	0	0	0	0	0	0
J	2	2	2	2	2	2	2	2	2	2	2	2	1	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Cost		1441	1426	1411	1397	1388	1381	1374	1367	1361	1355	1349	1347	1345

	88	89	90	91	92	93	94	95	96	97	98	99	100
Extra Crash Cost	67	52	37	23	14	7	0	-7	-13	-19	-25	-27	-29
Reward Value	-42	-35	-28	-21	-14	-7	0	0	0	0	0	0	0
Fine Imposed	0	0	0	0	0	0	0	7	14	21	28	35	42
Overhead	-6	-5.5	-5	-4.5	-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0
Contractor Saving	-19	-11.5	-4	2.5	[illegible]	3.5	3	2.5	1	-0.5	-2	-7.5	-13
Contractor Cost	1393	1385.5	1378	1371.5	1370	1370.5	1371	1371.5	1373	1374.5	1376	1381.5	1387

Figure 4.17 The project schedule crashing optimization.

To determine the most economical project cost at the optimum duration, there should be use of various parameters such as project desired duration, rewards, liquidated damages, and overheads. A desired project duration is provided through 'Due Date' text box. To determine the optimum duration, the button 'Refresh Optimized Crashing' button is executed. This command refreshes all details for the optimized solutions. Finally, there is identification of the most optimum duration for the economical project cost and the cell with this data in the table is highlighted as presented in Figure 4.17.

For the given activity network in this study, the normal CPM duration was 100 weeks; after full crashing of all activities, the CPM duration would curtail to 88 weeks. This shows that the activity network can be shortened by 12 weeks. However, the client may want a different project completion time. The calculation table in Figure 4.17 signaled that even though the desired project duration was 94 weeks, based on the rewards, overheads, and penalty criteria, the optimal project duration was 92 weeks. If the contractor could complete this project by this optimal duration, the final project cost would be $1,370 million, saving $4 million out of the budgeted cost $1,374 million (the total cost for the desired project duration after considering the cost of crashing to the desired period).

In order to reanalyze the project, the variable parameters such as the project target date, the liquidated damage cost, the reward cost, and the overhead cost could be varied. After changing these fields, the economic analysis turns to action by clicking the 'Refresh Optimized Crashing' button again. This command provides the output for the most economic project duration.

The tool is also capable of generating a chart for the graphical presentation of the analysis. The Screenshot shown in Figure 4.18 is a chart for the project costs versus durations of the project. The curve shown in that figure distinctly presents the optimum point (the bottom most point) i.e. the most economical cost at the optimum duration. The chart generated for the sample project clearly indicated that the most optimal project duration was 92 weeks and the project cost was $1370 million.

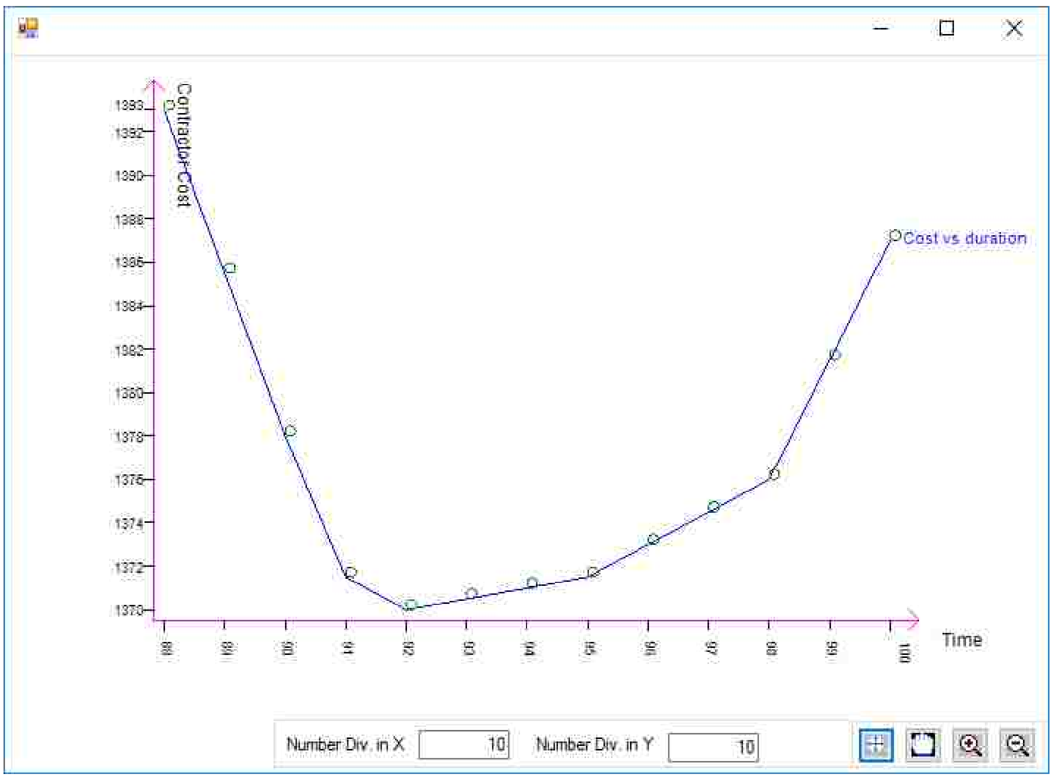


Figure 4.18 A chart generated for the project costs versus durations.

The procedure identifying the most economical cost at the most optimum project duration would assist a contractor willing to crash a project economically. This tool can be extended by considering resource usage while crashing the project schedule. Because, if there is a limit for a resource, it may restrict the total number of days that could be allocated for the group of activities. The resource limits should be addressed by introducing required constraints and rerunning the optimization model.

CHAPTER 5: CONCLUSIONS AND LIMITATIONS

At first, this study quantified the cost of CO on rural road maintenance contracts. Then the study identified the causes of CO and its preventative measures in road maintenance activities. Lastly the study developed change order contingency estimating tool and schedule crashing tool in order to assist in change management system of these contracts. The main conclusions and limitations of these three phase studies are described below.

5.1. Change Orders in Road Maintenance Contracts

This study determined the amount of CO on road maintenance projects contracted under the Kenya Rural Road Authority (KeRRA). The analysis of 614 road-maintenance projects showed that the average percentage of CO in these projects was 13.07%. The study also indicated that there was a negative correlation between the total cost of the projects and the percentage of CO cost; i.e. the percentage of CO decreases as the total project cost increases.

The study results showed that the '600 mm Culvert installation' and 'Provide gravel wearing course' were found to be the top two high risk and high frequent maintenance activities. However, 'Gravel patching' was the most frequent maintenance activity. The main reason behind high frequency CO in these activities was due to unforeseen conditions during the time of the estimates and the time of the road maintenance. Normally, estimates for gravel patching and wearing course were prepared based on the current surface conditions. In the time lag between the estimate and the construction work, the surface deterioration increased generating more work to complete the task. Feedback received from regional managers indicated that such reasons as 'under-packaging the amount of gravel during the bill of quantity (BOQ) preparation at the initial stage' contributed to highest frequency CO in these activities.

The non-parametric Kurskal-Wallis test showed that the median value of the CO percentages for the activity '600 mm culvert installation' was significantly higher than that of activities 'Heavy grading' and 'Heavy bush clearing.' The reason behind the difference could be: unpredictable site conditions, requiring extra works for culvert installation. In some cases, before the culvert installation, some protection works may be required that may change during maintenance work.

5.2. Causes of Change Orders

Two rounds of Delphi study were conducted with 33 state DOT engineers to identify causes and preventive measures of CO of maintenance contracts for five most frequent maintenance activities: chip-seal, striping, slope-repairs, asphalt overlay, and debris removal. The analysis revealed that the reasons of CO on these maintenance contracts were an incorrect work scope, errors in the estimate, failure to verify the work site condition before signing a contract, differences in site condition during and after the contract, new safety requirements, changes in the original plan, and changes in materials' specification. The ICC analysis indicated excellent agreement between ratings provided by the participants for most of these responses.

The important preventive measures suggested by the participants were reviewing of the specification before bid solicitation, preparing accurate estimates, reviewing design drawing, measuring the work done with the contractor, ensuring that the contractor is aware of materials' specification, meeting with contractor before starting the site work, visiting site before designing, performing thorough geo-technical site investigation before designing, and preparing a plan for additional works.

