PREDICTING COST OVERRUN

OF

RAILROAD BRIDGE CONSTRUCTION

BY

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ABSTRACT OF THE DISSERTATION

Predicting Cost Overrun of Railroad Bridge Construction

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Railroad Bridge Construction Projects have frequently exceeded their cost and schedule resulting in major financial losses to the owners and to the contractors, severe interruption of the rail operation schedules and consequently significant inconvenience to the rail commuters. Currently, there are very few methods available to predict the completed construction cost.

This research proposes cost estimating model that incorporates the “major uncertainty constraints” (MUC) which drive both the cost and schedule of Railroad bridge Construction. This approach is an advanced unique model that is proposed for calculation of adequate contingency in a portfolio of construction projects. It is used to update historical contingency values based on new railroad project data that becomes available as soon as construction projects are completed.

A comprehensive literature search reveals that many researchers have developed models to predict cost overruns by considering only change orders as the main driver of construction cost overrun without considering the MUC impact. Owners and managers,

who are in charge of estimating budget and construction duration in both public and private sectors, have limitations in predicting such tasks accurately.

Data on completed projects are obtained from one of the nation largest Transit agency for 70 Railroad bridge construction projects. It examines the challenging environment of Railroad Bridge Construction Industry and describes the development of a predictive model of cost deviation in such high-risk projects. Based on an in-depth evaluation and analysis of completed railroad bridge construction projects, historical data was obtained on reasons behind cost overrun and underrun from 25 Railroad bridge projects which experienced cost overrun and underrun as study cases out of 70 completed general Railroad construction projects.

This study contributes to a uniquely better understanding of the reasons for cost deviation in Railroad bridge construction projects and provides a decision support tool to quantify the extend of that deviation. Its results are expected to support the bridge owners and contractors who are in charge of estimating budget and construction duration in Railroad Bridge Construction sectors in accurately predicting the construction cost based on adequately calculated cost contingency at the business planning or early stage of a project.

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CHAPTER 1: INTRODUCTION

Transportation projects have historically experienced significant construction cost overruns from the time the decision to build has been taken by the owner. This paper addresses the problem of why transit projects overrun their predicted costs. It identifies the owner risk variables that have contributed to significant cost overrun and underrun based on lessons learned from 25 completed Transit Projects, and then uses factor analysis, expert elicitation and the nominal group technique to establish groups of importance ranked owner risks.

Most Railroad bridge construction projects are procured through competitive bidding. Constructors submit bids based upon a defined scope of work, and contracts are awarded to the first responsive responsible bidder. The constructor's compensation can be based upon a fixed lump sum fee for the defined scope of work but frequently a unit-price contract is used. Through change orders, additions and deductions to the scope of work are made, and the constructor's compensation is increased or decreased respectively.

The completed cost to the owner of a competitively bid project often exceeds the original low bid. Factors that contribute to cost overruns and schedule delay include level of accuracy of the pre-existing condition, the major uncertainty constraints (MUC), bidding errors, lack of constructability design consideration, project complexity, poor construction management, labor relations and material availability. The impact of these factors is difficult to predict. Construction completion delay and cost overrun present a risk to the owner because they can exceed the project budget. If the completed construction cost could be predicted, owner's assigned budget and construction duration could be adequately assigned and all the financial risk could be objectively minimized.

1.1 Problem Statement

The railroad construction industry, particularly the bridge sector, fails to manage critical factors such as construction duration and cost by reflecting on the characteristics of a project. On the contrary, the current trend is that the industry often fails to break away from passive methods in which it barely manages to meet the budget and construction duration presented by the policy (Bassioni et al. 2004).

To overcome such a problem and to improve the competitiveness of the construction industry, it is essential to ensure more accurate information on these critical. All available literatures and research conducted in this topic of predicting cost overrun have not considered the major significant impacts of the major uncertainty constraints (MUC) that drive both the cost and schedule of the Railroad Bridge in their studies. It is proposed to develop model for cost overrun that include the MUC effects.

Successful construction projects require that owners adequately predict the construction cost (Hong, Hyun, & Moon, 2009). To do this, various factors of construction costing should be comprehensively considered. However, time and information limitations often make such a task impossible. Because the prediction of construction costs directly affects the owner's business cost, many researchers around the world have sought to develop models with which they could adequately predict construction costs. Researchers have made various attempts to develop a prediction model for construction cost, but none of them has considered the railroad bridge construction (Al-Harbi, Johnston, & Fayadh, 1994; Arditi & Tokdemir, 1999; Attalla & Hegazy, 2003; Christian & Pandeya, 1997; Dogan, Arditi, &Günaydin, 2008; Hegazy & Ayed, 1998).

1.2 Research Objective

The goal of this research is to identify solutions to reduce or mitigate cost overruns occurring in the railroad bridge construction industry by developing an adequate cost overrun prediction model. This study will identify the key components of cost overruns for high speed and light Railroad bridge projects to show how this construction industry can become more efficient and respond better to meeting the national need for construction at an adequate cost level.

The objective in this research is to develop a new model that will effectively plan for projects cost overruns in a portfolio with allocation of sufficient and optimized contingency budget while it has the potential to be updated. To this end, there have been three main objectives:

1. Calculating the required cost increase in the portfolio based on historical performance data;

2. Estimating the pairwise correlation coefficient between costs of projects in the portfolio using a proposed structured guideline and/or a mathematical method;

3. Updating the model using the MUC approach considering the performance of recently completed projects.

The proposed model is a significant improvement over the state of art in research. Also, it is expected that after each time that the model is updated, the required increase (or decrease) in portfolio budget will be reduced, because the accuracy of estimating the contingency is improved.

1.3 Research Questions

1. What are causes of cost overrun in the Railroad bridge construction industry compared to other parts of the construction industry?
2. What is the project cost control procedures currently used in the Railroad bridge construction industry?
3. Why do Railroad bridge construction industry projects have significant cost overruns?
4. How do construction management consultants in the US and worldwide respond to cost overruns?
5. Can construction cost prediction model be developed to solve the problems that result from poor cost control and inadequate control of the uncertainties that result cost overruns in the railroad bridge construction industry?

1.4 Background

Despite the enormous sums of money being spent on infrastructure development around the world, surprisingly little systematic and reliable knowledge exists about the costs, benefits and risks involved. The objective is to provide answers to this research questions listed above in the transport infrastructure projects perform in terms of cost overrun which are highly uncertain phenomena involving significant elements of risk.

A research study conducted by Flyvbjerg, 2003, Touran, Ali, 2006, Schneck, Donald C, 2009 and by Williams, T.P., 2001, 2002, and 2003 on cost overrun in general and on U.S. Rail Transit Project Cost Overrun. This research is published in TRB 2006's annual meeting proceedings which demonstrated evidences of significant cost overrun in U.S. Rail Transit Projects. It concluded that cost estimating has not improved in the last two decades. The research recommended that further extensive studies need to be conducted in this most suffering field of construction.

Since the models developed in previous studies mainly predicted the construction cost in the feasibility phase of projects, it is difficult to use these models in the design phase. Predicting the construction cost in the design phase requires more detailed information than during the feasibility phase (Karshenas & Tse, 2002). Therefore, there are limitations in predicting the construction cost in the design phase with attributes that can only be verified in the feasibility phase.

The proposed model assists project managers, cost estimators and planners to investigate, predict and avoid construction overrun during the early stages of engineering and planning.

This study will focus on the cost overrun problem by conducting research and analyses on several completed high speed rail projects which are experienced significant cost overrun, Tables 1 through 4, and Figures 4 and 5. The research will conclude by developing sophisticated model that can adequately predict cost overrun in the Railroad Bridge Construction Industry. The mathematical model developed in this research provides an analytical tool for calculating contingency levels in such a way to meet agency goals with respect to individual projects and the project portfolio.

The model uses the historical data of completed railroad bridge projects to calculate the primary parameters of the model. The model defines the required confidence level for the risk assessment of an individual project with respect to the desired confidence level for sufficiency of the portfolio budget.

The required increase in the portfolio budget is calculated based on the desired confidence level. The correlation between costs of projects is recognized and a structured guideline along with a mathematical method is suggested for estimating correlation coefficients between costs of projects in the portfolio. To consider the recent performance of projects and to update model characteristics based on new project data that becomes available, an MUC approach is employed to update the model on regular intervals, such as once every two years. As more information becomes available, the required adjustment in portfolio budget will be reduced, because the accuracy of estimating the contingency is improved.

The proposed model using the MUC approach is an effective tool for the agencies to develop contingency budgets based on all the performance data historically available and the new data that becomes available in the future. Even though the proposed model is a generic model that can be used on any type of infrastructure projects, our emphasis in this research is mostly on Railroad Bridge projects.

1.5 Research Contribution

Based on all the prior researches conducted on predicting cost overrun in numerous field of the construction industry, there is no single study is conducted in the most suffering field of construction which is the Railroad Bridge Construction. This cost overrun has caused many Railroad bridge owners worldwide to go over their approved available restrictedly defined budget and fall into significant budget deficit for long term that resulted delays its beneficial uses and disturb its Railroad operations and at the end, it caused major inconvenience to the commuters which may negatively affect their work productivity and disturb their work schedule. Also, this cost overrun has caused many contractors to run out of business and vanished years of success in other construction fields due to the lack of experience of the uncertainties and the undefined factors in the Railroad Bridge Construction which lead to cost overrun.

This research study will focus on major factors that caused the cost overrun which are captured and defined at the completion of Railroad bridge construction projects after experiencing significant budget overrun. This study will also provide techniques, guidelines, models and a new road map to predict cost overrun in the early engineering and planning stages.

These major factors that need to be considered by the bridge owners as well as the contractors in order to avoid cost overrun are:

- Track outages
- Marine outages: Mariners approval, Port authorities, US coast guard
- Site access approval

- Construction staging/project planning
- Third parties approvals which are directly affected with the construction, such as township, fire dept., school,
- HEPO: Historical Environmental Preservation
- ROW permits: material storages
- Restricted Construction working time
- Geotechnical Investigation: categorical Exclusion, DEP and EPA approval
- Restricted working schedule: Hourly schedule
- Project wide Communication: between all project team/coordination between construction and design groups, owner, contractors, and third parties.
- Unforeseen existing Field condition/design change
- Material long lead fabrication and delivery time (such as Steel)
- Material cost inflation
- High Labor cost for experienced Railroad bridge worker (hardly to find)

The research will include 70 completed Transit construction railroad projects that are experienced cost underrun and overrun, as listed in table 1. Out of these 70 projects that experienced significant cost overrun which are analyzed, only 25 projects will be selected as cases studies as the author was the direct Project Manager on these contracts.

Table 1: Cost Performance Data from actual completed Transit Projects

Date Executed	Contract Title	Original Value	Current Value	% Greater or Less than Original
12/12/2002	North Jersey Coast Line, MP.3.22, Substructure Rehabilitation of Morgan Drawbridge over Cheesequake Creek, Borough of Sayreville and Old Bridge Township, Middlesex County, NJ	320,561	221,505	-31%
9/9/2005	Construction of Underground Conrete Duct Bank Encasements for Utilities at Fifty-one Grade Crossing Intersections Along the Pascack Valley Line Located in Rockland County New York and Bergen County, NJ	1,678,802	1,179,471	-30%
5/10/2002	Headwalls & Tunnels Rehabilitation at Raritan Valley Line Culvert M.P. 55.73 Glen Garner Borough, NJ	112,500	87,000	-23%
12/3/2008	Painting of Bridges at MP 25.01-26.27 Montclair Boonton Line, Montville, Morris County, NJ	371,000	296,553	-20%
6/20/2003	Boonton Line M.P. 19.43 Scouring Repair of Railroad Bridge over Passaic River, Township of Wayne and	167,200	135,474	-19%
7/3/2006	A..C. Rail Line Bridge Rehab of Absecon & Shore Road	796,500	667,779	-16%
11/29/2007	NJ Transit Newark Bus Rapid Transit Construction, Phase I	529,355	445,738	-16%
3/19/2007	Radburn Station New Canopy Installation, Fairlawn, New Jersey	611,100	518,919	-15%
9/5/2007	Rehabilitation of Main Line U.G. Bridge 12.13 over Clifton Boulevard	726,020	635,481	-12%
1/13/2003	West End Truss-Bearing Replacement Morris & Essex Line, (M.P. 1.89), Jersey City, NJ	238,000	209,541	-12%
10/10/2007	Pedestrian Tunnel Repairs Chatham Rail Station	332,816	296,045	-11%
1/26/2005	Construction of Pascack Valley Line Right-Of-Way Improvements, Rockland County NY, Bergen County	3,448,060	3,070,727	-11%
5/7/2004	Canopy and New Roof Structure Repair at Cranford Rail Station	584,000	525,046	-10%
6/22/2004	Canopy Restoration - Red Bank, NJ	589,802	531,031	-10%
6/14/2000	Long Branch Station Platform Canopy Improvements	89,906	81,226	-10%
3/10/2008	Painting of Spans 12 & 13 at HX Undergrade Drawbridge 5.48, (BCL),East Rutherford, NJ	1,676,500	1,517,232	-10%
10/27/2005	Pedestrian Tunnel Repairs-Morris Plains Rail Station	453,360	412,278	-9%
9/15/2005	Painting of Bridge and Walkway @ M.P. 11.34 Montclair-Boonton Line, Watsessing, Bloomfield,	96,333	87,650	-9%
7/10/2007	Construction of Big Shark Drawbridge Approach Span Replacement (NJCL Undergrade Bridge 30.43)	10,362,000	9,467,412	-9%
2/5/2010	Hoboken Rail Yard - Long Slip Bulkhead Wall Collapse - Emergency Repair Authorized	1,723,667	1,577,209	-8%
6/13/2008	Historic Building Exterior Restoration of Rutherford Train Station, Rutherford, NJ	1,382,000	1,278,602	-7%
3/7/2007	Rehabilatation of Four (4) UG Bridges on the Raritan Valley Line, City of Plainfield, NJ	11,224,411	10,441,405	-7%

Continuing Table 1: Cost Performance Data from actual completed Transit Projects

Date Executed	Contract Title	Original Value	Current Value	% Greater or Less than Original
2/26/2008	Newark Drawbridge & Approach Spans Rehabilitation Project	23,281,911	21,872,399	-6%
12/19/2007	Construction of the Hoboken Terminal Long Slip Pedestrian Bridge	6,446,310	6,076,524	-6%
12/18/2006	South Amboy Train Station Contract 1, Catenery Foundation and Structures	4,223,450	4,007,132	-5%
11/14/2005	Repairs to the Walter Rand Transportation Center	1,189,450	1,132,298	-5%
6/27/2005	Replacement of Little Brielle Timber Bridge, NJCL M.P. 36.38 Borough of Point Pleasant Ocean County, NJ	2,743,000	2,617,258	-5%
5/2/2000	Pennsylvania Station Accessibility Improve	4,417,800	4,220,899	-4%
7/7/2008	Construction of Communications Upgrades for Paterson Rail Station, Paterson, NJ	1,394,000	1,343,810	-4%
3/4/2004	Construction of Emergency Platform Repairs at Trenton Station, Trenton, NJ	209,205	201,705	-4%
4/1/2005	Rehabilitation and Outlet Stabilization of a Culvert on the Morristown Line M.P. 21.55 in Summit, New Jersey	219,500	212,394	-3%
7/11/2005	Raritan River Drawbridge Fender System - Emergency Repairs	207,039	201,841	-3%
6/19/2000	Construction of Overhead Contact System for Orange St.	410,500	400,239	-2%
5/22/2002	Replacement of M & E Line MP21.51 Bridge over Passaic Avenue in Summit, NJ	1,585,495	1,549,677	-2%
2/24/2009	Construction of Interior Improvements to Elizabeth Rail Station, Elizabeth, NJ	676,792	661,861	-2%
9/28/2004	Replacement of Jonathan's Thorofare Bridge, Atlantic City Line M.P. 54.86	673,700	661,456	-2%
2/11/2005	Machinery Replacement, HX Drawbridge-over Hackensack River, U.G. Bridge 5.48 Secaucus, Nj	3,065,000	3,033,543	-1%
7/16/2004	Ramsey Train Station Building Renovation	702,606	698,954	-1%
12/17/2002	Hog Back Bridge Replacement Gladstone Line over Raritan River	1,877,000	1,898,551	1%
3/30/2004	M&E Station Rehabilitation and Viaduct Repairs Effort B, Viaduct and Waterproofing Brick Church, East and	22,979,590	23,254,558	1%
10/17/2003	Substructure Repairs to HX Draw Bridge Over Hackensack River-Secaucus, Hudson County, NJ (U.G.	1,841,000	1,879,230	2%
12/3/2001	High Level Platforms at Hazlet Rail Station, Hazlet, NJ	5,976,609	6,149,951	3%
4/12/2002	Construction of the New County Road Bridge & Station Access Road for the Secaucus Transfer Station	17,373,627	17,903,828	3%
7/3/2002	Reha of U.G. Bridge 30.43 Big Shark Drawbridge over Shark River	2,767,550	2,859,070	3%
6/27/2005	Trenton Rail Station Rehabilitation-Main Contract	53,237,058	55,277,298	4%
11/30/2005	Morrisville Yard-Phase 2 Construction	97,877,000	101,746,954	4%