5.3. Contingency Estimations

Several studies mentioned that the traditional approach of allocating a determined percentage, such as 10% or 15% for contingency cost to the project is not an accurate method. To address this issue, in this study, a tool was developed for the estimation of contingency cost for a road maintenance contract. The prediction of contingency is based on historical records of change orders on road maintenance activities. For each of maintenance activities in a contract, a contingency is estimated and an adjusted contingency value is provided for each activity. According to the cost weighting value of each maintenance activity, the overall contingency value for the project is determined.

As this tool computes the contingency based on the cost weighting of maintenance activities and historical record of change orders, the contingency calculated for a contract is more empirical than simply adopting by a traditional approach. If this predicted contingency covers the future change orders, the risk of having a conflict between contracting parties and cost growth problems can be prevented.

5.4. Schedule Crashing Optimization

The laborious and time-consuming problem of schedule crashing could be made easier and less error prone by developing a tool capable of finding the necessary details for crashing a schedule. This tool developed during this study also has a capability to determine the most optimal duration within allowable project duration ranges. The optimization technique provided by the Microsoft ® Solver Foundation tool supported this rapid software development. In this study, a procedure was formulated that incorporated parameters such as construction cost overheads, rewards, and liquidated damage costs for the optimization problem of project schedule crashing.

If this tool is properly used, the contractor will receive benefits by identifying the optimum project completion duration. This tool offers flexibility in controlling the project duration by a reasonable amount, which will help reduce the negative effects of the change orders associated with time extensions. Finally, if commercial software, such as the Oracle ® Primavera and the Microsoft ® Project, incorporate this type of optimization system, users could perform a time-cost trade-off analysis.

5.5. Limitations

This study covered the rural road maintenance contracts and reported the average CO percentage for these contracts. Further research can be conducted on the road maintenance contracts on urban roads. That is why the Delphi study was conducted for the five most frequent maintenance activities on urban road maintenance in the USA. However, this study did not quantify the CO for the urban road maintenance contracts.

The contingency estimation tool developed in this study considered seven predetermined input variables, which are fixed, i.e. they cannot be deleted or new one cannot be added. Nonetheless, for the flexibility in the system, the tool could provide a system that allows users to select input parameters. The tool could also be improved to make the database system flexible by providing options to add new input parameters to include in prediction processes. Similarly, to make the schedule-crashing tool more optimizable, the system could be designed in such a way that it allows users to add some external constraints such as budget constraints, resource constraints to each activity, and milestones in activity network.

APPENDIX A: Delphi Round 1- Open Questionnaire for the Phone Interview

Round 1: Please provide the reasons that caused change orders in the following road maintenance activities and also list preventive measures to reduce them.

Contracted road maintenance activities	**Causes of the change orders** (Please provide top five reasons for each activity, if any)	**Possible measures to reduce or avoid change orders**
1. Chip Seal		
2. Paint Striping		
3. Slope Repairs		
4. Remove debris		
5. Overlay		

APPENDIX B: Software Requirements

All the software, supporting the tools developed during this study, should be installed properly before running the source code that provided in CD attached with this report. The software that needed to be installed to run these source codes in a computer are given below.

1) Windows operating system (above Windows XP)
2) Microsoft Visual Studio 2012
3) Microsoft Solver Foundation (version 3.0.1.10599)
4) R version 3.2.1
5) Microsoft Excel
6) Microsoft Access
7) RDotNet (version rClr 0.7-2)

APPENDIX C: Delphi Round 1- Summary of Responses Received from Phone Interviews

1A) Causes of Change Orders on the Chip Seal.

a) Extending or deleting a section due to different site conditions.

b) Section not ready to be done at the time of maintenance works.

c) Quantity overrun. Sometimes, needing extra oil and chips.

d) Error in Estimates (Normally calculation mistakes).

e) Missed to verify the site correctly before doing the estimate.

f) Wrong estimation of oil application rate and problem with chip seal design.

g) Need of different equipment than mentioned in the contract.

h) Adverse weather condition.

i) Extra items added to the project after scoping and advertising. (e.g. guard rails, pavement markings.)

j) Awarding to the lowest bid contractor.

k) Unforeseen condition. (e.g. Need to repair slope before doing chip seal.)

l) Incorrect measurement during the plan developments.

m) Quality and acceptability of materials issues because not meeting specification.

n) Materials rate inflation.

o) Traffic rerouting and traffic control requirements. (e.g. Required more signage for the traffic control).

p) Changes in Employees.

q) Equipment failure problem during the construction.

r) Schedule problems because of not enough contract time.

s) Delay in the contract awarding.

1B) Preventive Measures for the Change Orders in the Chip Seal.

a) Having well prepared schedules.

b) Preparing the Section well before the contract.

c) Having better quantity estimations (Better estimation).

d) Defining work scope correctly before assigning to a contractor and making better plans.

e) The oil grade and application rate agreement between the contracting parties.

f) Making sure that the works follow as given in the performance specifications.

g) Agreement for the work method before starting the contract.

h) Having better tools to evaluate the total surface area within a project limit. (e.g. Using a GIS information system correctly).

i) Have enough budget before the construction begins.

j) Spending enough time and efforts for the plan development.

k) Prepare the chip seal design correctly.

l) Ensure that the materials contract requirements are clear to the contractor.

m) Revisiting specifications to discover if any faults in it.

n) Field validation of work sites before signing the contract.

o) Forward planning (e.g. Plan for emergencies.)

p) Allocating some contingency money to unforeseen conditions.

2A) Causes of Change Orders on the Paint Striping.

a) Extending or deleting a section due to different site conditions.

b) Because of time gaps, a new requirement of redoing paint striping.

c) Forget to account for the temporary striping that is required to begin the construction.

d) Missing to capture some quantities. (While working stage-wise in multiple lane roads.)

e) Overgrinding the area.

f) The complexity in traffic control in case of heavy traffics.

g) Not using proper equipment.

h) Timing of the work. (Such as working at peak traffic flow time or off-peak time.)

i) Wrong estimate. Wrong material quantity calculations.

j) Unforeseen problems such as bad road conditions.

k) Additions of extra works.

l) Mistakes in the plan.

m) Issues on the quality and acceptability of materials.

n) Quality of workmanships.

o) Inadequacy of the contract time for the paint striping.

p) Additional temporary works required for the traffic diversion.

q) Inclement weather.

r) Plan or Scope Changes.

s) Material shortages.

2B) Preventive Measures for the Change Orders on Paint Striping.

a) Pre-planning before doing the job.

b) Having well prepared budget.

c) Better job of performing a constructability review of the design drawing.

d) Stipulate exactly how the grinding is to be done.

e) Spell out the equipment in the contract.

f) Having the traffic control planning.

g) Weather check before doing the job. Specify in contract what to do in inclement weather.

h) Better tools to identify material quantities required.

i) Well planned measurement.

j) Ensure all of the work needed is included in the contract.

k) Ensure materials contract requirements are clear.

l) Measure quantities with contractor to ensure concurrence.

m) Be aware of the possible extra works.

n) Study well the project site.

3A) Causes of Change Orders in the Slope Repairs.

a) Changes in the scope of the work– The scope increases because of additional drainage and shoulder works to be done.

b) Less time to prepare estimates.

c) The extent of the slope failure is not exactly same as what mentioned in the original contract.

d) More deterioration at the time of repair work as compared at the time of estimation.

e) The field condition being captured in the plan incorrectly. Item missing in the plan.

f) Problems in quantity estimate. (Quantity overrun because of the rough estimate.)

g) Unforeseen conditions such wet lands, storm water effects.

h) Forgetting to get the wetland permit or the permit to work with storm water.

i) Equipment not suitable for the locality.

j) Additional materials required during maintenance. (Extra filling or extra stone required.)

k) New damages detected where the initial work order had been done.

l) The depth of rock being different than anticipated.

m) The detection of bad turf or required to sod again.

n) Requiring soil treatment due to infestation or bugs.

o) Technology changes in work.

p) Inclement weather delay.

3B) Preventive Measures for the Change Orders on the Slope Repairs.

a) Better planning because well planned maintenance has less change orders.

b) Increasing the time to prepare estimates. Emergency works had more changes.

c) Constructability review, field visit, field validation before the design.

d) Having construction staff who are skilled enough to judge the site conditions and more capable of doing alternative solutions.

e) Being more specific on the section to be done.

f) Defining the acceptable slope treatments.

g) Getting the permit to work on time.

h) Agreement on the use of the equipment.

i) Having better estimating tools.

j) Make sure the work required to be done and design the work order correctly.

k) Judge the site requirement correctly.

l) Based on site conditions, prepare well for the necessary repairs.

m) Provide some contingency pay items.

n) Better construction inspections and monitoring works.

o) Extensive soil investigations in front end and having a detailed study. (More investigative drilling or geotechnical investigations.)

p) Engaging experienced person to prepare estimates.

q) Emphasis on the performance based contract rather than simply having lump-sum contracts.

r) Provide accurate survey data and study the meteorological data correctly.

s) Having drainage facilities checked periodically to identify the maintenance requirement.

4A) Causes of Change Orders on the Asphalt Overlay.

a) Milling deeper than what was in the original contract or didn’t estimate milling correctly.

b) Patching plan changes after once the milling work done.

c) Changes in the depth of the overlay that needed to be done. Ruts are deeper than anticipated.

d) Encountering more deterioration than that at the time of contract.

e) Unforeseen conditions. (Such as leaking pipe underneath the road.)

f) Inclement weather.

g) Scarcity and cost escalation of materials.

h) Error in estimates.

i) Quantity overruns due to placement of materials outside of the identified project limits. Quantity variation because of incorrect site judgment.

j) Scope of the work is not properly defined.

k) Changes in materials because of not meeting specifications and what required by the site.

l) Changes in the mix design.

m) Estimating time limit causing the estimate error.

n) Not following the design during constructions.

o) Negligence in site condition verification.

p) Addition of works such as striping, shoulders or guard rail at the last minute.

q) Traffic control requirements.

4B) Preventive Measures for the Change Orders in the Asphalt Overlay.

a) Estimate surface area accurately and adhere to design standard during construction.

b) Manage the project budget properly. If the budget is sufficient to do all the work, do it otherwise delete some portion of the route?

c) Get better handle on the overruns, change the bidding process. Not carrying bid at winter time and bidding only in summer time.

d) Include some extra quantities. Check the base course before applying the overlay.

e) Set up extra weather days. So no need to go for extra days in case of a delay.

f) Provide some additional money as contingencies.

g) Make sure the required amount of the materials in the market and confirm an agreement with the supplier to provide the sufficient amount on time. (Material Availability).

h) Having better estimating tools to avoid the calculation errors in the estimate.

i) Better planning, inspections, and documentations.

j) Visit the site before the planning.

k) Study the work specification requirement thoroughly.

l) Spend an adequate time during the plan development.

m) Pay more attention on the front end and back end. This may require more trained employees.

n) Conducting pre-pave meeting.

o) Ensure materials specifications are clear to the contractor.

p) Provide sufficient time to perform the work.

q) Measure quantities in conjunction with the contractor to ensure the agreement.

r) Negotiate change orders in a good faith.

s) LIDAR scanning method while determining the depth of the ruts instead of simply judging by field inspections.

t) Setting incentive and disincentive method for the contract modification.

5A) Causes of Change Orders on the Remove Debris.

a) Unforeseen conditions.

b) Difficulties in preparing the accurate estimate.

c) Planning time limit.

d) Wrong quantity estimate.

e) The method of hauling not wisely decided.

f) Encountering hazardous materials.

g) Heavy materials needing specialized equipment to remove the debris. (Requiring a new equipment).

h) Scope of the work is not properly defined and changes after the contract.

i) Additional work requirements.

j) Weather conditions.

k) Safety requirement to public.

l) Natural disasters.

5B) Preventive Measures for the Change Orders on the Remove Debris.

a) Anticipate more debris and make plan to tackle it.

b) Having better jobs and estimates.

c) Preplanning for unforeseen conditions and emergencies.

d) Estimating correctly the line items and durations.

e) Know the site condition well before planning the contract.

f) Hiring skilled people.

g) Payment based on the unit price.

h) Adopting performance based contracts.

i) Define works properly.

j) Make sure that there is enough budgets to support the debris removal.

k) Providing a contingency amount to cover unforeseen conditions.

l) Thinking of innovative ways of dealing the debris removal in cheaper price.

APPENDIX D: Delphi Round 2- Rating the Causes and Preventive Measures Questionnaire

Q1 Please rate **the causes of the Change Order on the Chip Seal** maintenance contract. Please rate each of the causes on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Causes	**Ratings**
Calculation error in estimates	
Error in estimating quantity of oil and chips	
Error in estimate due to lack of site verification	
Incorrect estimate of oil application rate	
Change in length of road sections (addition or deletion)	
Road section not ready for chip seal	
Different equipment required than mentioned in the contract	
Adverse weather condition	
Additional traffic control measures required than mentioned in a contract	
Awarding the contract to the lowest bidder	
Unforeseen site conditions	
Change in materials' specifications	
Material cost escalation	
Change in traffic management plan	
Delay in the contract awarding	

Q2 Please rate **the preventive measures to reduce the Change Order on the Chip Seal** maintenance contract. Please rate each of the measures on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Preventive measures	**Ratings**
Prepare accurate estimates	
Define scope of work correctly	
Design chip seal correctly	
Review the specifications before bid solicitation	
Allocate contingency for unforeseen site conditions	
Revisit the road section before signing the contract	
Plan and prepare up-to-date schedules	
Ensure that the contractor is aware of materials' specification	
Perform contract with the contractor regarding oil grade and its application	
Approve contractors' work method before starting chip seal	
Make road section ready for chip seal before the contract	

Q3 Please rate **the causes of the Change Order on the Paint Striping** maintenance contract.

Please rate each of the causes on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Causes	**Ratings**
Calculation error in estimate	
Error in quantity estimate of paint striping	
Error in estimating temporary striping	
Change in length of road sections (addition or deletion)	
Rework of paint striping because of time gaps	
Different equipment required than mentioned in the contract	
Adverse weather condition	
Additional traffic control measures required than mentioned in a contract	
Timing of paint striping (peak traffic vs. off-peak traffic)	
Unforeseen site conditions	
Change in materials' specification	
Unavailability of materials	
Change in traffic management plan	

Q4 Please rate **the preventive measures to reduce the Change Order on the Paint Striping** maintenance contract. Please rate each of the measures on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Preventive measures	**Ratings**
Prepare accurate estimates	
Define scope of work correctly	
Review the design drawing properly	
Mention equipment requirement in the contract	
Mention in the contact what to do during inclement weather	
Ensure that the contractor is aware of materials’ specification	
Revisit the road section before signing the contract	
Plan for possible additional work	
Prepare traffic control plan	
Check the weather before performing striping	
Measure the work done with the contractor	

Q5 Please rate **the causes of the Change Order on the Asphalt Overlay** maintenance contract.

Please rate each of the causes on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Causes	**Ratings**
Error in quantity estimate of milling works	
Change in patching plan after the milling work is done	
Encountered more deterioration than at the time of contract	
Adverse weather condition	
Unavailability of materials	
Material cost escalation	
Change in mix design	
Change in materials' specification	
Inaccurate planning during contract procurement due to poor site condition survey	
Additional traffic control measures required than mentioned in a contract	
Change in traffic management plan	

Q6 Please rate **the preventive measures to reduce the Change Order on the Asphalt Overlay** maintenance contract. Please rate each of the measures on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Preventive measures	**Ratings**
Estimate surface area accurately	
Use better estimating tools	
Spend enough time during planning phase	
Solicit the bid only in summer	
Plan for possible additional weather delays	
Provide sufficient contingency costs	
Ensure that the materials are available in the market	
Ensure that the contractor is aware of materials' specification	
Provide sufficient contract duration	
Set incentive and disincentive for contract modifications	
Revisit the road section before signing the contract	
Conduct the meeting with the contractor before asphalt overlay	
Measure the work done with the contractor	

Q7 Please rate **the causes of the Change Order on the Slope Repair** maintenance contract.