Continuing Table 1: Cost Performance Data from actual completed Transit Projects

Date Executed	Contract Title	Original Value	Current Value	% Greater or Less than Original
4/12/2004	Hoboken Ferry Terminal Structural Repairs and Plaza Façade Stabilization	7,747,000	8,058,710	4%
8/23/2001	Rehabilitation of Franklin Avenue Railroad Bridge, Mainline M.P. 20.98	1,821,775	1,895,710	4%
8/12/2002	Replacement of Welch Spur Rod Bridge over Raritan Valley Line	136,000	144,625	6%
8/12/2003	Newark Rail Link, Contract #2, Surface Stations and Systems	62,812,777	67,835,823	8%
4/17/2003	NERL Tunnel Construction	21,632,625	23,641,989	9%
12/14/2007	Station Repairs to the Park Avenue Light Rail Station	897,000	995,318	11%
4/17/2009	Market Street Bus Garage MPE Groundwater Remediation	849,005	950,618	12%
12/14/2000	Replacement of Morristown Line Culvert MP 48.00 in the Boro of Netcong, NJ	73,000	81,780	12%
5/23/2001	Replacement of Gladstone Line Culvert at MP 34.25 Morristown Road, Bernardsville, NJ	124,670	141,247	13%
12/27/2006	Construction of the 31st Street Entrance for New York Penn Station	11,711,500	13,311,397	14%
4/2/2001	Rehabilitation of Bergen Tunnel - North Tube	56,388,044	67,241,233	19%
10/29/2001	Overhead Feeders for the South Amboy Substation	218,000	260,175	19%
9/10/2001	Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	33,728,949	22%
4/2/2003	Newark-Elizabeth Rail Link MOS-1 Advance Utilities-A+ Grade Portion	3,357,210	4,149,985	24%
8/13/2002	Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%
3/14/2005	Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	2,074,424	32%
5/6/2005	North Retaining Wall Repairs Morristown Line M.P. 8.0 to M.P. 9.1 Newark, NJ	3,521,341	5,192,093	47%
9/11/2000	Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth	2,676,315	4,272,426	60%
11/8/2002	Construction of the Station Signage Program for the Secaucus Transfer Station: GC-09	1,152,598	1,892,728	64%
10/30/2002	Culvert Rehabilitation Headwall Extension and Retaining Wall Replacement, Morristown Line M.P. 17.46, Millburn, NJ	73,500	130,893	78%
8/2/2000	Repair of the Raritan River Bridge Fender System	104,106	200,502	93%
6/17/2002	NJCL Catenary Structure Repairs	2,239,730	4,639,160	107%
2/24/2003	Design/Construction of Roebling Station Stop Parking Facility at Designation Superfund Site	2,176,000	5,435,381	150%

CHAPTER 2: LITERATURE REVIEW

2.1. Prior Studies in cost overrun prediction

Uncertainty characterizes situations where the actual outcome of a particular event or activity is likely to deviate from the estimate or forecast value (Raftery 1994). There are many uncertain variables during project implementation that dynamically affect project duration and cost (de Cano, A. and de la Cruz, P.E.2002). In fact, all construction projects are, by their very nature, economically risky undertakings and projects let on the basis of competitive bids can add to such risks. There are considerable research studies are conducted in predicting cost overrun at completion using the regression modeling where highly considerable achievement are reached. However, most of these studies did not reached the level of details of the most unique factors in the specific field of railroad bridge construction that directly impacting the cost at completion.

Most transit projects in Australia, Canada, New Zealand, Sweden, the UK and the US adopt a common delivery model known as the 'traditional model', or Design-Bid-Build (Pakkala 2002). This means that the design/engineering services are produced first, and then another procurement contract is tendered for the actual construction or physical works based upon the design/engineering portion of the contract. However, the main criticisms of the traditional DBB method are the lack of innovation, delayed completion periods and cost overruns that are sometimes encountered. Since the owner bears most of the risks of both the design and construction aspects, there needs to be better practices to ensure the owner's needs are being met and that quicker project completion times and cost effective solutions are provided (Pakkala 2002).

Considerable amount of researches and findings) are conducted on cost overrun using multivariate regression which the most common method of modelling construction costs by Dr. Williams, T.P. (1998, 2001, 2002, 2003, 2007). This regression analysis technique was used here to manage the multiple project variables and relationships between projects, project risks and project cost overrun.

But no research is conducted on the actual risk factors that are specifically impacting the Railroad bridge construction.

A wide variety of factors influence construction costs of railroad bridge projects. In a study conducted in Newfoundland, Hegazy and Ayed (1998) found that season, location, type of project, contract duration and contract size had a significant impact on individual contract costs. Similarly, Herbsman (1986) found that in addition to input costs of materials; labor, equipment and the total volume of contracts bid each year (the so-called bid volume) all influence project costs. Yeo (1990) and Minato & Ashley (1998) suggest that cost overrun arises primarily because of four factors: external risk (due to modifications in the scope of a project and changes in the legal, economic and technologic environments); technical complexity of the project; inadequate project management (due to the control of internal resources, poor labor relations and low productivity) and unrealistic estimates (because of the uncertainties involved). Akinci and Fischer (1998), on the other hand, consider design and project-specific factors to be the key factors affecting the cost estimate of a project, including vagueness in scope, design complexity, and project size. Engineering designs have a high level of influence on project costs and sometimes unsatisfactory design performance can lead to cost overrun

(Barrie and Paulson 1992). Anderson and Tucker (1994) report that their survey found about one-third of architectural/engineering projects miss cost and schedule targets. Chang (2002) notes that, as reported by Smith (1996), there have been few instances where an engineering design is so complete that a project could be built to the exact specifications contained in the original design documents.

Furthermore, in their research study to quantify the impact that project changes have on engineering and construction project performance, Ibbs and Allen (1995) define change as any event which results in a modification of the original scope, execution time or cost of work.

Because change may occur throughout all phases of a project, their research focuses on the quantitative impacts that change has on the detailed design and construction phase of projects.

They found that project change has a large effect on the financial performance of a construction project. In addition, Thomas (1985) studied railroad bridge construction programs and reports on selected claims for project changes and cost/schedule overrun on these same projects. The study concludes that project change has a direct effect on costs and schedules of construction projects, primarily cost/schedule overrun.

While the reasons for cost overrun can be obvious, the problem still remains that an estimate is a forecast of a cost to be incurred sometime in the future — the problem being that the future is not always predictable. Kayode (1979) reports that project cost overruns are caused by rising costs largely due to inflation, inadequate analysis and inadequate information. Orji (1988) is of the opinion that the causes include certain government fiscal/monetary policies, poor costing of projects, inflation within the economy and some practices of project participants, especially those involving government projects. A further reason advanced for the incidence of project cost overrun is attributed to costing methods.

In construction research, models have been developed showing cost influencing factors derived from past records of construction costs (Wilmot and Cheng 2003). Extrapolation of past trends has been used to forecast future overall construction costs, however such models are usually only used for short-term forecasting because of their reliance on the notion that past conditions and specifications do not always prevail in the future.

Many factors affect project construction costs and most construction cost models developed in the past have used only a few of the many possible influential factors identified to date. Research of this type has also been hampered in the past because adequate data have not been available. The interrogation of in-house historical databases is probably the best source of data to assess risk occurrences or consequences of risk events and in many cases these databases are inadequate or disjointed, unavailable or supplemented with personal information bias (Al-Bahar and Crandall 1990).

Many research projects to date consider only the final outcome of contracts within the project and have not considered the owner’s risks associated with the full project budget. That is, the failures that leads to cost overrun in the overall project from the time the owner's decision-to-build is made until its completion. On the other hand, owners require different contingencies for different elements of projects (Eden et al. 2005). The establishment of a range of contingencies can require a considerable amount of work by estimators and so a simple contingency across the board is included in order to acknowledge the difficulty of identifying project uncertainty (Baccarini 2004). Therefore, this research aims to address this issue by providing owners with a cost overrun model that correlates risk contingency with railroad bridge project attributes.

In general, the literature supports the notion that accurate early cost estimates for engineering and construction projects are extremely important to the sponsoring organization. Accurate cost estimates are vital for business unit decisions that include strategies for asset development, potential project screening, and resource commitments for further project development. Several research studies of railroad bridge construction projects attempt to predict the amount a construction contract might increase in cost while taking into account various factors that could be used for such predictions.

While some research to date has generally revolved around the cost increase in contracts within projects, several research studies have also demonstrated that changes initiated during construction projects have a large effect on their financial performance. Research studies demonstrate that the estimating methodology and accuracy of cost estimates can be major reasons for cost increases. Research has also been conducted to predict the extent to which the cost of a construction contract might increase, taking into account various project prediction factors.

In conclusion, therefore, although many of the risk techniques are effective for the particular types of projects to which they are applied, these generally treat projects as independent entities with little attempt to categorize projects into specific sub-types from which detailed analyses can be undertaken. Also, little empirical research has determined owner risks leading to cost overrun associated with certain types of railroad bridge projects and their delivery methods. In the past, railroad bridge cost estimating models have been established that describe construction risks as a function of factors believed to influence construction costs. Typically, the models established in this manner have been used to estimate the cost of individual contracts only, rather than project budgets. Therefore, empirical research is needed to assess whether certain railroad bridge projects' characteristics and delivery methods indicate a higher propensity to cost overrun. The research needs to be focused on the owner, not the contractor, and with a particular focus on overrun relating to the decision-to-build baseline budget.

In this study the literature review of cost overrun prediction and control procedures consists of three major parts. The first part deals with the project cost control procedures as applied currently in the transit construction industry and the concepts of cost overruns. The second part discusses the concept and causes of cost overruns found in the Transit Construction industry including the time impact analysis and schedule delay causing the cost overrun. The third part covers cost overrun prevention by applying the developed proposed model.

Prior studies conducted by Pickrell report illustrate trends of cost overruns of transit projects in general. The results of the Pickerel's (1990) UMTA report on cost overruns in rail projects in the United States have been widely cited in several articles and research publications (Flyvbjerg et al 2002; Touran et al 1994). The report looked at 10 rail projects built in the 1980s. Many more rail projects have been built in the United States since 1990. Flyvbjerg etal. (2002, 2003) conducted a study for projects worldwide and concluded that cost estimating has not improved in the last two decades. Other research compares the results of the Pickrell study to cost overruns of transit projects completed after 1990 to see if there is any improvement in estimating the capital costs of rail transit projects.

Many factors have been suggested for the cause of cost overrun including but not limited to optimistic underestimation of costs at conceptual phase, the lengthy project approval and construction process, omission of project components during early phases, addition to project scope during project development, and unforeseen latent conditions that are difficult to predict. Comparison is performed at a macro level and is not looking at causes of cost overrun due to significant rail operation constraints to the construction of the Railroad Bridge Construction.

2.1.1. Concept of Cost Overrun

Cost overrun is critical and needs to be study more to alleviate this issue in the future. Cost overruns are a major problem in the construction industry (Angelo & Reina, 2002).

Failure of accurate estimates and inadequate contingency leading to cost overruns results from many factors, including the general state of the economy, government regulation, inadequate supervision, and poor plans and specifications (American Society of Civil Engineers, 1985).

A potential project overrun can be detected from the major deviation of actual and proposed costs (Bent & Humphreys, 1996). Practically, an inaccurate estimate will more likely lead to project overruns than a lack of control and poor site management (Bent & Humphreys,

1996). Components related to project costs usually cause overruns, e.g. project specification. Because the specifications can affect the entire cost of the project and budget, it is essential to construct the project to specifications to keep project cost on budget.

Cost overrun results from lack of effective cost control, lack of reliable data, ineffective planning, insufficiency of updated data, or ineffective management (Construction Management Committee, 1999). One of the causes of cost overruns is ineffective work breakdown structure which some projects do not use for managing project costs. Effective work breakdown structure and cost control can reduce the problems with cost overruns and will help manage the project budget, cost estimate for bidding, and project cost control.

2.1.2. Causes and Impacts of Cost Overrun

Halpin (1985) points out that both project management and upper-level management must be concerned about the costs of all construction activities since cost overruns can increase project cost and reduce profits. Matthews (2002) states that many factors can cause cost overruns, including inaccuracy of project documents and estimates (Matthews, 2002). Other causes of overruns are underestimated costs, overestimated revenue, underestimate of environmental impacts and overvalued economic development (Flyvbjerg, 2003). Goodyear (2002) indicates that the requirements of project participants beyond projected requirements can result in cost overruns (Goodyear, 2002).

In 1997, Harris, Holt, Kaming, and Olomolaiye (1997) researched cost overruns and discussed some of the factors responsible which included unpredictable inflationary material costs, inaccurate material estimates, project complexity, lack of information about the site geography, lack of contractor experience on certain type of projects, and unfamiliarity with local regulations. Even a small percentage in cost overruns can equal a large amount of money, especially in the case of large projects.

In a construction project, many parties work together to execute the project in a timely manner and within budget. However, the responsibility of each party needs to be identified before the construction starts, so that they can work efficiently (Kormani, 2002). Since cost overruns can create a considerable risk, Komarni (2002) recommends that owners and contractors share this risk together.

Possible causes of overruns from the beginning of projects include omission of some items and out-of-date cost data (Killingsworth, 1988). The cost information such as local labor and equipment rates, labor productivity, and material costs used in estimating should be accurate. These data can be obtained from historical data, past projects, a proprietary database, or current local and material costs. Besides the inaccuracy of cost data or failure of estimation, the type of contract can have an impact on cost deviation. Extensive documentation associated with any contract should illustrate both client and contractor objectives to protect their own interests. In addition, the contractor needs money to provide bonds, safety barriers, and to prepare schedules and reports which depend on direct labor, materials, equipment and project supervisory costs (Neil, 1982).

Cost overruns in railroad bridge construction projects occurred due to the following constraints which resulted extensive construction delays:

- Unavailability of track outages
- Marine closure (third party)
- Site access
- Owner’s Changer Orders

- Incomplete Drawings Originating from Architects
- Inexperienced Construction Personnel
- Unqualified Laborers

According to their research, in addition to the critical causes of cost overruns listed above especially in large public construction projects, there are other contributing factors such as the inaccuracy of quantity estimate, increased material cost due to inflation, environmental restriction and the inappropriate design.

2.1.3. Impact of time delay on cost overrun

Design changes resulting in construction delays can cause critical problems for the owner and the contractor who may incur higher expenses in the costs of materials or because of delays in material deliveries. As a result, all alternatives proposed should be evaluated and estimated separately from other construction items. In many cases, it is difficult to complete the design before the construction begins. The American Society of Civil Engineers (ASCE) (1985) states that project cost control is conducted based on the estimate and budget, while project schedule control is conducted based on the project schedule. They further point out that the network is the plan which becomes the schedule after time durations are assigned to the network activities.

Ritz (1994) states that the fundamental objective of the construction team is to complete the project as indicated in the contract, on schedule and within the proposed budget, thus project scheduling can have an impact on other project components such as estimating or budgeting.

The plan will need to be updated to achieve the project's target which is to keep costs within budget and keep the schedule on track. (Gould, 2002). Management needs to modify the project schedule and estimates because of changes or discrepancies that may occur during the construction period (Civil and Environmental Engineering, 2004). Ritz (1994) also points out that one-time completion can help owners achieve their requirements and schedules, and reduce high costs due to added interest and start-up costs. The owner may lose the advantage of cost control if the project schedule needs to be extended (Ritz, 1994). Time and cost are critical to the project because of their complex interrelationship. As the project proceeds, the cost and budget can be influenced by delays and can lead to the adjustment of the activity schedule (Civil and Environmental Engineering, 2004). Bent and Humphreys (1996) mention that timely evaluation of potential and schedule risk and the presentation of recommended solutions to project management are required to achieve effective project control. It is difficult to have effective project control processes that cover both time and schedule.

The schedule is an important component of the cost estimate. As a result, the schedule should be made prior to estimating the project costs based on construction techniques (Oberlender & Peurifoy, 2002). The construction period of each phase of the project and of the project as a whole affect the direct and indirect costs (Oberlender & Peurifoy, 2002). In some case, the schedule needs to incorporate and be compatible with decisions made in the detailed cost estimate (Oberlender & Peurifoy, 2002).

2.1.4. Cost Overrun Prevention

A project has to be planned effectively and operated professionally to accomplish the objectives of time, cost and performance (Choudhury, 2001). Management must be vigilant to detect actual or potential cost overruns in field construction alleviate the possibility of cost overruns (Halpin, 1985). Effective construction management can prevent cost overruns (Kaming, Olomolaiye, Holt, &Harris, 1997) with Ill-established numbering or coding system to manage costs effectively (Civil and Environmental Engineering, 2004). Besides a numbering or coding system, a sensitive chart of cost accounts can provide evidence of cost deviation (Halpin,1985). In addition, this chart should establish a detailed cost plan which is not too complex.

This plan should be based on the cost estimate and its scaling to the time frame scheduled for the project. Several researchers discussed cost overrun concepts and provide guidelines on the prevention of this problem. Cost control is a significant task for the construction management team (Bureau of Engineering, 2003a). The purpose of project cost control is to first maintain control of the final budget for a project and second, identify the existence and extent of problems that may cause cost overruns on a project (Civil and Environmental Engineering, 2004). Project control not only provides recommendations for cost savings; but also identifies the costs associated with deviations from the construction plan. Construction planning and cash flow projections support the effective management of the total project cost control. Analysis of cost estimates and change orders can identify the potential for cost overruns. To achieve a successful project, the deviations and work progress need to be evaluated periodically to deal with contingencies from inside or outside the project (Construction Management Committee, 1999). Project inspection and control are major factors of successful construction management. Cost overrun problems are caused by ineffective construction management and inadequate cost control systems

2.2. Gaps and arguments in prior and existing researches

Many causes of cost overruns are discussed; however, none of the previous research discussed how to implement cost overrun concepts that minimize the extreme high risks caused by the significant rail operation constraints to the construction of the Railroad Bridge Construction. Many factors have been suggested for the cause of cost overrun including but not limited to optimistic underestimation of costs at conceptual phase, the lengthy project approval and construction process, omission of project components during early phases, addition to project scope during project development, and unforeseen latent conditions that are difficult to predict, but none of the prior researches has considered looking at causes of cost overrun due to significant rail operation constraints to the construction of the Railroad Bridge Construction.

There are many causes for cost overruns (Halpin, 1985; Kaming, Olomolaiye, Holt, &Harris, 1997; Kerzner, 1995; Killingsworth, 1988). Yet, there are many ways that cost overruns can be avoided on major construction project. However, there has been no significant research on how these cost control procedures can be improved and how cost overruns can be avoided in given the peculiarities and development stage of the construction industry in Railroad Bridge Construction.

2.3. Justification for the need of the proposed research

The proposed research will fill the gap on all the previous research in the cost overrun prevention protocol in the railroad bridge construction which is experiencing significant cost overrun that reaches up to 150% above the original contract amount and underrun up to 40% below the contract amount as illustrated in Fig. 1, 2, 4 and 5, which demonstrates the variation between the original contract value and the cost at completion. This will be accomplished by developing a model to capture all the significant rail operation construction constraints that are directly impacting the construction cost of rail bridge rehabilitation projects and represent major risk in bridge construction which leads to the cost overrun.

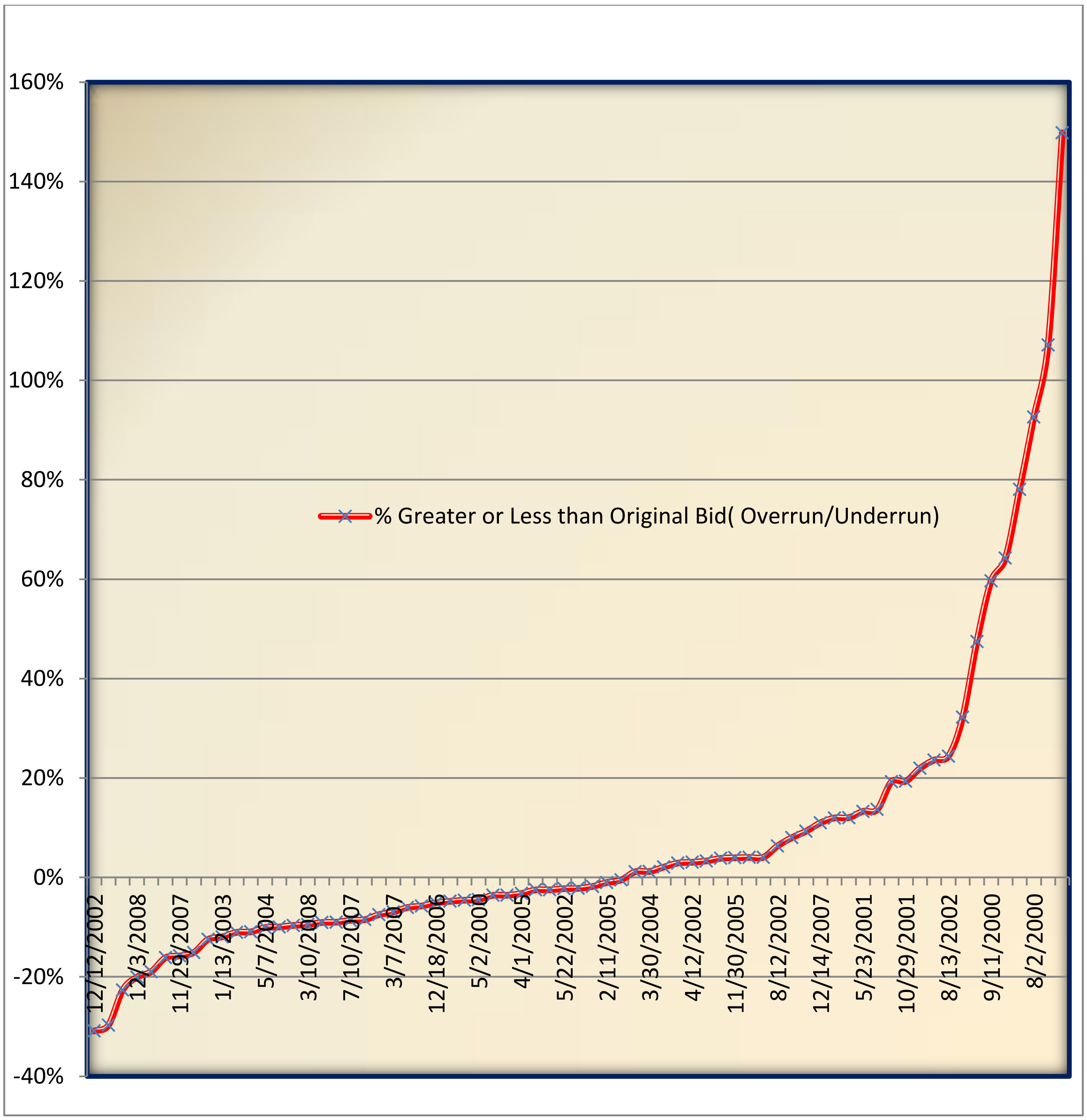

Figure 1: Percentage of Cost Overrun/ Underrun vs. years completed

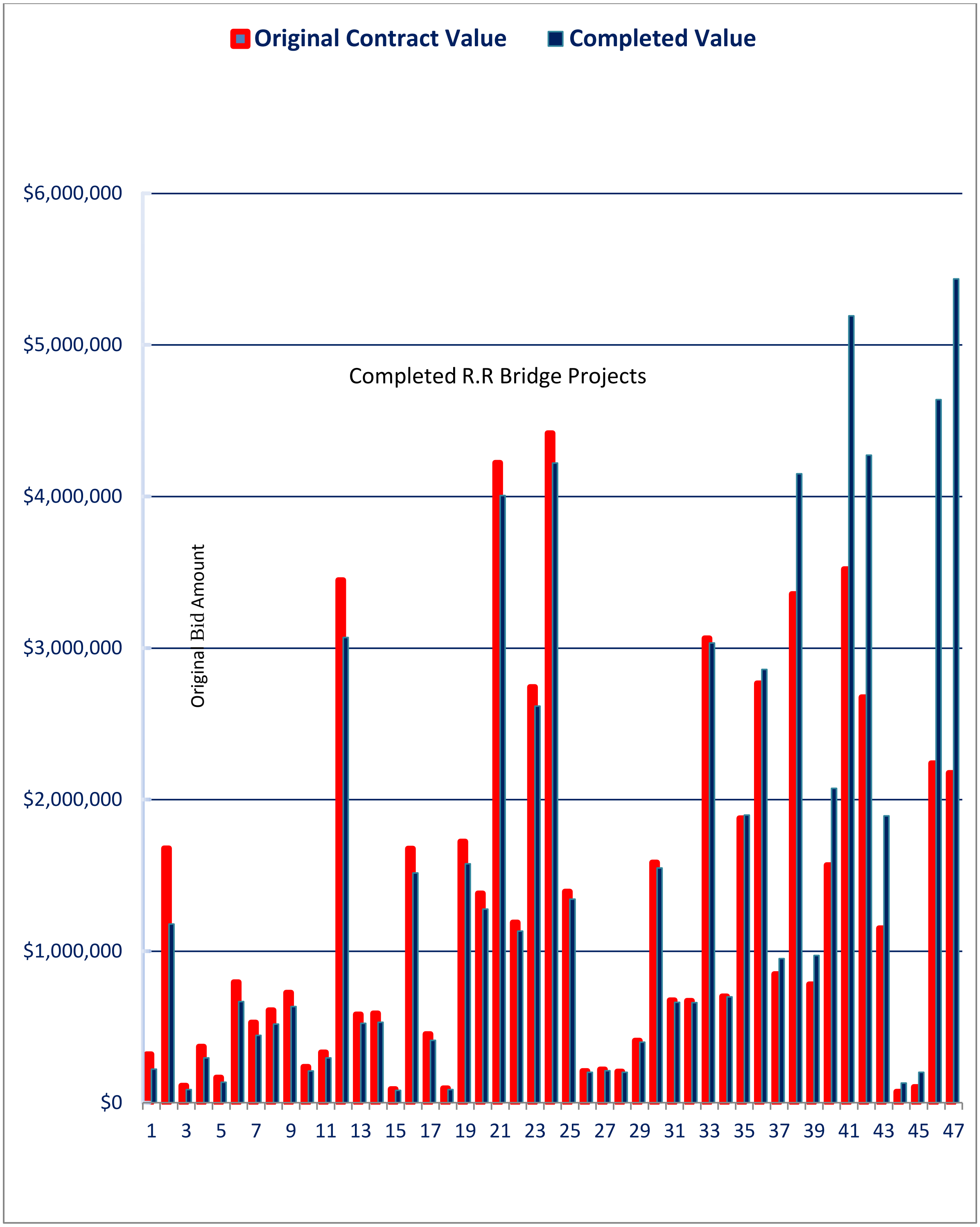

Figure 2: Completed contract values vs. Original Bid values on R.R. Bridge Projects

CHAPTER 3: METHODOLOGY

This research will deal with 70 actual railroad bridge construction projects that are completed and have experienced cost overrun. The research will dig deeply into only 25 projects as case studies into the actual conditions that contributed to cost overrun including human behavior, site conditions, organizational and third parties constraints related to analyze common and unique causes of cost overruns and uncertainties. Regression analysis will be conducted on only 15 cases that experienced cost overrun.

A proposed model will be developed and tested on 30 new cases, which were not part of the cases used in the regression analysis, where the first 3 cases initially tested for the model's level of efficiency followed by the remaining 27 new cases for confirming the model's efficiency and accuracy level in predicting the cost overrun or underrun.

A qualitative approach will be employed as the primary research tool for the study.

The main objective of the research described in this paper was to identify the factors that influence significant project cost overruns for the owner and to propose an analytical model that correlates project attributes to the level of their cost overruns and owner project risks relating to decision-to-build budgets.

This chapter explains the overall framework, methods, and underlying assumptions for predicting and analyzing the problem of cost overruns. Figure3 presents an overview of the steps. The methodology includes preliminary descriptive statistics that examines the general temporal and spatial trends in the data. It also includes correlation matrix analysis, pairwise tests, analysis of variance, and statistical modeling. The methodologies include definitions of dependent variables (cost overrun amounts and rates) and independent variables (potential influential factors), and selection of model categories and appropriate mathematical forms.

The methodology was designed to yield statistical models with a view to predict cost overruns, but more importantly, to identify significant factors that influence cost overruns. In order to provide adequate answers to the research questions, the following five research stages were adopted:

1. Establishment of a data source for the railroad bridge construction projects
2. Identification of project work types and cost overrun factors from historic project data
3. Utilization of principal component analysis and factor rotation on cost overrun factors in order to consolidate data
4. Use of the nominal group technique with railroad bridge construction experts to elicit groupings of cost overrun factors and railroad bridge project types
5. Use of multivariate linear regression analysis to investigate correlations between cost overrun risk factors and project attributes by using historic project data.

An historical analysis methodology was used as it provides an insight into the current research problem relating to cost overruns in Transit railroad bridge construction estimates through the examination of what had happened in the past, using analysis, analogy and trend extrapolation of historic data (Kirszner and Mandell 1992). The approach entails researching construction delivery practices to identify risk occurrences as well as risk constraints and processes to minimize owner risk exposure leading to cost overrun. It also provides a means for the development of consensus of risk factors based on expert opinions and trend exploration in addition to the development of models of cost overrun based on historical project data and project attributes.

In order to establish a data source of railroad bridge construction projects, the research stage required an appropriate sample of rail bridge infrastructure projects that are large enough to allow statistical analyses of cost overrun factors and project costs. The research focused only on 25 R. R. Bridge projects as case studies which were analyzed in depth on the actual conditions that contributed to cost overrun. These projects are constructed within the last 10 years and they contained data on substantial project cost overruns. The railroad bridge project construction data was collected from the actual Transit construction contract and procurement divisions as well as the author file records when he was acting as the project manager on these contracts.

The question that will be analyzed in this research is what are the unique major uncertainty constraints that are directly impacting the cost overrun in specifically railroad bridge construction and how they can be minimized by preplanning for in the early stages of preliminary engineering planning, budgeting, estimating, design and procurement and very construction start-up using the MUC approach.

All projects subsequently analyzed were those delivered by the traditional design-bid-build method. For the purpose of the research, the total project cost estimate included the estimated costs of all component activities from the initiation of the project design to construction finalization.

The second stage of the research involved the identification of project work types and cost overrun factors from the historic data. The available railroad bridge data contained individual descriptions of all the work types as well as the reasons for individual projects having exceeded the owner's programmed budget. The third stage of the research involved the development of consolidated groupings of high level project risk factors contributing to cost overrun in rail bridge construction projects and to develop a statistical procedure that is able to uncover relationships among numerous variables that contribute to specific cost overrun reasons in railroad bridge construction projects.

The final stage of the research process involved the identification of statistical models that can explain the correlation between the cause, effect and other relationships relating to cost overrun. Multivariate regression is the most common method of modelling construction costs (Koppula 1981; Blair et al. 1993; Williams 2003) and it was used here to manage the multiple project variables and relationships between projects, project risks and project cost overrun.

The dependent variable adopted in the model was the continuous variable percentage cost overrun to denote the difference between the owner's actual project cost and programmed cost, expressed as a percentage of the programmed cost. This correlation between the following ten project variables was analyzed:

- Track outages constraints
- Construction staging/project planning
- Marine outages: Mariners approval, Port authorities, US coast guard
- Third parties approvals which are directly affected with the construction, such as township, fire dept., school, HEPO: Historical Environmental Preservation

- ROW permits and site access approval
- Bridge Functional Type (Movable or non-movable)
- Project wide Communication: between all project team/coordination between construction and design groups, owner, contractors, and third parties.
- Unforeseen existing Field condition/design change
- Bridge Material long lead fabrication and delivery time and Material cost inflation
- High Labor cost of experienced Railroad bridge worker (hardly to find)

The Multiple Regression Analysis technique that will be used in this research is a statistical procedure used to find relationships among a set of variables. In regression analysis, there is a dependent variable, which is cost overrun that will be analyzed, and ten related independent variables that are listed above. The multiple regression analysis finds the coefficients for each independent variable so that they make the line that has the lowest sum of squared errors. Each independent variable has another number attached to it in the regression result called "p-value" or significance level. The p-value is a percentage. It tells you how likely it is that the coefficient for that independent variable emerged by chance and does not describe a real relationship. A p-value of .05 means that there is a 5% chance that the relationship emerged randomly and a 95% chance that the relationship is real. Regression measures the effect of changes in the independent variable on the dependent variable

The null hypothesis was that there was no correlation between the size of cost overrun and the above variables. Linear normal models were used (i.e. regression analysis with appropriate f -tests and t-tests). For each test, the p-value was reported as a measure for rareness if identity of groups was assumed.