Please rate each of the causes on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Causes	**Ratings**
Error in quantity estimate of drainage and shoulder work	
Extent of slope failure is different than that mentioned in the contract	
Encountered more deterioration than at the time of contract	
Adverse weather condition	
Unforeseen site conditions such as wet lands, storm water effects	
Inaccurate planning during contract procurement due to poor site condition survey	
Bid solicitation without obtaining wetland storm water permit	
Different equipment required than mentioned in the contract	
New damages detected where the initial work order had been done	

Q8 Please rate **the preventive measures to reduce the Change Order on the Slope Repair** maintenance contract. Please rate each of the measures on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Preventive measures	**Ratings**
Spend enough time during planning phase	
Use better estimating tools	
Prepare the estimate with the help of experience person	
Define scope of work correctly	
Provide sufficient contingency costs	
Mention equipment requirement in the contract	
Review the design drawing properly	
Visit the site before designing	
Conduct geo-technical investigation before designing	
Obtain accurate meteorological data	
Define the acceptable slope treatments	
Obtain the required permits before the contract	
Identify the temporary construction required to fix the slope	
Use performance-based contract rather than lump-sum	

Q9 Please rate **the causes of the Change Order on the Remove Debris** maintenance contract. Please rate each of the causes on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Causes	**Ratings**
Error on quantity estimate	
Inappropriate hauling method chosen	
Encountered hazardous materials	
Different equipment required than mentioned in the contract	
Adverse weather condition	
Unforeseen site conditions	
New safety requirements	

Q10 Please rate **the preventive measures to reduce the Change Order on the Remove Debris** maintenance contract. Please rate each of the measures on the scale of 1 to 5 (5 being Very Important and 1 being very unimportant).

Preventive measures	**Ratings**
Prepare better estimate	
Define scope of work correctly	
Planning and estimating with the help of experience person	
Plan for possible additional work	
Provide sufficient contingency costs	
Revisit the road section before signing the contract	
Use performance-based contract rather than lump-sum	

APPENDIX E: The Output of ICC Analysis in the R-program

1. The R-Script file used for the ICC analysis.

```
#Install Intra-class correlation packages.
install.packages("psych")
library(psych)

#run considering rows with some missing data.
#codes 5-> very important and 1-> not so much important
(d1<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn1.csv"))
ICC(d1,missing=F,alpha=0.05)

(d2<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn2.csv"))
ICC(d2,missing=F,alpha=0.05)

(d3<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn3.csv"))
ICC(d3,missing=F,alpha=0.05)

(d4<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn4.csv"))
ICC(d4,missing=F,alpha=0.05)

(d5<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn5.csv"))
ICC(d5,missing=F,alpha=0.05)

(d6<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn6.csv"))
ICC(d6,missing=F,alpha=0.05)

(d7<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn7.csv"))
ICC(d7,missing=F,alpha=0.05)

(d8<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn8.csv"))
ICC(d8,missing=F,alpha=0.05)

(d9<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn9.csv"))
ICC(d9,missing=F,alpha=0.05)

(d10<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn10.csv"))
ICC(d10,missing=F,alpha=0.05)
```

2. The ICC analysis result for the question on causes of CO on the Chip-Seal.

```
> (d1<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn1.csv"))
   J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26
1   2  4  5  3  3  3  5  4  4   5   3   4   5   4   5   4   4   3   5   5   5   4   4   4   4   4
2   2  5  5  1  3  3  5  5  5   5   2   4   5   4   5   4   5   3   5   5   4   5   4   4   3   4
3   3  4  5  4  5  3  5  4  4   5   2   3   5   1   4   5   3   3   5   5   5   5   4   5   5   4
4   4  4  5  1  5  3  5  5  4   3   2   4   5   4   5   4   4   3   5   5   4   4   4   3   4   4
5   5  5  5  5  5  3  5  4  4   5   5   5   4   1   5   5   5   4   3   5   4   5   4   4   5   4
6   3  4  4  1  1  3  4  5  5   4   5   3   5   3   3   4   2   3   5   5   4   5   5   5   4   4
7   3  3  5  1  1  3  5  5  3   4   3   2   5   4   3   1   3   3   5   5   3   5   4   5   4   4
8   4  3  5  1  1  3  4  5  4   5   4   1   3   4   3   2   3   3   4   4   3   5   5   3   5   4
9   4  4  5  1  4  3  4  4  4   4   5   3   4   4   4   3   4   3   4   3   4   5   4   5   5   3
10  2  5  3  1 NA  3  3  4  3   3   1   1   3   3   2   5   5   4   3   3   3   3   3   3   3   3
11  3  4  5  3  2  3  3  5  3   5   5   3   4   3   4   4   5   4   5   3   3   4   4   3   5   5
12  4  5  5  3  5  3  4  5  4   3   4   1   4   4   5   3   5   5   5   4   3   5   5   4   4   5
13  5  3  5  1  1  3  4  5  4   5   4   4   3   4   3   3   5   3   4   4   3   5   4   4   4   3
14  4  5  5  1  4  3  5  4  3   4   4   2   4   4   5   4   4   3   5   3   4   5   4   4   5   3
15  5  4  5  4  1  3  5  5  4   3   2   1   5   3   4   3   5   3   5   3   4   4   4   4   3   5
> ICC(d1,missing=F,alpha=0.05)
Call: ICC(x = d1, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type   ICC   F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.049 2.3  14 375 4.0e-03       0.009        0.16
Single_random_raters     ICC2 0.061 3.5  14 350 2.4e-05       0.021        0.17
Single_fixed_raters      ICC3 0.087 3.5  14 350 2.4e-05       0.031        0.23
Average_raters_absolute ICC1k 0.574 2.3  14 375 4.0e-03       0.191        0.83
Average_random_raters   ICC2k 0.626 3.5  14 350 2.4e-05       0.354        0.84
Average_fixed_raters    ICC3k 0.713 3.5  14 350 2.4e-05       0.454        0.89

 Number of subjects = 15     Number of Judges =  26>
```

3. The ICC analysis result for the question on preventive measures to reduce CO on the Chip-Seal.

```
> (d2<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn2.csv"))
   J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26
1   5  4  5  5  4  3  5  5  5   4   5   4   5   4   5  NA   5   4   5   5   5   5   5   4   4   5
2   5  5  5  5  5  3  5  5  5   5   5   5   5   4   5   5   5   5   5   5   5   5   5   5   5   5
3   5  5  5  3  5  3  5  5  5   5   4   5   5   3   4   5   5   3   5   5   5   5   5   5   4   5
4   3  4  5  4  4  3  5  5  5   4   4   4   5   4   5   5   4   4   5   5   5   5   5   4   5   5
5   4  4  5  2  2  3  5  4  4   4   2   2   4   4   4   5   4   4   3   5   4   5   4   3   4   3
6   2  5  5  2  3  3  5  3  3   2   2   2   3   3   3   4   4   3   3   5   4   4   1   3   4   3
7   2  4  5  4  1  3  4  4  4   3   2   1   4   3   3   4   4   4   3   5   5   3   3   4   3   3
8   2  5  5  1  1  3  5  5  5   4   4   4   5   3   5   5   4   5   4   5   3   4   5   4   5   5
9   2  4  5  4  3  3  5  5  5   4   2   3   5   3   5   5   5   3   3   5   3   4  NA   4   4   4
10  2  3  5  1  1  3  5  4  5   4   4   3   5   4   4   5   4   4   3   4   5   5  NA   4   4   5
11  2  4  5  1  5  3  5  5  5   5   5   3   5   3   4   5   5   4   4   4   4   3   5   5  NA   5
> ICC(d2,missing=F,alpha=0.05)
Call: ICC(x = d2, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type  ICC    F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.21  7.9  10 275 3.6e-11       0.096        0.48
Single_random_raters     ICC2 0.22 13.0  10 250 0.0e+00       0.106        0.48
Single_fixed_raters      ICC3 0.32 13.0  10 250 0.0e+00       0.166        0.60
Average_raters_absolute ICC1k 0.87  7.9  10 275 3.6e-11       0.735        0.96
Average_random_raters   ICC2k 0.88 13.0  10 250 0.0e+00       0.755        0.96
Average_fixed_raters    ICC3k 0.92 13.0  10 250 0.0e+00       0.838        0.98

 Number of subjects = 11     Number of Judges =  26>
```

4. The ICC analysis result for the question on causes of CO on the Paint Striping.

```
> (d3<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn3.csv"))
```

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J17	J18	J19	J20	J21	J22	J23	J24	J25	J26	J27	J28	J29
1	4	4	5	5	2	3	5	5	4	4	4	4	4	4	5	4	5	NA	4	5	4	5	5	5	5	4	4	4	4
2	4	4	5	4	4	3	5	5	4	4	4	4	4	4	5	4	4	4	5	5	4	5	5	5	4	5	4	4	4
3	2	4	5	3	4	3	5	4	4	4	4	4	4	4	5	4	5	3	5	5	4	5	5	4	4	5	3	3	4
4	5	5	4	5	2	3	5	5	5	5	5	5	1	5	4	3	5	5	5	3	4	5	4	5	4	3	2	5	5
5	2	4	5	1	1	3	4	5	4	2	4	3	3	4	4	1	4	3	4	3	3	5	4	5	4	4	1	3	3
6	3	3	5	1	1	3	4	5	4	2	2	1	4	1	4	4	4	4	4	3	3	5	3	4	4	5	2	3	3
7	3	3	5	2	1	3	4	5	4	5	5	1	1	2	3	4	3	3	5	4	3	3	3	4	4	3	2	5	5
8	4	4	5	2	4	3	5	5	4	4	4	1	3	4	4	4	4	3	4	4	3	3	4	4	4	4	3	4	3
9	3	4	5	2	1	3	5	4	4	5	4	2	4	4	4	1	4	3	5	5	3	3	4	4	4	4	3	5	5
10	4	3	5	1	1	3	3	4	3	4	5	3	3	5	3	3	4	3	5	4	4	4	4	4	4	3	2	4	4
11	5	3	5	3	4	3	4	5	3	4	4	1	4	3	4	4	5	4	5	4	5	3	5	5	4	4	3	3	5
12	4	3	5	2	1	3	5	5	3	4	5	1	2	3	4	4	4	3	5	5	3	3	3	5	4	4	4	4	4
13	4	4	5	3	4	3	5	5	4	4	2	1	3	4	5	4	4	3	5	4	3	3	4	4	4	4	3	3	5

```
> ICC(d3,missing=F,alpha=0.05)
Call: ICC(x = d3, missing = F, alpha = 0.05)
```

Intraclass correlation coefficients

	type	ICC	F	df1	df2	p	lower bound	upper bound
Single_raters_absolute	ICC1	0.085	3.7	12	364	3.0e-05	0.029	0.24
Single_random_raters	ICC2	0.096	6.1	12	336	8.7e-10	0.040	0.25
Single_fixed_raters	ICC3	0.151	6.1	12	336	8.7e-10	0.068	0.35
Average_raters_absolute	ICC1k	0.728	3.7	12	364	3.0e-05	0.462	0.90
Average_random_raters	ICC2k	0.755	6.1	12	336	8.7e-10	0.550	0.91
Average_fixed_raters	ICC3k	0.837	6.1	12	336	8.7e-10	0.677	0.94

```
 Number of subjects = 13     Number of Judges =  29>
```

5. The ICC analysis result for the question on preventive measures to reduce the CO on the Paint Striping.

```
> (d4<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn4.csv"))
   J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26 J27 J28 J29
1   4  5  5  5  4  3  5  5  5   4   4   5   1   5   5   4   5  NA   5   5   4   5   5   5   5   4   4   5   5
2   4  5  5  5  5  3  5  5  5   5   4   5   1   5   5   4   5   5   5   5   5   5   5   4   5   5   5   5   5
3   3  4  5  4  4  3  5  5  5   4   4   4   1   5   5   4   4   5   5   5   4   5   5   4   4   4   2   4   5
4   3  4  5  1  1  3  5  5  3   3   4   4   4   1   4   4   3   4   5   3   3   5   4   3   1   4   1   3   3
5   3  4  5  2  1  3  4  4  4   5   5   3   4   2   4   3   4   5   5   4   4   5   4   4   4   3   3   5   5
6   3  3  5  3  1  3  4  5  5   4   5   4   1   5   5   3   4   5   5   4   5   5   3   5   5   4   3   5   5
7   2  4  5  4  4  3  4  4  3   4   3   1   1   4   3   3   3   3   4   3   4   5   3   4   1   4   3   4   3
8   3  4  5  4  1  3  4  4  3   3   3   2   2   4   4   3   4   4   4   4   3   4   4   5   4   4   3   4   4
9   2  5  5  3  2  3  4  5  3   4   4   1   1   4   5   4   4   4   5   4   3   3   4   5   4   5   3   4   3
10  2  5  5  3  1  3  5  4  4   5   5   4   1   5   5   4   3   5   5   3   4   4   3   5   5   4   4   5   5
11  2  4  5  4  3  3  5  5  4   4   5   4   1   5   5   4   4   5   5   4   4   5   5   5   5   4   2   5   5
> ICC(d4,missing=F,alpha=0.05)
Call: ICC(x = d4, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type  ICC   F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.12 5.1  10 308 6.5e-07       0.047        0.34
Single_random_raters     ICC2 0.14 9.6  10 280 9.0e-14       0.060        0.35
Single_fixed_raters      ICC3 0.23 9.6  10 280 9.0e-14       0.110        0.50
Average_raters_absolute ICC1k 0.80 5.1  10 308 6.5e-07       0.591        0.94
Average_random_raters   ICC2k 0.82 9.6  10 280 9.0e-14       0.647        0.94
Average_fixed_raters    ICC3k 0.90 9.6  10 280 9.0e-14       0.782        0.97

 Number of subjects = 11     Number of Judges =  29>
```

6. The ICC analysis result for the question on causes of the CO on the Asphalt Overlay.

```
> (d5<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn5.csv"))
   J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26 J27 J28 J29
1   2  5  5  1  1  4  5  5  5   4   5   4   4   4   5   4   1   4  NA   4   4   4   5   5   5   4   5   4   5
2   2  4  5  4  5  4  5  5  5   5   5   2   3   5   5   4   1   4   5   5   4   4   5   3   5   4   4   5   4
3   4  4  5  3  5  5  5  5  5   5   5   4   2   5   4   4   4   4   5   5   5   4   5   4   5   4   3   5   4
4   2  3  5  1  1  2  4  4  4   4   4   1   1   4   3   3   1   3   3   4   4   3   3   3   4   5   3   4   3
5   3  4  5  1  1  2  5  5  4   5   4   1   2   3   4   4   1   3   3   5   5   3   3   1   4   5   4   3   4
6   4  4  5  4  1  2  4  4  4   4   5   5   1   3   4   4   1   4   3   5   4   3   5   4   4   4   4   4   4
7   2  4  5  1  1  2  5  4  3   5   2   4   3   3   5   4   1   5   5   5   4   4   3   3   5   4   5   3   5
8   2  4  5  1  4  2  4  5  3   4   4   3   3   3   5   4   1   5   5   5   4   5   3   3   5   4   5   3   5
9   3  5  5  4  5  2  5  5  5   5   5   2   4   4   5   3   1   3   5   5   4   5   5   4   5   5   5   4   5
10  2  4  5  3  3  2  5  4  4   4   2   2   4   4   4   4   1   4   4   4   3   3   3   4   5   4   4   4   3
11  2  5  5  1  3  2  5  5  4   4   2   2   4   4   4   4   1   4   4   5   3   3   3   4   4   4   4   4   5
> ICC(d5,missing=F,alpha=0.05)
Call: ICC(x = d5, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type   ICC   F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.078 3.5  10 308 2.4e-04       0.022        0.25
Single_random_raters     ICC2 0.094 7.4  10 280 2.0e-10       0.037        0.27
Single_fixed_raters      ICC3 0.181 7.4  10 280 2.0e-10       0.080        0.43
Average_raters_absolute ICC1k 0.712 3.5  10 308 2.4e-04       0.397        0.91
Average_random_raters   ICC2k 0.750 7.4  10 280 2.0e-10       0.530        0.91
Average_fixed_raters    ICC3k 0.865 7.4  10 280 2.0e-10       0.717        0.96

 Number of subjects = 11     Number of Judges =  29>
```