Forward, backward and stepwise selection regression methods were used. The stepwise regression method delivered the most appropriate model after excluding outlier data and data transposition. Correlation analysis was undertaken to identify project variables that correlated with project cost overrun. This examined the performance of various models and the relationships between variables. Pearson's correlation coefficient "ρ" was used to examine the relationship and measure its strength between the data and for developing the rank order of regression models in terms of goodness of fit. The coefficients of multiple determinations – R square and adjusted R square statistics were also used as they allowed the identification of the best model.

The “case study approach” on 25 completed Transit rail projects will be used to explore the progress of the work and describe certain interventions that occurred during the actual construction period. In addition, the technique will be employed to examine the interplay of all variables in order to provide as complete an understanding of an event or situation as possible Through case studies, I will address the research questions and investigate why a cost overrun occurred and how cost control could be applied to reduce the level of cost overruns on bridge railroad construction projects. The data required for this study include the project’s initial costs, the actual costs after completion, monthly reports, project’s location, starting and completion date and information about the parties involved in the project.

The cost control procedures and cost overrun theory used in the bridge railroad construction industry will be analyzed.

The research is conducted on multiple actual case studies which represent some particular features of a typical project and provides a basis for investigation into the fundamental research question related to the prevalence of cost overruns in the Bridge railroad construction industry. These case studies are based on personal deep investigations of the all project field actual conditions that contributed to cost overrun where the author was either the head or principal of the original management team.

There are two rationales to apply single case study in this research. The first rationale is that the selected case study meets all of conditions to answer the research questions. Those cases were a successful bridge railroad projects. It can represent a significant contribution to knowledge. In addition, those study cases will also help to refocus future research in this field. The second rationale is that I had an opportunity to observe and analyze the events prior to begin the research. My observation of the problems of cost overruns occurred in 70 completed bridge railroad projects which are constructed from 2000 to 2011, in Tables 1. Detailed breakdown analysis of Cost data of only 25 Transit completed contracts which are selected as case studies are displayed in Table 2.

Table 2: Cost data of 25 Transit completed contracts (case studies)

Procurement Method	Date Executed	Contract Title	Original Value	Current Value	% Greater or Less than Original Bid	Cost Overun ($)	% of Cost Overun
IFB	12/12/2002	North Jersey Coast Line, MP.3.22, Substructure Rehabilitation of Morgan Drawbridge over Cheesequake Creek, Borough of Sayreville and Old Bridge Township, Middlesex County, NJ	320,561	221,505	-31%	99,056	-31
IFB	12/3/2008	Painting of Bridges at MP 25.01-26.27 Montclair Boonton Line, Montville, Morris County, NJ	371,000	296,553	-20%	74,447	-20
IFB	7/3/2006	A..C. Rail Line Bridge Rehab of Absecon & Shore Road	796,500	667,779	-16%	128,721	-16
IFB	9/5/2007	Rehabilitation of Main Line U.G. Bridge 12.13 over Clifton Boulevard	726,020	635,481	-12%	90,539	-12
IFB	7/10/2007	Construction of Big Shark Drawbridge Approach Span Replacement (NJCL Undergrade Bridge 30.43)	10,362,000	9,467,412	-9%	894,588	-9
PBE	7/11/2005	Raritan River Drawbridge Fender System - Emergency Repairs	207,039	201,841	-3%	5,198	-3
IFB	2/11/2005	Machinery Replacement, HX Drawbridge-over Hackensack River, U.G. Bridge 5.48 Secaucus, Nj	3,065,000	3,033,543	-1%	31,457	-1
IFB	7/3/2002	Rehab of U.G. Bridge 30.43 Big Shark Drawbridge over Shark River	2,767,550	2,859,070	3%	-91,520	3
IFB	6/27/2005	Trenton Rail Station Rehabilitation- Main Contract	53,237,058	55,277,298	4%	-2,040,240	4
IFB	11/30/2005	Morrisville Yard-Phase 2 Construction	97,877,000	101,746,954	4%	-3,869,954	4
IFB	8/23/2001	Rehabilitation of Franklin Avenue Railroad Bridge, Mainline M.P. 20.98	1,821,775	1,895,710	4%	-73,935	4
IFB	8/12/2002	Replacement of Welch Spur Rod Bridge over Raritan Valley Line	136,000	144,625	6%	-8,625	6
IFB	8/12/2003	Newark Rail Link, Contract #2, Surface Stations and Systems	62,812,777	67,835,823	8%	-5,023,046	8
IFB	4/17/2003	NERL Tunnel Construction	21,632,625	23,641,989	9%	-2,009,364	9
IFB	12/14/2000	Replacement of Morristown Line Culvert MP 48.00 in the Boro of Netcong, NJ	73,000	81,780	12%	-8,780	12
IFB	5/23/2001	Replacement of Gladstone Line Culvert at MP 34.25 Morristown Road, Bernardsville, NJ	124,670	141,247	13%	-16,577	13
IFB	12/27/2006	Construction of the 31st Street Entrance for New York Penn Station	11,711,500	13,311,397	14%	-1,599,897	14
IFB	4/2/2001	Rehabilitation of Bergen Tunnel - North Tube	56,388,044	67,241,233	19%	-10,853,189	19
IFB	9/10/2001	Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	33,728,949	22%	-6,069,529	22
IFB	8/13/2002	Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%	-190,512	24
IFB	3/14/2005	Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	2,074,424	32%	-505,424	32
IFB	9/11/2000	Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County,	2,676,315	4,272,426	60%	-1,596,111	60
IFB	10/30/2002	Culvert Rehabilitation Headwall Extension and Retaining Wall Replacement, Morristown Line M.P.	73,500	130,893	78%	-57,393	78
IFB	8/2/2000	Repair of the Raritan River Bridge Fender System	104,106	200,502	93%	-96,396	93
IFB	6/17/2002	NJCL Catenary Structure Repairs	2,239,730	4,639,160	107%	-2,399,430	107

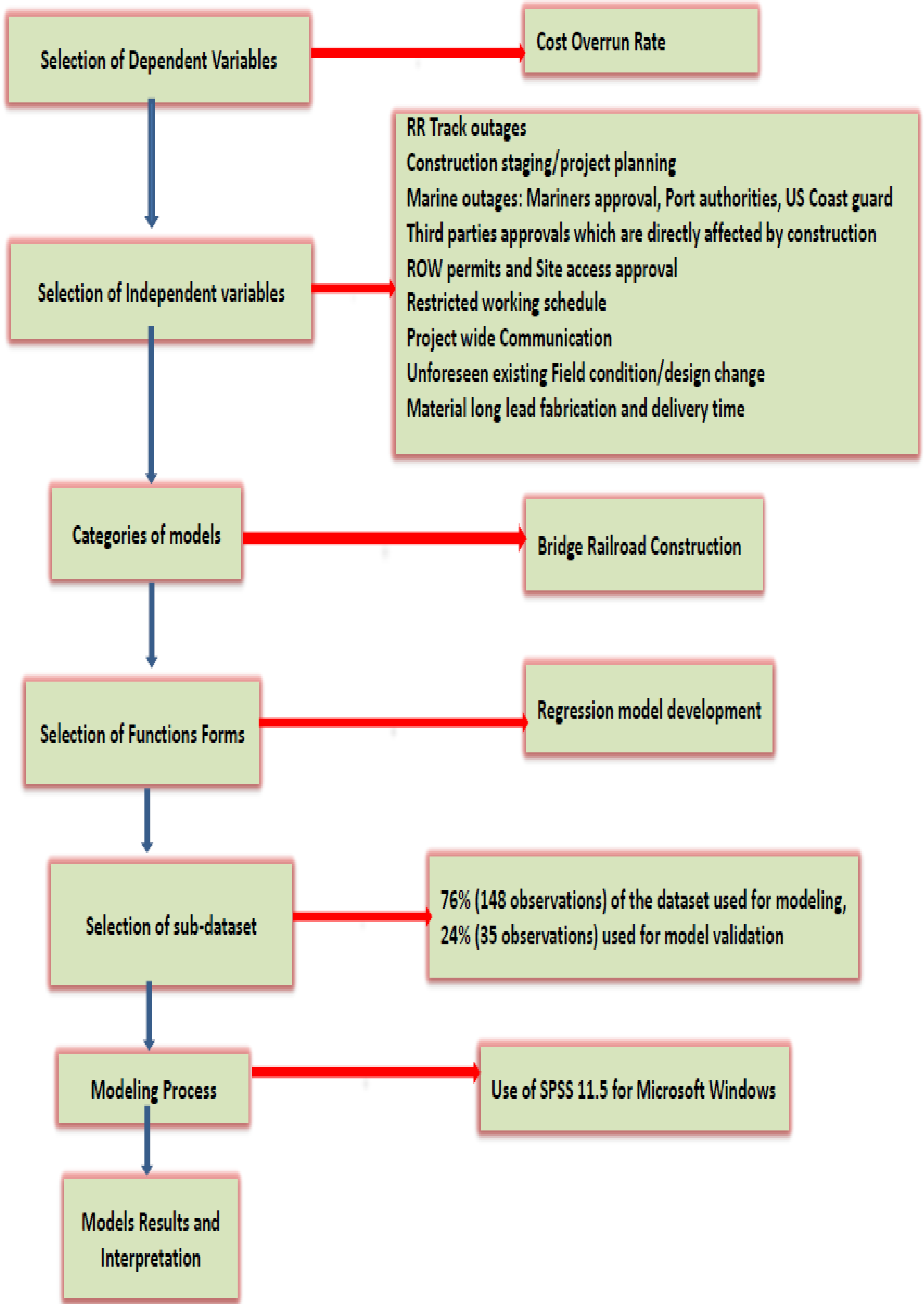

Figure 3: Outline of this Research Methodology

In this research, strategies and techniques will be established to identify cases and established a methodology for analysis. The completed bridge railroad project, which is the unit of the study, illustrates cost overruns occurring with conventional projects. Each project case study has data from the beginning to the completion of the contract.

Typical features of the case include ownership, contract types, management concepts, and scope of work performed by the construction management firm and the contractor. Events occurring from the beginning to the completion of the project will be analyzed and examined to identify the potential causes of project overruns. The steps in conducting the study are data collection, data analysis, and analysis of cost overruns.

The following are the steps for conducting the study:

1. Data collection
2. Data analysis
3. Analysis of cost overrun
4. Data Interpretation

While this research is conducted on 70 Transit construction projects that are actually completed over the last 10 years where the author was involved directly with the design and construction of these projects as either project manager or Program manager and most of them have experienced significant percentage of under run and overrun, only 25 projects are selected as case studies where I searched deeply in details for the actual main causing factors that contributed to the cost overrun.

Most of these factors are unique to railroad bridges (undergrade and overhead bridges), and were not touched in any prior research in the field of cost overrun in transit projects.

A model is developed using multiple regression linear analysis to predict an adequate contingency fund in the project budget that covers the cost overrun.

Multiple regression provides a powerful method to analyze multivariate data. It is a flexible method of data analysis that may be appropriate whenever a quantitative variable (the dependent or criterion variable) is to be examined in relationship to any other factors (expressed as independent or predictor variables). Relationships may be nonlinear, independent variables may be quantitative or qualitative, and one can examine the effects of a single variable or multiple variables with or without the effects of other variables taken into account.

Contingency funds are moneys retained to pay for mandatory and optional changes initiated either by the user or construction agent after construction contract award. These post contract award changes, collectively referred to as cost overruns, represent additional expenses increasing the project cost. The typical method of determining the required amount of contingency funding is to use an arbitrary percentage of the basic construction cost. To provide a more objective method of estimating the contingency funding required, research efforts have identified various sources of risk and linked them to construction cost overruns. Using these identified sources of risk as predictors, a statistical analysis should be able to produce a predictive model for project cost overruns and the associated need for construction contingency funds.

The author selected cases from the projects that I had participated in as Project Manager or Program manager during my last 35 years in construction field and in particular the Transit under grade and overhead bridges. This will allow me to go deeply into the project detail and obtain information from my observations while working for the project. The problems with project cost control and cost overruns on a conventional project being built during a regular period are examined.

Sensitivity analysis is conducted on the value and the proportion of each factor that caused the cost overrun by case specific in relation to the total overrun of the project.

Table 4 displays the individual percentage and the value of the overrun of all the major factors that contributed to the cost overrun in the 25 study cases of Transit Projects.

Figures 4 and 5 respectively demonstrate the significant percentage of cost overrun on the Transit Projects vs. the original bid amount and vs. year completed.

Table 3: Percentage of each cost overrun factor on 25 case studies of Transit Projects

Procurement Method	Date Executed	Contract Title	Original Value	Current Value	% of Cost Overrun	Cost Overrun ($)	Track outage Constraints	Construction staging	Marine outages : Mariners approval, Port authorities, US coast guard	Third parties approvals	ROW permits & Site Access	Restricted working schedule	Project wide Communication	Unforeseen existing Field condition/design change	Material long lead fabrication and delivery time	High Labor cost for experienced Railroad bridge worker (hardly to find) & Cost inflation
							INDEPENDABLE VARIABLES									
					Y (Dependable variable) to be predicted		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
IFB	12/12/2002	North Jersey Coast Line, MP 3.44, Substructure Rehabilitation of Morgan Drawbridge over Cheesequake Creek,	320,561	221,505	-31%	99,056	7.00	7.00	15.00	4.00	7	6	5	25	17	7
IFB	12/9/2000	Painting of Bridges at MP 26.81-26.87 Montclair Boonton Line, Montville, Morris County, NJ	371,000	296,553	-20%	74,447	10	2	17	6	3	15	8	15	14	10
IFB	7/3/2006	A..C. Rail Line Bridge Rehab of Absecon & Shore Road	796,500	667,779	-16%	128,721	8	5	14	7	5	12	6	19	15	9
IFB	5/5/2007	Rehabilitation of Main Line U.G. Bridge 12.45 over Clifton Boulevard	726,020	635,481	-12%	90,539	7	6	15	6	4	14	5	24	11	8
IFB	7/10/2007	Construction of Big Shark Drawbridge Approach Span Replacement (NJCL Undergrade Bridge 30.49)	10,362,000	9,467,412	-9%	894,588	8	7	18	7	7	11	4	21	11	6
PRE	7/11/2005	Raritan River Drawbridge Fender System - Emergency Repairs	207,039	201,841	-3%	5,198	6	8	14	6	5	9	7	23	14	8
IFB	2/11/2005	Machinery Replacement, HX Drawbridge over Hackensack River, U.G. Bridge 5.40 Secaucus, NJ	3,065,000	3,033,543	-1%	31,457	5	7	15	7	6	10	5	24	15	6
IFB	7/3/2002	Rehab of U.G. Bridge 30.49 Big Shark Drawbridge over Shark River	2,767,550	2,859,070	3%	-91,520	6	6	14	4	5	15	5	25	10	10
IFB	6/27/2005	Trenton Rail Station Rehabilitation-Main Contract	53,237,058	55,277,298	4%	-2,040,240	4	8	5	7	7	12	7	18	21	11
IFB	11/30/2005	Morrisville Yard-Phase 2 Construction	97,877,000	101,746,954	4%	-3,869,954	6	7	8	8	8	13	7	19	17	7
IFB	8/25/2004	Rehabilitation of Franklin Avenue Railroad Bridge, Mainline M.P. 20.30	1,821,775	1,895,710	4%	-73,935	8	6	14	7	6	8	6	22	15	8
IFB	8/12/2002	Replacement of Welsh Spur Rod Bridge over Raritan Valley Line	136,000	144,625	6%	-8,625	4	5	16	6	7	12	9	20	12	9
IFB	8/12/2003	Newark Rail Link, Contract 02, Surface Stations and Systems	62,812,777	67,835,823	8%	-5,023,046	7	8	13	6	9	10	7	18	14	8
IFB	4/17/2003	HERL Tunnel Construction	21,632,625	23,641,989	9%	-2,009,364	5	9	14	7	9	8	8	22	9	9
IFB	12/14/2000	Replacement of Morristown Line Culvert MP 40.00 in the Boro of Netcong, NJ	73,000	81,780	12%	-8,780	6	8	10	7	8	12	5	22	12	10
IFB	5/25/2004	Replacement of Gladstone Line Culvert at MP 34.25 Morristown Road, Bernardsville, NJ	124,670	141,247	13%	-16,577	9	8	5	7	7	9	8	23	15	9
IFB	12/27/2006	Construction of the 31st Street Entrance for New York Penn Station	11,711,500	13,311,397	14%	-1,599,897	6	6	5	9	6	10	10	20	17	11
IFB	4/2/2004	Rehabilitation of Bergen Tunnel - North Tube	56,388,044	67,241,233	19%	-10,853,189	7	6	8	7	10	11	8	19	15	9
IFB	3/10/2004	Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	33,728,949	22%	-6,069,529	6	5	6	7	9	12	13	18	12	12
IFB	8/19/2002	Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%	-190,512	5	8	3	8	8	15	10	21	14	8
IFB	5/14/2005	Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.33	1,569,000	2,074,424	32%	-505,424	6	8	14	7	6	9	8	16	17	9
IFB	5/11/2000	Substructure Rehabilitation of Manasquan Bridge, NJCL over Manasquan River MP 36.03 (Brielle, Monmouth County, NJ)	2,676,315	4,272,426	60%	-1,596,111	7	6	17	5	8	8	6	21	14	8
IFB	10/30/2002	Culvert Rehabilitation Headwall Extension and Retaining Wall Replacement, Morristown Line M.P. 17.46, Millburn, NJ	73,500	130,893	78%	-57,393	6	7	19	5	10	8	7	18	11	9
IFB	8/2/2000	Repair of the Raritan River Bridge Fender System	104,106	200,502	93%	-96,396	6	5	15	6	4	10	9	24	14	7
IFB	6/17/2002	NJCL Culvert Structure Repairs	2,239,730	4,639,160	107%	-2,399,430	7	5	14	7	8	9	6	20	16	8
			Mean	$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$			6.48	6.52	12.32	6.52	6.88	10.72	7.16	20.68	14.08	8.64
		410					0.039									
			Standard deviation:	$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2}$			1.42	1.53	4.63	1.16	1.88	2.46	2.03	2.73	2.69	1.50