7. The ICC analysis result for the question on preventive measures to reduce the CO on the Asphalt Overlay.

```
> (d6<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn6.csv"))
   J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26 J27 J28 J29
1   5  5  5  5  4  4  5  5  5   4   5   5   1   5   5   4   5   5  NA   5   5   4   5   5   5   5   4   5   5
2   2  4  5  1  2  4  5  4  5   4   4   4   3   3   4   4   3   3   5   5   5   4   5   4   4   4   4   3   5
3   2  4  5  4  3  5  5  4  5   4   3   4   1   4   4   3   4   4   5   5   5   4   5   4   5   4   5   5   5
4   2  3  5  4  1  4  3  4  2   3   5   1   5   1   2   3   5   3   1   4   3   3   3   3   3   1   2   3   3
5   2  4  5  3  1  3  3  3  3   4   4   1   1   4   3   3   3   3   3   5   4   3   3   3   4   3   4   4   3
6   2  4  5  1  2  3  5  4  4   4   4   2   2   5   4   3   2   4   5   4   4   3   4   4   4   4   4   3   3
7   4  5  5  1  1  3  5  3  4   5   4   3   2   3   4   3   3   4   4   5   3   4   5   3   4   5   5   3   4
8   2  4  5  1  1  3  5  5  5   4   3   4   3   5   5   4   4   4   5   5   4   5   5   3   4   5   5   5   5
9   4  5  5  5  3  3  5  4  4   4   3   5   1   4   5   4   5   4   4   5   5   4   5   4   4   4   5   5   5
10  3  4  5  3  2  3  5  5  4   2   3   4   2   3   3   4   5   4   4   5   5   3   5   3   4   3   4   4   3
11  3  4  5  3  4  3  4  3  5   4   3   2   2   4   3   3   2   3   3   4   3   3   5   3   3   1   4   4   3
12  5  5  5  1  4  3  4  5  4   4   4   4   1   5   5   4   4   4   5   5   4   3   5   4   5   4   4   5   4
13  4  4  5  4  3  3  5  5  5   5   5   4   1   5   4   4   5   4   5   5   4   4   5   5   5   5   4   5   3
> ICC(d6,missing=F,alpha=0.05)
Call: ICC(x = d6, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type  ICC    F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.16  6.7  12 364 7.8e-11       0.075        0.37
Single_random_raters     ICC2 0.17 10.6  12 336 0.0e+00       0.084        0.38
Single_fixed_raters      ICC3 0.25 10.6  12 336 0.0e+00       0.131        0.49
Average_raters_absolute ICC1k 0.85  6.7  12 364 7.8e-11       0.703        0.95
Average_random_raters   ICC2k 0.86 10.6  12 336 0.0e+00       0.727        0.95
Average_fixed_raters    ICC3k 0.91 10.6  12 336 0.0e+00       0.813        0.97

 Number of subjects = 13     Number of Judges =  29>
```

8. The ICC analysis result for the question on causes of the CO on the Slope Repair.

```
> (d7<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn7.csv"))
  J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26
1  4  4  5  4  4  3  5  5  5   4   5   4   4   5   4   4  NA   5   5   5   5   4   5   4   4   5
2  5  5  5  5  5  3  5  5  5   4   5   3   1   5   4   4   5   5   5   5   5   5   5   5   5   5
3  5  4  5  4  5  3  5  5  4   4   5   5   1   5   4   4   5   5   5   4   4   5   4   5   5   5
4  4  3  5  2  1  3  4  4  4   4   4   1   1   3   3   4   4   4   4   4   3   4   4   3   3   3
5  3  5  5  5  1  3  4  5  5   4   5   1   4   4   4   4   4   5   5   5   4   3   3   4   4   5
6  3  5  5  3  4  3  5  5  5   4   4   2   4   4   3   4   5   5   5   5   4   5   4   2   5   5
7  3  5  5  1  4  3  5  5  5   4   3   1   5   4   4   4   5   5   4   4   4   5   5   2   2   5
8  3  3  5  1  1  3  5  4  3   3   3   2   4   4   4   3   4   4   3   4   3   4   4   2   2   4
9  5  5  5  3  5  3  5  5  4   5   3   4   1   5   4   5   5   5   4   4   4   4   4   4   5   5
> ICC(d7,missing=F,alpha=0.05)
Call: ICC(x = d7, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type  ICC   F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.16 5.9   8 225 8.4e-07       0.058        0.44
Single_random_raters     ICC2 0.17 9.2   8 200 9.3e-11       0.069        0.45
Single_fixed_raters      ICC3 0.24 9.2   8 200 9.3e-11       0.106        0.56
Average_raters_absolute ICC1k 0.83 5.9   8 225 8.4e-07       0.616        0.95
Average_random_raters   ICC2k 0.84 9.2   8 200 9.3e-11       0.657        0.95
Average_fixed_raters    ICC3k 0.89 9.2   8 200 9.3e-11       0.755        0.97

 Number of subjects = 9     Number of Judges =  26>
```

9. The ICC analysis result for the question on preventive measures to reduce the CO on the Slope Repair.

```
> (d8<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn8.csv"))
   J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26
1   4  4  5  4  4  3  5  5  5   4   4   5   1   5   4   4  NA   5   5   5   5   4   4   3   5   5
2   3  4  5  3  2  3  5  4  5   4   4   4   3   4   4   3   5   4   5   4   4   4   4   2   3   5
3   3  5  5  5  2  3  5  4  4   5   4   4   1   4   3   4   5   5   5   4   4   5   4   2   4   4
4   5  5  5  4  3  3  5  5  5   5   4   5   1   5   4   4   5   5   5   5   5   5   5   5   5   5
5   3  5  5  2  4  3  5  4  4   4   5   2   2   4   3   4   5   5   4   4   4   4   4   2   3   3
6   3  3  5  1  1  3  4  4  2   4   4   2   4   4   4   3   3   5   3   3   3   3   3   2   2   3
7   3  5  5  4  3  3  5  5  5   4   5   4   1   5   4   4   5   5   5   4   5   5   4   2   4   5
8   5  5  5  5  5  3  5  5  5   5   5   5   1   5   4   5   5   5   5   5   5   5   5   4   4   5
9   4  5  5  5  4  3  5  5  5   4   5   4   1   5   4   5   5   5   5   5   5   5   5   1   3   5
10  5  5  5  1  1  3  4  5  4   2   4   2   2   4   4   4   4   4   3   4   5   4   3   2   4   5
11  4  4  5  3  4  3  5  5  5   4   5   4   1   5   4   4   5   5   5   5   5   5   5   3   4   5
12  3  5  5  1  4  3  5  5  5   5   4   5   1   4   4   4   5   5   5   4   4   5   5   3   5   5
13  3  5  5  2  3  3  5  5  4   4   3   4   2   5   4   4   4   5   3   3   4   4   4   3   4   5
14  1  4  5  1  1  3  5  5  3   3   2   1   1   3   3   3   4   5   3   4   3   4   3   4   3   3
> ICC(d8,missing=F,alpha=0.05)
Call: ICC(x = d8, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type  ICC    F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.15  5.5  13 350 5.1e-09       0.065        0.34
Single_random_raters     ICC2 0.16 12.2  13 325 0.0e+00       0.078        0.35
Single_fixed_raters      ICC3 0.30 12.2  13 325 0.0e+00       0.169        0.54
Average_raters_absolute ICC1k 0.82  5.5  13 350 5.1e-09       0.645        0.93
Average_random_raters   ICC2k 0.83 12.2  13 325 0.0e+00       0.687        0.93
Average_fixed_raters    ICC3k 0.92 12.2  13 325 0.0e+00       0.841        0.97

 Number of subjects = 14     Number of Judges =  26>
```

10. The ICC analysis result for the question on causes of the CO on the Remove Debris.

```
> (d9<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn9.csv"))
  J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26
1  4  4  5  4  4  3  5  3  5   4   3   4   4   5   4   4  NA   5   4   5   5   5   4   3   4   4
2  3  5  5  2  2  3  4  4  3   4   4   3   4   5   3   4   3   3   4   5   3   4   5   2   3   5
3  5  5  5  3  5  3  5  5  4   5   5   4   1   4   4   5   5   5   5   5   5   4   5   4   4   5
4  4  3  5  1  1  3  5  3  3   3   2   3   4   5   4   3   3   3   4   5   4   4   5   3   3   3
5  2  3  5  1  1  3  4  3  3   4   2   2   1   4   3   4   3   4   3   3   3   5   3   3   2   3
6  3  4  5  3  3  3  4  4  4   4   4   4   1   4   3   4   4   5   4   5   4   4   3   3   3   5
7  3  5  5  1  3  3  4  4  4   4   4   3   4   4   4   4   4   3   3   5   5   4   4   2   4   5
> ICC(d9,missing=F,alpha=0.05)
Call: ICC(x = d9, missing = F, alpha = 0.05)

Intraclass correlation coefficients
                         type  ICC    F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.17  6.4   6 175 4.0e-06       0.058        0.54
Single_random_raters     ICC2 0.18 11.1   6 150 3.4e-10       0.070        0.54
Single_fixed_raters      ICC3 0.28 11.1   6 150 3.4e-10       0.117        0.67
Average_raters_absolute ICC1k 0.84  6.4   6 175 4.0e-06       0.613        0.97
Average_random_raters   ICC2k 0.85 11.1   6 150 3.4e-10       0.661        0.97
Average_fixed_raters    ICC3k 0.91 11.1   6 150 3.4e-10       0.775        0.98

 Number of subjects = 7     Number of Judges =  26>
```

11. The ICC analysis result for the question on preventive measures to reduce the CO on the Remove Debris.

```
> (d10<-read.csv("E:/Dissertation/Delphi/2nd phase-Qualtrics Survey/Analysis Result/Qtn10.csv"))
  J1 J2 J3 J4 J5 J6 J7 J8 J9 J10 J11 J12 J13 J14 J15 J16 J17 J18 J19 J20 J21 J22 J23 J24 J25 J26
1  5  4  5  5  3  3  5  3  5   4   4   5   1   5   4   4  NA   5   4   5   5   5   4   3   3   5
2  5  5  5  3  5  3  5  3  5   4   4   5   1   5   4   4   5   5   5   5   5   5   5   5   5   5
3  5  4  5  4  3  3  5  3  4   4   4   4   1   4   4   4   5   5   4   5   5   5   5   2   4   4
4  3  4  5  2  1  3  5  3  4   3   3   2   1   4   3   4   4   5   4   5   4   4   4   4   3   3
5  3  4  5  2  3  3  5  3  4   4   5   2   2   4   3   4   5   3   4   5   4   4   4   3   4   3
6  3  3  5  1  1  3  5  3  4   4   5   2   1   3   3   4   4   3   4   5   2   3   4   4   3   5
7  3  4  5  1  1  3  5  3  3   2   2   2   1   3   3   3   4   4   3   5   3   4   3   4   4   3
> ICC(d10,missing=F,alpha=0.05)
Call: ICC(x = d10, missing = F, alpha = 0.05)

Intraclass correlation coefficients 
                         type  ICC    F df1 df2       p lower bound upper bound
Single_raters_absolute   ICC1 0.14  5.4   6 175 4.0e-05       0.043        0.49
Single_random_raters     ICC2 0.16 12.8   6 150 1.2e-11       0.060        0.50
Single_fixed_raters      ICC3 0.31 12.8   6 150 1.2e-11       0.137        0.70
Average_raters_absolute ICC1k 0.81  5.4   6 175 4.0e-05       0.538        0.96
Average_random_raters   ICC2k 0.83 12.8   6 150 1.2e-11       0.623        0.96
Average_fixed_raters    ICC3k 0.92 12.8   6 150 1.2e-11       0.805        0.98

 Number of subjects = 7     Number of Judges =  26>
```

APPENDIX F: Some Details on the Contingency Estimator

Some functions prepared in C# to run the R-program

```
private void prepareR_environment()

{

            //Set Environmental variables.

            string rhome = System.Environment.GetEnvironmentVariable("R_HOME");

            if (string.IsNullOrEmpty(rhome))

            {

                rhome = @"C:\Program Files\R\R-3.2.1"; //reset this path for new version of R.

                System.Environment.SetEnvironmentVariable("R_HOME", rhome);

            }

            string rpath = rhome + @"\bin\i386";

            string path= System.Environment.GetEnvironmentVariable("PATH");

            if (string.IsNullOrEmpty(path) || !path.Contains(rpath))

              System.Environment.SetEnvironmentVariable("PATH", System.Environment.GetEnvironmentVariable("PATH") + ";" +

              rhome + @"\bin\i386");

            //here are several options to initialize the engine, but by default the following suffice:

            engine = REngine.GetInstance();

            engine.Evaluate("chooseCRANmirror(graphics = false, ind = 0)"); //1 is index for Cloud 0 or checked with

            getCRANmirrors() function in R.

            string expr = "install.packages(\"neuralnet\")"; //install neural packages.
```

```
            engine.Evaluate(expr);
            engine.Evaluate("library(neuralnet)"); //load neural network.
            expr = "install.packages(\"car\")"; //install car packages.
            engine.Evaluate(expr);
            engine.Evaluate("library(car)"); //load car network.
            REngine.SetEnvironmentVariables();
}

private double estimate_changeorders_NN(uContract pkg, uroad aroad, long actcode, DataGridViewRow r,
               string filename, string filepath)
{
            double rslt = 0;
            try {
                object[][] d = read_COdata(ref pkg, actcode);
                     if (d == null || d.Length < (6 * 6)) return 0; //(Number of independent variable * Number of
                     independent variable)
                string actname = get_road_activity(actcode).name;
                int k = 0;
                string act_c = "_" + (r.Index + 1).ToString();
                engine.SetSymbol("wrkcat" + act_c, engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;
                engine.SetSymbol("accessibility", engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;
```

```
  engine.SetSymbol("weather", engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;

  engine.SetSymbol("rsurface", engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;

  engine.SetSymbol("rcondition", engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;

  engine.SetSymbol("cregion", engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;

  engine.SetSymbol("bidamount", engine.CreateNumericVector(getOneDimensionalArray(d, k))); k++;

  engine.SetSymbol("variation_pct", engine.CreateNumericVector(getOneDimensionalArray(d, k)));

       DataFrame dframe = engine.Evaluate("trainingdata <- data.frame(wrkcat" + act_c +

       ",accessibility,weather,rsurface,rcondition,cregion,bidamount,variation_pct)").AsDataFrame();

  //run neural network.

string exprs = "colnames(trainingdata) <- c(\"wrkcat" + act_c +

"\",\"accessibility\",\"weather\",\"rsurface\",\"rcondition\",\"cregion\",\"bidamount\",\"variation_pct\")";

  engine.Evaluate(exprs);

  double qty = getDoubleValue(r.Cells[2].Value);

  double prc = getDoubleValue(r.Cells[3].Value);

  int n_input_neurons = 7; int n_input_bias = 2; int n_output_neurons = 1;

       int n_hidden_nodes = (n_input_neurons + n_input_bias + n_output_neurons) * 2 / 3; //thumb rule. 2/3 of

       (input counts + output count) // two count for bias too.

       string neulogic = "ann <- neuralnet(variation_pct~(wrkcat" + act_c +

       "+accessibility+weather+rsurface+rcondition+cregion+bidamount),trainingdata,";

  neulogic += " hidden=" + n_hidden_nodes + ", threshold=0.01)";

  GenericVector result = engine.Evaluate(neulogic).AsList();
```

```
        //plot ANN model
        if (chkANN.Checked) engine.Evaluate("plot(ann)");
            string testdata = pkg.workcategory.ToString() + "," + pkg.accessibility.ToString() + "," +
            pkg.weatherfactor.ToString();
            testdata += "," + aroad.surface.ToString() + "," + aroad.condition.ToString() + "," +
            pkg.regioncode.ToString() + "," + (qty * prc).ToString();
        exprs = "testdata <- matrix(c(" + testdata + "), nrow = 1, ncol =" + n_input_neurons +")";
        engine.SetSymbol("testdata", engine.Evaluate(exprs));
        //predict the Change order.
        exprs = "results <- compute(ann, testdata)";
        GenericVector testResult = engine.Evaluate(exprs).AsList();
        appendRegression_R_file(filepath, "results$net.result");
            rslt = Math.Round(testResult["net.result"].AsNumeric().First(), 2);
    }
    catch { rslt = 0;}
    return rslt;
}
```