Table 4: Value of each cost overrun factor on 25 case studies of Transit Projects

Contract Title	Original Value	Current Value	% of Cost Overrun	Cost Overrun ($)	Track outage Constraints	Construction staging	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approvals	ROW permits & Site Access	Restricted working schedule	Project wide Communication	Unforeseen existing Field condition/design change	Material long lead fabrication and delivery time	High Labor cost for experienced Railroad bridge worker (hardly to find) & Cost Inflation
					INDEPENDABLE VARIABLES									
			(Dependable variable) to be predicted		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
A..C. Rail Line Bridge Rehab of Absecon & Shore Road	796,500	667,779	-16%	128,721	$10,298	$6,436	$18,021	$9,010	$6,436	$15,447	$7,723	$24,457	$19,308	$11,585
Rehabilitation of Main Line U.G. Bridge 12.13 over Clifton Boulevard	726,020	635,481	-12%	90,539	$6,338	$5,432	$13,581	$5,432	$3,622	$12,676	$4,527	$21,729	$9,959	$7,243
Drawbridge Approach Span Replacement (NJCL Undergrade Bridge 30.43)	10,362,000	9,467,412	-9%	894,588	$71,567	$62,621	$161,026	$62,621	$62,621	$98,405	$35,784	$187,863	$98,405	$53,675
Raritan River Drawbridge Fender System - Emergency Repairs	207,039	201,841	-3%	5,198	$312	$416	$728	$312	$260	$468	$364	$1,196	$728	$416
HX Drawbridge-over Hackensack River, U.G. Bridge 5.48 Secaucus, Nj	3,065,000	3,033,543	-1%	31,457	$1,573	$2,202	$4,718	$2,202	$1,887	$3,146	$1,573	$7,550	$4,718	$1,887
Rehab of U.G. Bridge 30.43 Big Shark Drawbridge over Shark River	2,767,550	2,859,070	3%	-91,520	-$5,491	-$5,491	-$12,813	-$3,661	-$4,576	-$13,728	-$4,576	-$22,880	-$9,152	-$9,152
Trenton Rail Station Rehabilitation-Main Contract	53,237,058	#######	4%	-2,040,240	-$81,610	-$142,817	-$102,012	-$142,817	-$142,817	-$244,829	-$142,817	-$367,243	-$428,450	-$224,426
Morrisville Yard-Phase 2 Construction	97,877,000	#######	4%	-3,869,954	-$232,197	#REF!	-$309,596	-$309,596	-$309,596	-$503,094	-$270,897	-$735,291	-$657,892	-$270,897
Rehabilitation of Franklin Avenue Railroad Bridge, Mainline M.P. 20.98	1,821,775	1,895,710	4%	-73,935	-$5,915	-$4,436	-$10,351	-$5,175	-$4,436	-$5,915	-$4,436	-$16,266	-$11,090	-$5,915
Replacement of Welch Spur Rod Bridge over Raritan Valley Line	136,000	144,625	6%	-8,625	-$345	-$431	-$1,380	-$518	-$604	-$1,035	-$776	-$1,725	-$1,035	-$776
Newark Rail Link, Contract #2, Surface Stations and Systems	62,812,777	#######	8%	-5,023,046	-$200,922	-$251,152	-$803,687	-$301,383	-$351,613	-$602,766	-$452,074	-$1,004,609	-$602,766	-$452,074
NERL Tunnel Construction	21,632,625	#######	9%	-2,009,364	-$140,655	-$160,749	-$261,217	-$120,562	-$180,843	-$200,936	-$140,655	-$361,686	-$281,311	-$160,749
Replacement of Morristown Line Culvert MP 48.00 in the Boro of Netcong, NJ	73,000	81,780	12%	-8,780	-$439	-$790	-$1,229	-$615	-$790	-$702	-$702	-$1,932	-$790	-$790
Line Culvert at MP 34.25 Morristown Road, Bernardsville, NJ	124,670	141,247	13%	-16,577	-$829	-$1,492	-$2,321	-$1,160	-$1,492	-$1,326	-$1,326	-$3,647	-$1,492	-$1,492
Construction of the 31st Street Entrance for New York Penn Station	11,711,500	13,311,397	14%	-1,599,897	-$95,994	-$127,992	-$159,990	-$111,993	-$127,992	-$191,988	-$79,995	-$351,977	-$191,988	-$159,990
Rehabilitation of Bergen Tunnel - North Tube	56,388,044	#######	19%	-10,853,189	-$976,787	-$868,255	-$542,659	-$759,723	-$759,723	-$976,787	-$868,255	-$2,496,233	-$1,627,978	-$976,787
Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	#######	22%	-6,069,529	-$364,172	-$485,562	-$606,953	-$424,867	-$485,562	-$728,343	-$303,476	-$1,335,296	-$728,343	-$606,953
Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%	-190,512	-$17,146	-$15,241	-$9,526	-$13,336	-$13,336	-$17,146	-$15,241	-$43,818	-$28,577	-$17,146
Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	2,074,424	32%	-505,424	-$30,325	-$30,325	-$25,271	-$45,488	-$30,325	-$50,542	-$50,542	-$101,085	-$85,922	-$55,597
Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09	2,676,315	4,272,426	60%	-1,596,111	-$111,728	-$95,767	-$127,689	-$111,728	-$159,611	-$175,572	-$127,689	-$303,261	-$239,417	-$143,650
Headwall Extension and Retaining Wall Replacement, Morristown	73,500	130,893	78%	-57,393	-$3,444	-$2,870	-$3,444	-$4,017	-$5,165	-$6,887	-$7,461	-$10,331	-$6,887	-$6,887
Repair of the Raritan River Bridge Fender System	104,106	200,502	93%	-96,396	-$4,820	-$7,712	-$2,892	-$7,712	-$7,712	-$14,459	-$9,640	-$20,243	-$13,495	-$7,712
NJCL Catenary Structure Repairs	2,239,730	4,639,160	107%	-2,399,430	-$143,966	-$191,954	-$335,920	-$167,960	-$143,966	-$215,949	-$191,954	-$383,909	-$407,903	-$215,949

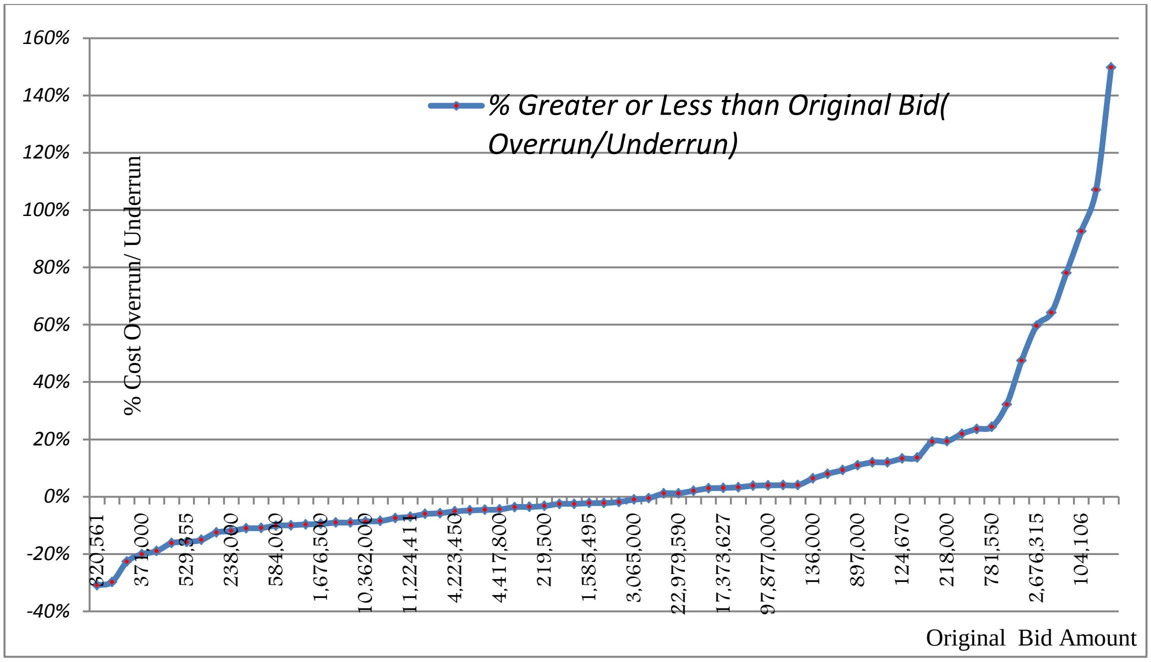

Figure 4: Percentage of Cost Overrun/ Underrun vs. Bid Amount of 25 completed projects

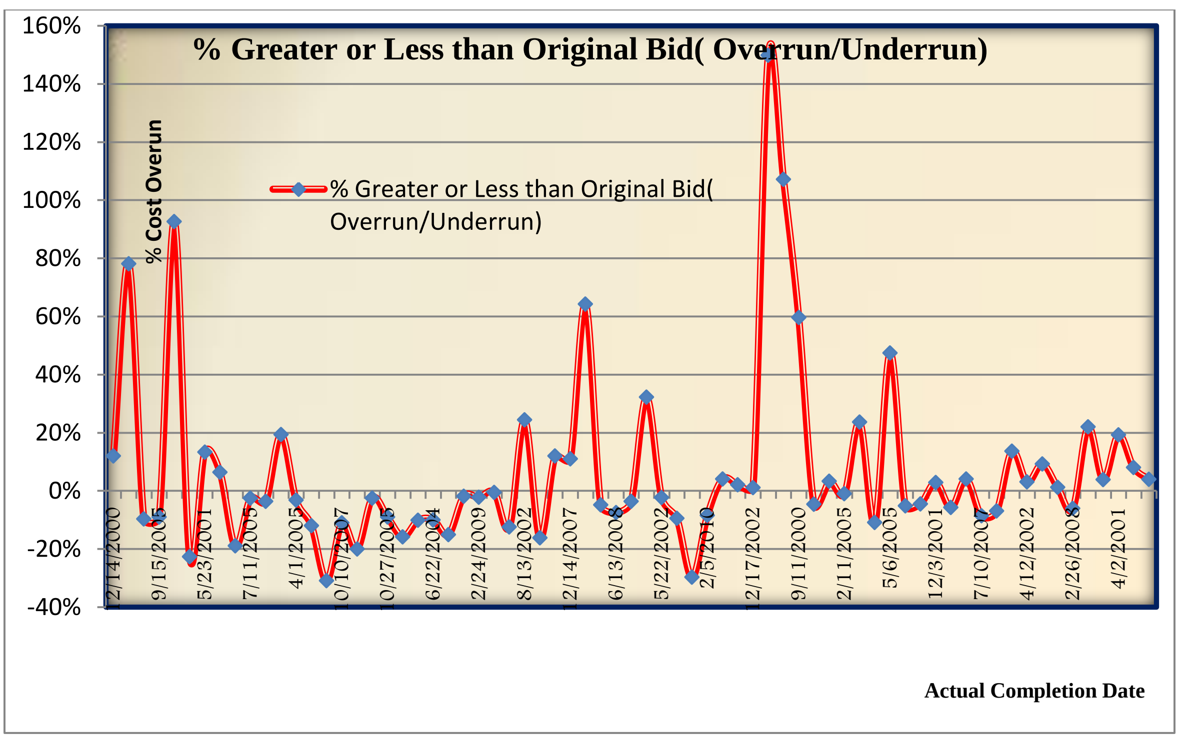

Figure 5: Percentage of Cost Overrun/ Underrun vs. Year completed of 25 completed projects

3.1 Data Collection

The data were collected from 70 completed projects within the last 10 years. The in-depth analysis of the causes of the cost overrun has identified unique factors resulted from the lessons learned of actually completed railroad bridge projects as listed below are significantly impacting the railroad bridge construction cost overrun, and referred to in this research as independent variables (X1,…Xn), while the contingency (Y) is considered as the dependable variable that will be predicted by the application of the model:

- Track outages constraints
- Marine outages: Mariners approval, Port authorities, US coast guard
- Construction staging/project planning
- Third parties approvals which are directly affected with the construction, such as township, fire dept., school, HEPO: Historical Environmental Preservation
- ROW permits
- Site access approval
- Restricted Construction working time
- Restricted working schedule: Hourly schedule
- Project wide Communication: between all project team/coordination between construction and design groups, owner, contractors, and third parties.
- Unforeseen existing Field condition/design change
- Material long lead fabrication and delivery time (such as Steel)
- Material cost inflation
- High Labor cost for experienced Railroad bridge worker (hardly to find)

Some of these factors are merged in order to limit those independent variables to ten only as follows:

- X1: Track outages
- X2 Construction staging/project planning
- X3 Marine outages: Mariners approval, Port authorities, US coast guard
- X4 Third parties approvals which are directly affected with the construction
- X5 ROW permits and Site access approval
- X6 Restricted working schedule
- X7 Project wide Communication
- X8 Unforeseen existing Field condition/design change
- X9 Material long lead fabrication and delivery time (such as Steel)
- X10 High Labor cost for experienced Railroad bridge worker (hardly to find) and material cost inflation

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Most of the data will be obtained from the Railroad company database for the project in project cost control procedures. The data that can affect the project cost overruns will be collected. These data include the changes in the inflation rate while the project was being constructed, since this can affect construction costs. Although these projects were completed some years ago, it represents the effect of inflation on the construction of any current bridge railroad project because inflation plays a significant role in project cost estimates.

3.2 Data Analysis

Practically, subjects' documents will be categorized based on their data types and time period. The time periods in this study refer to the time construction activities were performed. The analysis of all notes and construction contracts, project expenditures, procurements, and field files documents will be based on the construction phase. The case analysis was based on construction periods so that all events or activities can be tracked and compared.

3.3 Contingency Calculation Methods

Contingency is a budget for prevailing cost growth due to risks and uncertainties associated with a project. In other words, contingency is meant to offset the cost impact of uncertainties and risks that influence a project. This magnifies the importance of conducting a formal risk assessment to estimate as accurate as possible the contingency budget.

Owners usually need to have an accurate early cost estimate for their projects in order to provide sufficient budget for projects. A total cost of project is broken down to: (1) base cost, and (2) contingency cost. Base cost is the cost of project which is not including contingency (Touran 2006b). These are certain cost items of a project with a given scope necessary to physically deliver the project. Contingency is budget or time set aside to cope with uncertainties and risks during a project design and construction. The contingency calculation methods are illustrated in Fig 6. The Parametric Method (regression) is used in this research. Contingency is meant to keep the total project budget constant (Olumide et al 2010). In other words, by increasing the level of design and the clarity of scope, base cost should go up and contingency becomes less. When a project experiences cost overrun, one of the reasons could be an insufficient established contingency budget to absorb cost growth.