A Sample R-script generated by the contingency estimation while running the R-program

A) A Sample R-script file generated by the contingency estimator while executing the ANN methods.

temRNN.R - Notepad

File Edit Format View Help

```
(d <- read.csv("E:/Dissertation/CPM/CPMsrc/ContingecyEstimate/ContingecyEstimate/bin/Debug/temNN.csv"))
names(d)
chooseCRANmirror(graphics = false, ind = 0)
install.packages("neuralnet")
library(neuralnet)
install.packages("car")
library(car)

#Activity:Culvert Installation 600 mm with surround
#Number of data point =164
trainingdata<-d
colnames(trainingdata) <- c("wrkcat_1","accessibility","weather","rsurface","rcondition","cregion","bidamount","variation_pct")
ann <- neuralnet(variation_pct~(wrkcat_1+accessibility+weather+rsurface+rcondition+cregion+bidamount),trainingdata, hidden=6, threshold=0.01)
plot(ann)
testdata <- matrix(c(1,1,1,1,3,48,6000), nrow = 1, ncol =7)
results <- compute(ann, testdata)
results$net.result

#Activity:Provide  gravel wearing  course-excavation,free haul, spread, water and compact gravel  to specifications
#Number of data point =104
trainingdata<-d
colnames(trainingdata) <- c("wrkcat_2","accessibility","weather","rsurface","rcondition","cregion","bidamount","variation_pct")
ann <- neuralnet(variation_pct~(wrkcat_2+accessibility+weather+rsurface+rcondition+cregion+bidamount),trainingdata, hidden=6, threshold=0.01)
plot(ann)
testdata <- matrix(c(1,1,1,1,3,48,400), nrow = 1, ncol =7)
results <- compute(ann, testdata)
results$net.result

#Activity:Heavy Bush Clearing
#Number of data point =131
trainingdata<-d
colnames(trainingdata) <- c("wrkcat_3","accessibility","weather","rsurface","rcondition","cregion","bidamount","variation_pct")
ann <- neuralnet(variation_pct~(wrkcat_3+accessibility+weather+rsurface+rcondition+cregion+bidamount),trainingdata, hidden=6, threshold=0.01)
plot(ann)
testdata <- matrix(c(1,1,1,1,3,48,45000), nrow = 1, ncol =7)
results <- compute(ann, testdata)
results$net.result
```

B) A Sample R-script file generated by the contingency estimator while executing the LRM method.

temRReg.R.txt - Notepad

File Edit Format View Help

```
(d <- read.csv("E:/Dissertation/CPM/CPMsrc/ContingecyEstimate/ContingecyEstimate/bin/Debug/temReg.csv"))
names(d)
chooseCRANmirror(graphics = false, ind = 0)
install.packages("neuralnet")
library(neuralnet)
install.packages("car")
library(car)

#Activity:Culvert Installation 900 mm with surround
#Number of data point =47
reg1 <- lm(variation_pct~(wrkcat+accessibility+weather+rsurface+rcondition+cregion+bidamount),data=d)
#check the vif values for the predictors.
v<-vif(reg1)
#The predictor 'weather' has vif value greater than 2, hence the dropping it and running the regression model again.
reg1 <- lm(variation_pct~(wrkcat+accessibility+rsurface+rcondition+cregion+bidamount), data=d)
#check vif again.
v<-vif(reg1)
#all predictor satisfied the vif criteria i.e. all predictors have vif less than 2.
#check p-values for the regression model.
cm<-summary(reg1)$coefficients
#drop the most insignificant predictor 'rcondition' and prepare new model.
reg1 <- lm(variation_pct~(wrkcat+accessibility+rsurface+cregion+bidamount), data=d)
#check p-values for the model
cm<-summary(reg1)$coefficients
#drop the most insignificant preditor 'accessibility' and prepare a new regression model.
reg1 <- lm(variation_pct~(wrkcat+rsurface+cregion+bidamount), data=d)
#check p-values for the new model
cm<-summary(reg1)$coefficients
#drop the most insignificant preditor 'rsurface' and prepare a new regression model.
reg1 <- lm(variation_pct~(rsurface+cregion+bidamount), data=d)
#check p-values for the new model
cm<-summary(reg1)$coefficients
#All predictors have p-values less than 0.1 (significant level considered.)
#retrieve coefficient for the predictors for forecasting purpose.
(cff1<-coef(reg1))
```

APPENDIX G: An Optimization Routine used in the Schedule Crashing Tool.

```
public double[] runMsSolverModel(double dueDate, string[] task, double[] normalTime,
                double[] crashTime, double[] crashCostperUnit, double[] EF, string[] pred)
{
            SolverContext usolver = SolverContext.GetContext();
            usolver.ClearModel();
            Model umodel = usolver.CreateModel();
            //Decision variable for days to be crashed. //create decision variables.
            List<clsBasicActivity> activities = createActivityList(task,normalTime,crashTime,crashCostperUnit,EF,pred);
            var uC = activities.Select(act => new Decision(Domain.IntegerNonnegative, act.task));
            umodel.AddDecisions(uC.ToArray());
            //Decision variable for EF assigned to each activity. //Create decision variables.
            var uEF = activities.Select(act => new Decision(Domain.IntegerNonnegative, act.task + "_ef"));
            umodel.AddDecisions(uEF.ToArray());

            //Create objective functions.
            var crashcost = new SumTermBuilder(activities.Count);
            foreach (clsBasicActivity act in activities)
            {
                var udecision = umodel.Decisions.First(it => act.task == it.Name);
                crashcost.Add(udecision * act.crashCostperUnit);
```

```
}

//Console.WriteLine(crashcost.ToTerm());
umodel.AddGoal("MinimumCrashCost", GoalKind.Minimize, crashcost.ToTerm());

int tmpcounter = 1;
//Add crashing limit constraints.
foreach (clsBasicActivity act in activities)
{
    var ucrash = umodel.Decisions.First(it => act.task == it.Name);
    umodel.AddConstraints(act.task + tmpcounter.ToString(), ucrash <= (act.normalTime - act.crashTime));
    tmpcounter++;
}

//Calculate the earliest possible finish time and add as constraint for each activity;
foreach (clsBasicActivity act in activities)
{
    for (int i = 0; i < act.predecessor.Length; i++)
    {
        clsBasicActivity pred_act = currentActivity(act.predecessor[i], activities);
        if (pred_act == null) continue;
```

```
            var ucrash = umodel.Decisions.First(it => act.task == it.Name); //crashing days.
            var actEF = umodel.Decisions.First(it => (act.task + "_ef") == it.Name); //current activity EF time.
             var pred_actEF = umodel.Decisions.First(it => (act.predecessor[i] + "_ef") == it.Name); //predecessor
             activity EF time.
            //Add constraint for relationship between the EF time of current activity and predecessor activity.
            umodel.AddConstraints(act.task + tmpcounter.ToString(), actEF >= pred_actEF + act.normalTime - ucrash);
            tmpcounter++;
        }
    }

    //Check the desired duration limit;
    foreach (clsBasicActivity act in activities)
    {
        var actEF = umodel.Decisions.First(it => (act.task + "_ef") == it.Name);//Current activity EF time.
        //Add constraint to check the EF time of each activity w.r.t. due time given.
        umodel.AddConstraints(act.task + tmpcounter.ToString(), actEF <= dueDate);
        tmpcounter++;
    }

    //solve the optmization problem.
    var solution = usolver.Solve();
```

```
            //Report rpt = solution.GetReport(); //by default selected Gurobi solver for muliple integer problem (MIP).
            //Console.WriteLine(rpt); //check the solver picked automatically and time to solve the problem.
            //return the crash data.
            double[] crash = new double[task.Length];

            int j = 0;
            foreach (clsBasicActivity act in activities)
            {
                var ucrash = umodel.Decisions.First(it => act.task == it.Name);
                //var actEF = umodel.Decisions.First(it => (act.task + "_ef") == it.Name);
               //Console.WriteLine(act.task + ":crash-" + ucrash.GetDouble().ToString() + ":EF-" +
              actEF.GetDouble().ToString());
                crash[j++] = ucrash.ToDouble();
            }
            return crash;
    }
```

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Dissertation Title:

Causes of Change Orders and its Impact on Road Maintenance Contracts

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