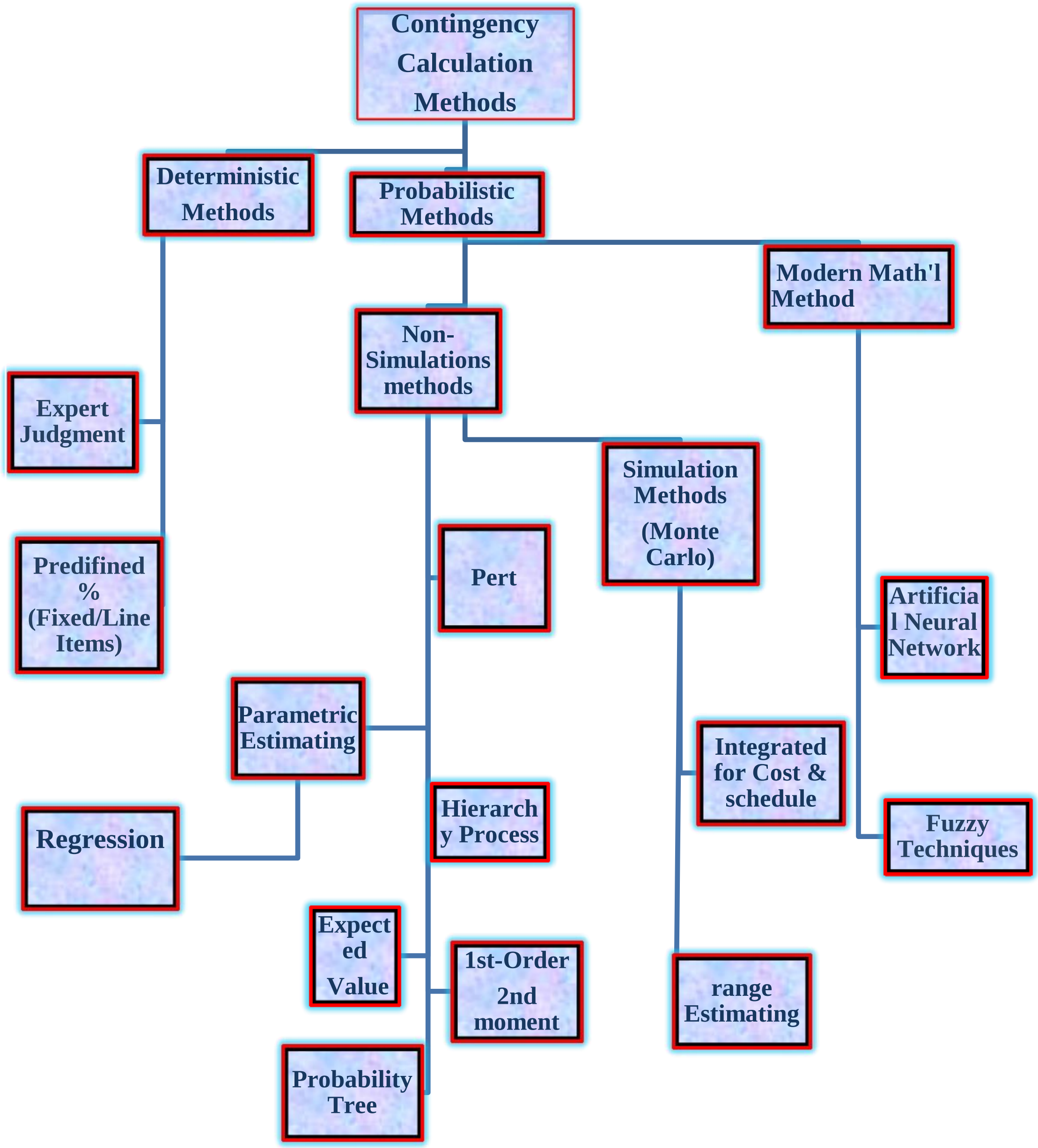


Figure 6- Contingency Calculation Methods

The procedure to calculate total project cost (TPC) is depicted in (Fig. 7)

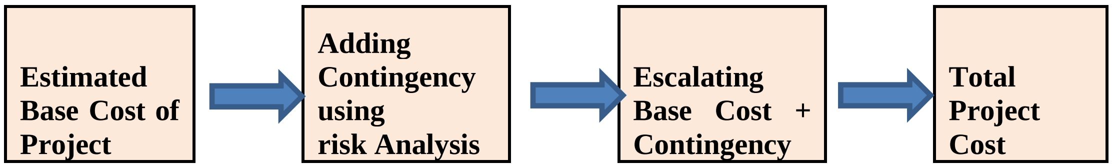


Figure 7: Estimating Total Project Cost (TPC)

The Association for the Advancement of Cost Engineering (AACE 2008a) categorizes the methods to estimate risk cost and establish contingency in the following four major groups:

1. Expert judgment: An expert or a group of experts with strong experience in risk management and risk analysis define(s) the percentage of contingency for the project under consideration;

2. Predetermined guidelines: A set of predetermined contingency values is provided for different key phases of certain project types;

3. Simulation analysis including range estimating and expected value: This method usually integrates expert judgment with an analytical model. Then a simulation process such as Monte Carlo simulation is employed to obtain probabilistic output;

4. Parametric modeling: This method usually quantifies the amount of cost growth using risk drivers by the means of multi variable regression or artificial neural network;

the common methods for establishing contingency budget into three main groups:

1. Deterministic methods
2. Probabilistic methods
3. Modern mathematical methods

3.3.1 Parametric modeling

This method creates a relationship between an output which can be the cost overrun and inputs which can be a set of risk factors. This relationship is developed using historical data and methods such as multivariate regression analysis, artificial neural network, or even trial and error. Even though this method is simple and quick to apply, precaution is needed to select the risk factors that have predictable relationship with the outcome. First, parameters of the model which are risk factors such as scope definition, level of complexity, and size of project must be identified (AACE 2009b). It is recommended by AACE (2009b) that outcome is set as cost growth percentage relative to the base estimate excluding contingency.

Data must be controlled to be free of any obvious and significant errors. After establishing all input and output parameters and collecting the necessary data, the relationship model can be constructed using traditional multivariate regression analysis

3.3.1.1 Regression

Regression method is recommended where there is a linear relationship between dependent (*e.g.* cost growth) and independent variables (risk factors).

3.3.1.1.1 Assumption of Linearity

For simplicity, it is assumed that the relationship between variables is linear. In practice this assumption can virtually never be confirmed; fortunately, multiple regression procedures are not greatly affected by minor deviations from this assumption.

3.3.1.1.2 Predicted and Residual Scores

The regression line expresses the best prediction of the dependent variable (Y), given the independent variables (X). However, nature is rarely perfectly predictable, and usually there is substantial variation of the observed points around the fitted regression line. The deviation of a particular point from the regression line (its predicted value) is called the residual value.

3.3.1.1.3 Tests of Significance for R Squared Added

The ability of any single variable to predict the criterion is measured by the simple correlation, and the statistical significance of the correlation is tested with the t-test, or with an F-test.

3.3.1.1.4 Residual Variance and R-square

R-Square, known as the Coefficient of determination is a commonly used statistic to evaluate model fit.

R-square is 1 minus the ratio of residual variability. When the variability of the residual values around the regression line relative to the overall variability is small, the predictions from the regression equation are good. If there is no relationship between the X and Y variables, then the ratio of the residual variability of the Y variable to the original variance is equal to 1.0. Then R-square would be 0. If X and Y are perfectly related then there is no residual variance and the ratio of variance would be 0, making R-square = 1.

R-square will fall somewhere between 0.0 and 1.0. This ratio value is immediately interpretable in the following manner.

If I have an R-square of 0.84156, then I know that the variability of the Y values around the regression line is 1-0.84 times the original variance; in other words I have explained 84% of the original variability, and am left with 16% residual variability. The R-square value is an indicator of how well the model fits the data (e.g., an R-square close to 1.0 indicates that I have accounted for almost all of the variability with the variables specified in the model)

3.3.1.1.5 Interpreting the Correlation Coefficient "ρ"

Customarily, the degree to which two or more predictors (independent or X variables) are related to the dependent (Y) variable is expressed in the correlation coefficient "ρ", which is the square root of R-square. In multiple regressions, R can assume values between 0 and 1. To interpret the direction of the relationship between variables, look at the signs (plus or minus) of the regression or B coefficients. If a B coefficient is positive, then the relationship of this variable with the dependent variable is positive (e.g., the greater the IQ the better the grade point average); if the B coefficient is negative then the relationship is negative (e.g., the lower the class size the better the average test scores). If the B coefficient is equal to 0 then there is no relationship between the variables.

3.3.1.1.6 The Importance of Normality of Residuals

Even though most assumptions of multiple regressions cannot be tested explicitly, gross violations can be detected and should be dealt with appropriately. In particular outliers can seriously bias the results by "pulling" or "pushing" the regression line in a particular direction (see the animation below), thereby leading to biased regression coefficients. Excluding just a single extreme case can yield a completely different set of results. R^2 measures the proportion of the total variation in y. R^2 falls between 0 and 1. The larger the value of R^2, the better the set of explanatory variables (x1; : : : ; xk) collectively predict y. R^2 = 1 only when all the residuals are 0, that is, when all y = ^y, so that SSE = 0. In that case, the prediction equation passes through all the data points. R^2 = 0 when the predictions do not vary as any of the x-values vary.

Adjusted R-squared = 1 - Mean Square Error /Total Mean Square

Intercept: the intercept in a multiple regression model is the mean for the response when all of the explanatory variables take on the value 0.

Regression Coefficients: Typically the coefficient of a variable is interpreted as the change in the response based on a 1-unit change in the corresponding explanatory variable keeping all other variables held constant. In some problems, keeping all other variables held fixed is impossible

The "b" values are called regression weights and are computed in a way that minimizes the sum of squared deviations. $\sum_{i=1}^{N}(Y_i - Y'_i)^2$

Regression Analysis is conducted on the 18 completed contracts (study cases) which are used as detailed case studies as displayed in tables 5 where the cost overrun is broken-down by each causing factor.

3.3.2.7 Regression Analysis on Transit bridge projects with Cost Overrun (18 case Studies)

Regression Analysis is conducted using Microsoft Excel on 18 Transit bridge projects out of the 25 cases that are listed in Tables 5 with all the 10 independent variables which are significantly contributed to the cost overrun. Table 7 displays the summary output of this analysis.

Table 5: Regression Analysis on Transit bridge projects with Cost Overrun (18 case studies)

SUMMARY - Considering Cost Overrun Only on on 18 Case Studies

Regression Statistics	
Multiple R	0.694910057
R Square	0.482899988
Adjusted R Squ	-0.223837526
Standard Error	34.496451
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	8890.403394	889.0403394	0.830099445	0.618751604
Residual	8	9520.041051	1190.005131		
Total	18	18410.44444			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-563.7867902	1176.545861	-0.47918811	0.644629347	-3276.906411	2149.332831
X Variable 1	2.339678065	13.78153689	0.169769024	0.86940632	-29.44060299	34.11995912
X Variable 2	-2.388266485	15.13058543	-0.15784363	0.878491408	-37.27945905	32.50292608
X Variable 3	7.464230967	10.84702642	0.688136147	0.510823707	-17.54905681	32.47751875
X Variable 4	2.164500205	10.6396837	0.100045692	0.92276977	-21.67665855	18.00565896
X Variable 5	11.27068391	15.01755548	0.750500567	0.63445648	-23.35986113	45.90122895
X Variable 6	1.164500205	11.6396837	0.100045692	0.92276977	-25.67665855	28.00565896
X Variable 7	9.821560942	15.36096396	0.639384414	0.540444983	-25.60088548	45.24400736
X Variable 8	9.695265142	14.22331898	0.681645764	0.514708035	-23.10376725	42.49429754
X Variable 9	10.20111329	14.57466507	0.699920941	0.503817846	-23.40812464	43.81035122
X Variable 10	-0.384677536	12.55056814	-0.03065021	0.976299363	-29.32633956	28.55698448

RESIDUAL OUTPUT

Observation	*Predicted Y*	*Residuals*		*Original*	*Actual*	*Overrun*
1	3.895626326	-0.895626326		2,767,550	2,859,070	**-3.31%**
2	9.913360299	-5.913360299		53,237,058	55,277,298	**-3.83%**
3	22.23838204	-18.23838204		97,877,000	101,746,954	**-3.95%**
4	44.20485198	-40.20485198		1,821,775	1,895,710	**-4.06%**
5	47.177688	-41.177688		136,000	144,625	**-6.34%**
6	26.6048492	-18.6048492		62,812,777	67,835,823	**-8.00%**
7	21.88483465	-12.88483465		21,632,625	23,641,989	**-9.29%**
8	-9.102848241	21.10284824		73,000	81,780	**-12.03%**
9	15.97881198	-2.978811975		124,670	141,247	**-13.30%**
10	13.82032502	0.179674983		11,711,500	13,311,397	**-13.66%**
11	35.82867329	-16.82867329		56,388,044	67,241,233	**-19.25%**
12	18.49778315	3.502216853		27,659,420	33,728,949	**-21.94%**
13	0.385478762	23.61452124		781,550	972,062	**-24.38%**
14	17.40254317	14.59745683		1,569,000	2,074,424	**-32.21%**
15	66.9028562	-6.902856202		2,676,315	4,272,426	**-59.64%**
16	49.39248951	28.60751049		73,500	130,893	**-78.09%**
17	68.20440325	24.79559675		104,106	200,502	**-92.59%**
18	58.76989143	48.23010857		2,239,730	4,639,160	**-107.13%**

3.3.1.1.8 Regression Analysis on Transit bridge projects (15 Case studies-excluding underrun)

Regression Analysis is conducted using Microsoft Excel on 15 Transit bridge projects after excluding outliers' data. Table 6 displays the summary output of this analysis.

Table 6: Regression Analysis for completed Transit Bridges (15 Case studies excluding underrun)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.917365895
R Square	0.841560185
Adjusted R Square	0.445460648
Standard Error	26.19214681
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	14575.48578	1457.548578	2.124617946	0.243494393
Residual	4	2744.114218	686.0285544		
Total	14	17319.6			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	270.3045056	670.153689	0.403347038	0.707323273	-1590.340424	2130.949435
X Variable 1	0.508211333	12.12814648	0.041903463	0.968583894	-33.1649216	34.18134427
X Variable 2	-12.84242098	9.74363185	-1.318032247	0.257905253	-39.89507994	14.21023797
X Variable 3	3.755027628	5.235616433	0.717208313	0.512897195	-10.78137399	18.29142925
X Variable 4	2.46878129	9.346709161	0.264133745	0.804727259	-23.48184361	28.41940619
X Variable 5	-3.008239943	8.993192936	-0.33450188	0.754804933	-27.97734645	21.96086656
X Variable 6	-13.21393177	6.972034001	-1.895276439	0.130950558	-32.57140144	6.143537903
X Variable 7	-4.447077575	5.615016212	-0.791997281	0.472682883	-20.03686185	11.1427067
X Variable 8	-8.201485222	10.49153642	-0.781723944	0.478059605	-37.33066015	20.9276897
X Variable 9	9.648661589	12.95921791	0.744540424	0.497912927	-26.33189554	45.62921872
X Variable 10	-1.521994826	9.874118826	-0.154139813	0.884963816	-28.93694371	25.89295406

RESIDUAL OUTPUT **Residual= Actual -Predicted**

Observation	*Predicted Y*	*Residuals*	*Actual Cost Overrun*
1	5.13277408	-2.13277408	**3**
2	-0.081347741	4.081347741	**4**
3	-6.030534032	10.03053403	**4**
4	23.58360293	-19.58360293	**4**
5	6	3.73035E-14	**6**
6	10.75299495	-2.75299495	**8**
7	-4.437072111	13.43707211	**9**
8	23.51195067	-11.51195067	**12**
9	32.30409899	-19.30409899	**13**
10	12.0227469	1.977253097	**14**
11	37.86466621	-18.86466621	**19**
12	10.83528947	11.16471053	**22**
13	58.19506212	19.80493788	**78**
14	103.1372777	-10.13727773	**93**
15	83.20848984	23.79151016	**107**

Residual= Actual –Predicted.

To avoid overrun: Predicted should be higher than the estimated amount

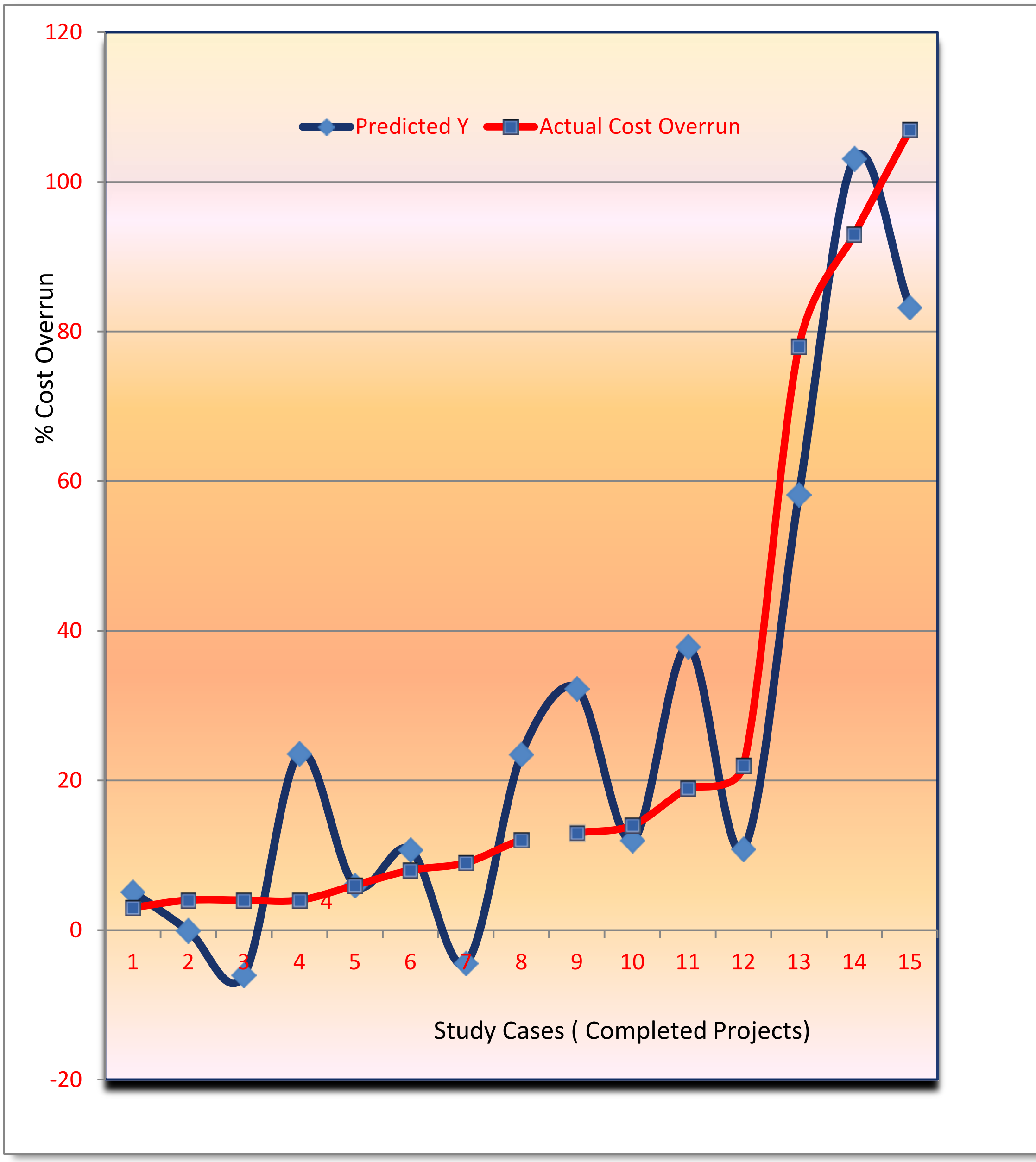


Figure 8: Predicted cost Overrun vs. Actual cost overrun

The above figure compares the predicted overrun(%) resulted from the regression analysis summary output as shown in Table 8 vs. the actual overrun (%) at completion above the bid price.

INTERPRET REGRESSION STATISTICS TABLE

This is the following output. Of greatest interest is **R Square**

Regression Statistics:

Multiple R	0.917365895
R Square	0.841560185
Adjusted R Square	0.445460648
Standard Error	26.19214681
Observations	15

The above gives the overall goodness-of-fit measures:
R^2 = **0.8416**
Correlation between y and y-hat is 0.92 (when squared gives 0.84).
Adjusted $R^2 = R^2 - (1-R^2)*(k-1)/(n-k) =.4456$.

The standard error here refers to the estimated standard deviation of the error term u. It is also called the standard error of the regression. It equals sqrt (SSE/(n-k)).

R^2 = 0.8416 means that 84.16% of the variation of y_i around ybar (its mean) is explained by the regressors x_{2i} and $x10_i$.

The ANOVA (analysis of variance) table splits the sum of squares into its components.

Total sums of squares
= Residual (or error) sum of squares + Regression (or explained) sum of squares.

Thus $\Sigma_i (y_i - ybar)^2 = \Sigma_i (y_i - yhat_i)^2 + \Sigma_i (yhat_i - ybar)^2$

where $yhat_i$ is the value of y_i predicted from the regression line and ybar is the sample mean of y.

Table 7: Interpret regression coefficients

	Coefficients	*Standard Error*	*t Stat*	***P-value***	*Lower 95%*	*Upper 95%*
Intercept	270.3047056	670.153689	0.403347038	0.707323273	-1590.340424	2130.949435
X Variable 1	0.708211333	12.12814648	0.041903463	0.968583894	-33.1649216	34.18134427
X Variable 2	-12.842421	9.74363185	-1.318032247	0.257905253	-39.89707994	14.21023797
X Variable 3	3.757027628	5.235616433	0.717208313	0.512897195	-10.78137399	18.29142925
X Variable 4	2.46878129	9.346709161	0.264133745	0.804727259	-23.48184361	28.41940619
X Variable 5	-3.00823994	8.993192936	-0.33470188	0.754804933	-27.97734645	21.96086656
X Variable 6	-13.2139318	6.972034001	-1.895276439	0.130970558	-32.57140144	6.143537903
X Variable 7	-4.44707757	5.617016212	-0.791997281	0.472682883	-20.03686185	11.1427067
X Variable 8	-8.20148522	10.49153642	-0.781723944	0.478059605	-37.33066015	20.9276897
X Variable 9	9.648661589	12.95921791	0.744540424	0.497912927	-26.33189554	45.62921872
X Variable 10	-1.52199483	9.874118826	-0.154139813	0.884963816	-28.93704371	25.89295406

The regression output of most interest is the following table of coefficients & associated output:

Let β_j denote the population coefficient of the j^{th} regressor

Then

- Column "**Coefficient**" gives the least squares estimates of β_j.
- Column "**Standard error**" gives the standard errors (i.e. the estimated standard deviation) of the least squares estimates b_j of β_j.
- Column "**t Stat**" gives the computed t-statistic for H0: $\beta_j = 0$ against Ha: $\beta_j \neq 0$. This is the coefficient divided by the standard error. It is compared to a t with (n-k) degrees of freedom where here n = 15 and k = 11.

- Column "**P-value**" gives the p-value for test of H0: $\beta_j = 0$ against Ha: $\beta_j \neq 0$.. This equals the Pr{|t| > t-Stat}where t is a t-distributed random variable with n-k degrees of freedom and t-Stat is the computed value of the t-statistic given in the previous column.
- Columns "Lower 95%" and "Upper 95%" values define a 95% confidence interval for β_j.

3.4 PROPOSED MODEL

Using the Excel Statistical Discovery Software, the final model in equation form was, as per the attached spread sheet:

The multiple regression function:

$$\mathbf{Y = a + b_1*X_1 + b_2*X_2 + ... + b_p*X_p}$$

A simple summary of the above output is that the fitted line is

Contingency (% Overrun) "Y" = 270.304 + 0.708 X1 + -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10

Where the constant "a" (the intercept) and the coefficients "b1" through "b10" of the 10 independent variables X1 to X10 are derived from the result of the regression analysis as listed in Table 7.

Table 8: Predicted cost overrun by applying the proposed model on the 15 case studies

Case Studies	Predicted % of Overrun for each case study after applying the proposed model	Project Descriptions
1	5.1327741	Rehab of U.G. Bridge 30.43 Big Shark Drawbridge over Shark River
2	-0.0813477	Trenton Rail Station Rehabilitation-Main Contract
3	-6.030534	Morrisville Yard-Phase 2 Construction
4	23.583603	Rehabilitation of Franklin Avenue Railroad Bridge, Mainline M.P. 20.98
5	6	Replacement of Welch Spur Rod Bridge over Raritan Valley Line
6	10.752995	Newark Rail Link, Contract #2, Surface Stations and Systems
7	-4.4370721	NERL Tunnel Construction
8	23.511951	Replacement of Morristown Line Culvert MP 48.00 in the Netcong, NJ
9	32.304099	Replacement of Gladstone Line Culvert at MP 34.25 Bernardsville, NJ
10	12.022747	Construction of the 31st Street Entrance for New York Penn Station
11	37.864666	Rehabilitation of Bergen Tunnel - North Tube
12	10.835289	Main Bergen Connection Project - Secaucus Transfer Program
13	58.197062	Culvert Rehabilitation Headwall Extension and Retaining Wall Replacement, Morristown Line M.P. 17.46, Millburn, NJ
14	103.13728	Repair of the Raritan River Bridge Fender System
15	83.20849	NJCL Catenary Structure Repairs

3.6 TESTING THE PROPOSED MODEL

The multiple regression function:

$$Y = a + b_1*X_1 + b_2*X_2 + ... + b_p*X_p$$

The definition of each independent variable, X1 through X10, is as shown in section 3.1.

Using the proposed model equation by substituting the values of the coefficients a, b1, b2, ….b10, which resulted from the regression analysis output as listed in Table 7.

Each independent variable (risk factor), X1 to X10 is estimated, as per Table 9, as a percentage of the total contingency (predicted overrun), based on the confidence level of each contract condition between average range of 5 to 15, where 5 if the condition does not exist to 15 if highly exist. The total percentage of X1 to X10 should be 100.

Table 9: Cost data on completed Transit Bridge Project (3 new case studies not included in the tested projects)

Date Executed	Contract Title	Original Value	Current Value	% Greater or Less than Original Bid	Cost Overun ($)	% of Cost Overun	Track outage Constraints that restrict the working schedule	Construction staging	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approvals	ROW permits & Site Access	Cost Inflation	Project wide Communication	Unforeseen existing Field condition/design change	Material long lead fabrication and delivery time	High Labor cost for experienced Railroad bridge worker
							INDEPENDABLE VARIABLE									
				Y (Dependable variable) to be predicted			X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
8/13/2002	Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%	-190,512	24	15	5	10	8	6	12	5	18	12	9
3/14/2005	Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	2,074,424	32%	-505,424	32	16	5	16	5	5	11	5	19	10	8
9/11/2000	Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County, NJ)	2,676,315	4,272,426	60%	-1,596,111	60	15	5	15	5	9	10	5	16	11	9

		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Mean:	$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$	15.09	6.59	11.18	4.91	5.27	10.59	6.00	17.64	12.41	10.27
		0.04812398									
Standard deviation:	$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2}$	2.09	1.44	4.89	1.19	1.42	1.82	1.90	2.26	2.34	1.52

$Y = a + b_1 * X_1 + b_2 * X_2 + ... + b_p * X_p$

The proposed model equation:

Contingency (% Overrun) = 270.304 + 0.708 x1 + -12.842 x2 + 3.755 x3 + 2.468 x4 – 3.008 x5 -13.213 x6 - 4.447 x7 – 8.201 x8 + 9.648 x9 -1.521 x10

Table 10: Comparison between the predicted cost overrun derived from applying the proposed model and the actual overrun

New 3 case Studies (Not used for developing the proposed model)	Original Value	Current Value	Actual Cost Overrun (%)	Overrun-$	Predicted Overrun using the proposed model	Track outages	Construction staging	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approvals	ROW permits: material storages	Restricted working schedule	Project wide Communication	Unforeseen existing Field condition/design change	Material long lead fabrication and delivery time	High Labor cost for experienced RR bridge
Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%	-190,512	26%	-$28,577	-$15,241	-$19,051	-$9,526	-$7,620	-$17,146	-$15,241	-$34,292	-$26,672	-$17,146
Rehabilitation of Raritan River Drawbridge	1,569,000	2,074,424	32%	-505,424	33%	-$85,922	-$40,434	-$10,108	-$20,217	-$30,325	-$50,542	-$50,542	-$75,814	-$80,868	-$60,651
Rehabilitation of Bascule Bridge, NJCL over Manasquan River	2,676,315	4,272,426	60%	-1,596,111	62%	-$255,378	-$79,806	-$143,650	-$63,844	-$111,728	-$175,572	-$127,689	-$271,339	-$223,456	-$143,650

Applying the proposed model equation on the independent variables listed in Table 9, the predicted (Y) values of the cost overrun (Contingency) will be resulted as follows:

Y1 , the predicted overrun (contingency) = 26.62% vs. the actual overrun of 24%

Y2= the predicted overrun (contingency) =32.70% vs. the actual overrun of 32%

Y3= the predicted overrun (contingency) = 62.15% vs. the actual overrun of 60%

CHAPTER 4: CASE STUDY

This research is conducted on 70 actual railroad bridge construction projects with total construction costs between $70,000 to $60 million and which are completed and have experienced cost overrun. However, the research went deeply into only 25 projects as case studies into the actual detailed causes that contributed to cost overrun.

CHAPTER 5: EVALUATING THE PROPOSED MODEL

5.1 Application of the model demonstrated.

The proposed model can greatly help any Railroad agency and mainly the FTA. Projects' cost estimates will be adjusted based on past projects' performances. In the proposed approach, first the preparation of a set of historical projects' data including cost estimate and actual final cost (as-built cost) is required. Using this data, mean and standard deviation of cost overruns/underruns in the historical data set is determined. Based on this, the parameters of the model are calculated and the model can be applied on the first set of projects recommended in the upcoming annual report all projects' cost estimates are modified using the calculated increase/ decrease factor. Every single year or two, when the new projects are completed and new data becomes available; the model will be updated using the suggested MUC approach. The updating incorporates the performance of recently completed projects in the model. However, it will take a few years until the actual costs of projects used in the proposed model become available and their cost overruns/underruns input to the model. The model is updated in the regular intervals and performances of the projects completed are input in the model. The hope is to see the cost overrun and/or underrun close to zero after a few iterations.

The application of the model through numerical examples using actually completed Railroad Bridge projects, and the ability and effectiveness of the model to control cost overrun in a portfolio of projects are demonstrated on 33 new cases that are not part of the development the model. These new completed bridge projects were tested on the 3 cases as illustrated in Table 11, and Fig 9, through Fig.13 which show deviation of the predicted overrun from the actual overrun of 1%, 4% and 7%. The model is tested also on next new 30 cases as illustrated in Table 12 through 41 and shows deviation of the predicted overrun from the actual overrun rage from -6% to 10%. as per Fig. 37 to 41.

Table 11: Percent of deviation of the predicted Cost overrun using the proposed model from the actual overrun

New 3 case Studies (used for testing the proposed model)	Original Value	Current Value	Actual Cost Overun (%)	Overrun-$	Predicted Overrun using the proposed model	Checking the % of Tolerance of the proposed model from Actual
Rehabilitation of RR Bridge-Clifton Avenue	781,550	972,062	24%	-190,512	26%	7%
Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	2,074,424	32%	-505,424	33%	1%
Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County, NJ)	2,676,315	4,272,426	60%	-1,596,111	62%	4%

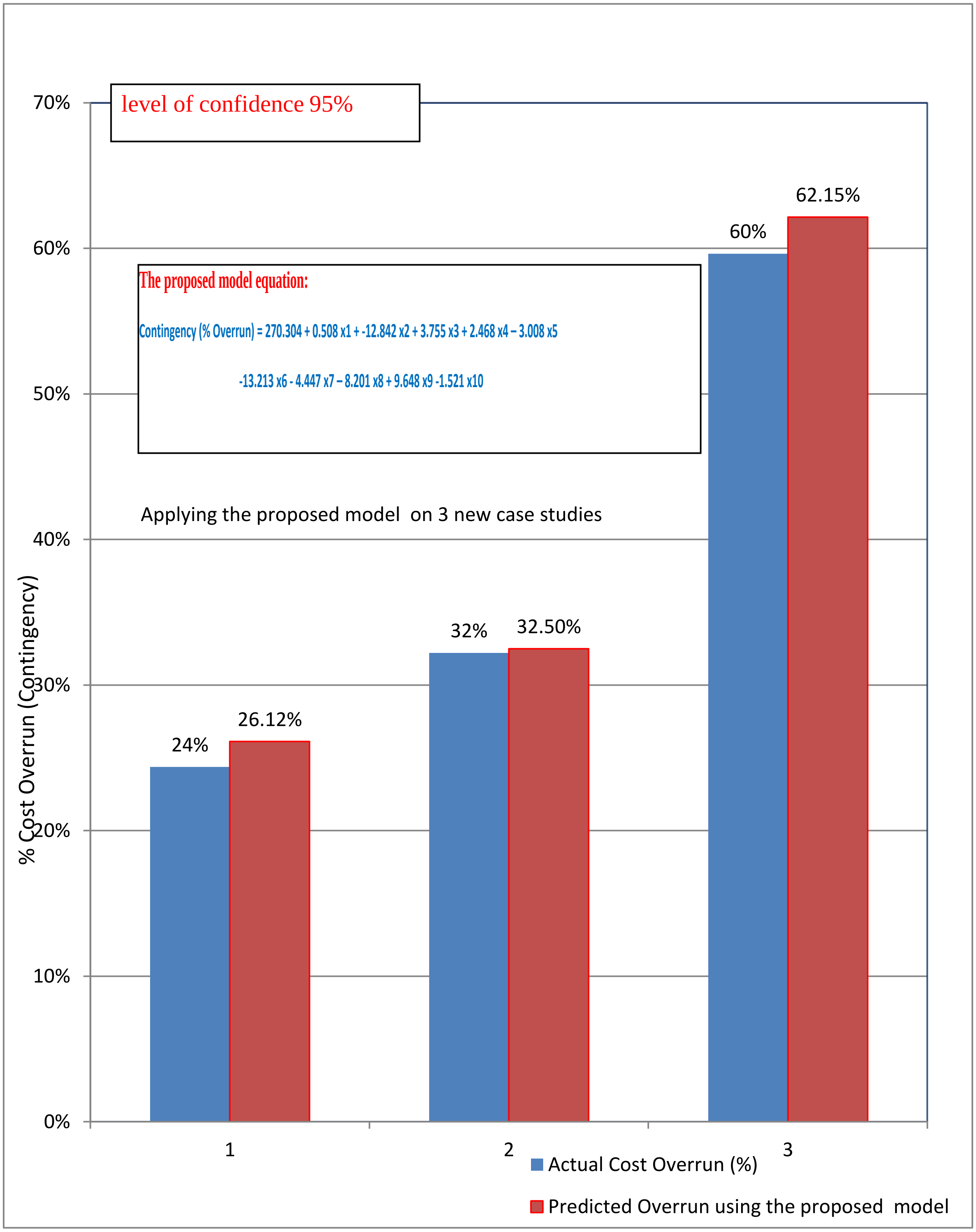


Figure 9: Predicted cost Overrun vs. Actual by applying the proposed model on the new case studies (that are not used in the model development)

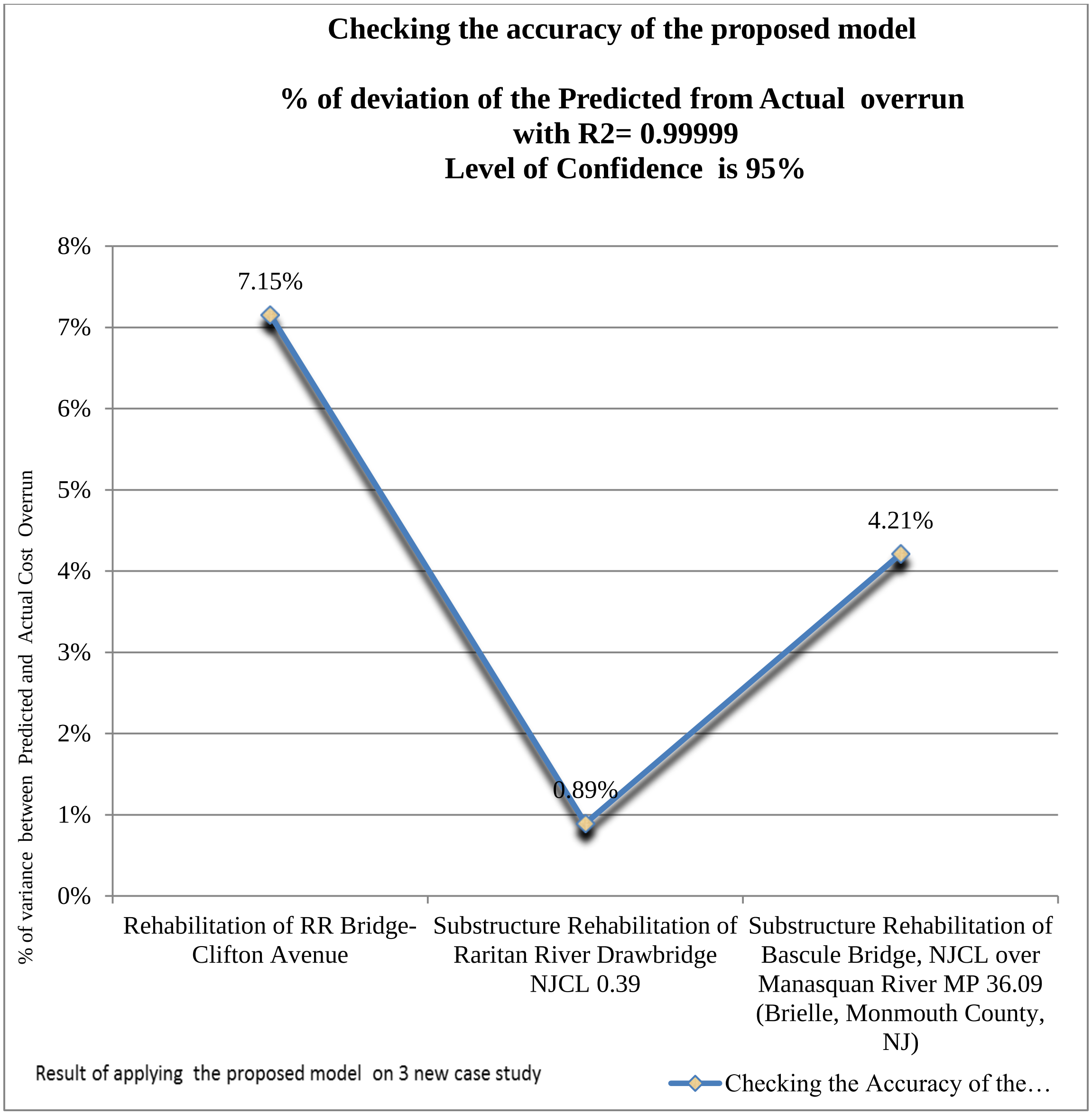


Figure 10: Percentage of variance between Predicted and Actual Cost Overrun when applying the proposed model for each new case study (Percentage of accuracy of applying the developed model for predicting the cost overrun= 100%-% of variance)

Table 12 -Cost data of 30 "New" Transit completed contracts, which are different from the contracts used to develop the Model.

30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion
Testinf the model case 1	REHAB: The Construction of the Submarine Duct Bank Installation, Shark River Draw, North JCL M.P. 30.43, Belmar, NJ	7,999,000	$9,600,709	$1,601,709	20%
Testinf the model case 2	REPLCMT:Culvert Replacement and diversionary Flow Morristown line culvert at M.P. 36.87, Randolph Township, Morris County, NJ	902,510	$1,319,196	$416,686	46%
Testinf the model case 3	NEW CONSTRTN:Construction of the 69th Street Grade bridge Project	22,027,109	$27,127,707	$5,100,598	23%
Testinf the model case 4	NEW CONSTRTN:Final Design and Construction of Palisades Tunnel	258,786,000	$331,507,813	$72,721,813	28%
Testinf the model case 5	REHAB: Highland Ave. Rail Station-Pedestrian Tunnel Repairs	479,946	$638,061	$158,115	33%
Testinf the model case 6	REHAB: Construction Improvements to New Brunswick Train Station bridge	1,670,470	$1,870,669	$200,199	12%
Testinf the model case 7	REHAB: Repair of Riverline Light Rail Roebling Embankment Failure	7,158,758	$9,137,337	$1,978,579	28%
Testinf the model case 8	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	3,572,825	$4,601,488	$1,028,663	29%
Testinf the model case 9	REPLCMT:Replacement of Welch Spur Rod Bridge over Raritan Valley Line	5,336,058	6,976,000	$1,639,942	31%
Testinf the model case 10	REHAB:Rehabilitation of Bergen Tunnel - North Tube	56,388,044	$66,084,629	$9,696,585	17%
Testinf the model case 11	NEW CONSTRTN: Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	$35,576,980	$7,917,560	29%

Table 12: Continuing -Cost data of 30 "New" Transit completed contracts, which are different from the contracts used to develop the Model.

30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion
Testinf the model case 12	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$871,243	$89,693	11%
Testinf the model case 13	REHAB:North Retaining Wall Repairs Morristown Line M.P. 8.0 to M.P. 9.1 Newark, NJ	3,521,341	$5,039,200	$1,517,859	43%
Testinf the model case 14	REHAB:Repair of the Raritan River Bridge Fender System	104,106	$149,962	$45,856	44%
Testinf the model case 15	REHAB:Substructure Repairs to HX Draw Bridge Over Hackensack River-Secaucus, Hudson County, NJ (U.G. Bridge 5.48	1,841,000	$2,717,442	$876,442	48%
Testinf the model case 16	REPLCMT: Replacement of the West Parapet and Sidewalk at MP 21.73, Gladstone Branch, New Providence, NJ	$427,215.00	$621,978	$194,763	46%
Testinf the model case 17	REHAB:Substructure Rehabiltation of Beach Thorofare Drawbridge on Atlantic City Line M.P. 57.63 Atlantic City, NJ	$1,469,000.00	$1,900,574	$431,574	29%
Testinf the model case 18	REPLCMT:Design, Engineering & Construction Assistance for the Replacement of NJ Transit's Undergrade Drawbridge at NJCL M.P. 30.43 over Big Shark River	$441,346.00	$578,525	$137,179	31%
Testinf the model case 19	REPLCMT:Construction of the White House Siding along the Raritan Valley Line Readington Township, NJ	$1,535,270.00	$2,152,035	$616,765	40%
Testinf the model case 20	REHAB:Painting of Undergrade Bridges, M.P. 7.07 & M.P. 7.25, Morristown Line, Harrison, Hudson County, NJ	$627,500.00	$776,627	$149,127	24%
Testinf the model case 21	REHAB:Painting of Undergrade Bridges, M.P. 21.57 (GLD) Chatham & M.P. 22.74 (M&F) Summit, Morris and Union City, NJ	$435,000.00	$491,038	$56,038	13%
Testinf the model case 22	REHAB:Secaucus Junction Station Improvements Stage 1- Faregate Relocation Project Stage 2 -Crew Quarters Quiet Room	$329,373.00	$431,922	$102,549	31%
Testinf the model case 23	REHAB:Newark City Subway Portal Curve Trackwork Phase 2, Located in Newark, NJ	$674,700.00	$825,255	$150,555	22%

Table 12: Continuing -Cost data of 30 "New" Transit completed contracts, which are different from the contracts used to develop the Model.

30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion
Testinf the model case 24	Emergency Repair: Hx Drawbridge, BCL M.P. 5.48 Upper Link Assembly- Emergency Enigneering Services	$80,310.00	$133,853	$53,543	67%
Testinf the model case 25	REHAB:Kings Road Retaining Wall & Elm Street Bridge Repairs M.P. 25.61 to 25.80 and 26.17 Morristown Line, Madison, Morris County, NJ	$1,368,000.00	$1,660,003	$292,003	21%
Testinf the model case 26	HBLR Weehawken Pedestrian Overpass, East Tower	$893,230.00	$1,161,341	$268,111	30%
Testinf the model case 27	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	$3,572,825.00	$4,520,854	$948,029	27%
Testinf the model case 28	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$972,062	$190,512	24%
Testinf the model case 29	REHAB:Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	$2,074,424	$505,424	32%
Testinf the model case 30	REHAB:Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County, NJ)	2,676,315	$4,272,426	$1,596,111	60%

Table 13: Effect of each variable on the Predicted Cost Overrun for the 30 "New" Transit completed contracts, which are different from the contracts used to develop the Model.

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10										
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overrun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%
Testing the model case 1	REHAB:Construction of Submarine Duct Bank, Shark River Draw, North JCL M.P. 30.43	7,999,000	$9,600,709	$1,601,709	20%	7	12	18	17	10	10	10	5	5	6	100%
Testing the model case 2	REPLCMT:Culvert Replacement Flow Morristown line , M.P. 36.87, NJ	902,510	$1,319,196	$416,686	46%	14	5	10	15	7	12	10	8	7	12	100%
Testing the model case 3	NEW CONSTRTN:Construction of the 69th Street Grade bridge Project	22,027,109	$27,127,707	$5,100,598	23%	7	5	7	10	15	10	11	13	11	11	100%
Testing the model case 4	NEW CONSTRTN:Final Design and Construction of Palisades Tunnel	258,786,000	$331,507,813	$72,721,813	28%	4	7	11	10	15	9	10	13	11	10	100%
Testing the model case 5	REHAB: Highland Ave. Rail Station-Pedestrian Tunnel Repairs	479,946	$638,061	$158,115	33%	6	5	16	6	7	10	9	20	12	9	100%
Testing the model case 6	REHAB: Construction Improvements to New Brunswick Train Station bridge	1,670,470	$1,870,669	$200,199	12%	14	8	9	4	5	10	7	18	14	11	100%
Testing the model case 7	REHAB: Repair of Riverline Light Rail Roebling Embankment Failure	7,158,758	$9,137,337	$1,978,579	28%	15	9	14	12	4	8	6	20	10	2	100%
Testing the model case 8	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	3,572,825	$4,601,488	$1,028,663	29%	18	8	8	7	8	8	5	17	11	10	100%

Table 13: Continuing-Effect of each variable on the Predicted Cost Overrun for the 30 "New"

Transit completed contracts, which are different from the contracts used to develop the Model.

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10										
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%
Testing the model case 9	REPLCMT:Replacement of Welch Spur Rod Bridge over Raritan Valley Line	5,336,058	6,976,000	$1,639,942	31%	15	8	10	5	4	9	8	18	14	9	100%
Testing the model case 10	REHAB:Rehabilitation of Bergen Tunnel - North Tube	56,388,044	$66,084,629	$9,696,585	17%	17	8	2	4	6	10	10	15	16	12	100%
Testing the model case 11	NEW CONSTRTN: Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	$35,576,980	$7,917,560	29%	4	7	11	10	15	9	10	13	11	10	100%
Testing the model case 12	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$871,243	$89,693	11%	16	5	6	7	7	11	6	18	12	12	100%
Testing the model case 13	REHAB:North Retaining Wall Repairs Morristown Line M.P. 8.0 to M.P. 9.1 Newark, NJ	3,521,341	$5,039,200	$1,517,859	43%	16	8	13	4	6	8	5	18	12	10	100%
Testing the model case 14	REHAB:Repair of the Raritan River Bridge Fender System	104,106	$149,962	$45,856	44%	15	7	10	13	9	9	10	10	7	10	100%
Testing the model case 15	REHAB:Substructure Repairs to HX Draw Bridge Over Hackensack River-Secaucus, Hudson County, NJ (U.G. Bridge 5.48	1,841,000	$2,717,442	$876,442	48%	13	7	9	14	6	10	7	13	10	11	100%
Testing the model case 16	REPLCMT: Replacement of the West Parapet and Sidewalk at MP 21.73, Gladstone Branch, New Providence, NJ	$427,215.00	$621,978	$194,763	46%	11	6	10	15	8	12	10	8	8	12	100%

Table 13: Continuing-Effect of each variable on the Predicted Cost Overrun for the 30 "New"

Transit completed contracts, which are different from the contracts used to develop the Model.

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10										
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%
Testing the model case 17	REHAB:Substructure Rehabiltation of Beach Thorofare Drawbridge on Atlantic City Line M.P. 57.63 Atlantic City, NJ	$1,469,000.00	$1,900,574	$431,574	29%	13	8	12	7	8	8	6	17	11	10	100%
Testing the model case 18	REPLCMT:Design, Engineering & Construction Assistance for the Replacement of NJ Transit's Undergrade Drawbridge at NJCL M.P. 30.43 over Big Shark River	$441,346.00	$578,525	$137,179	31%	15	5	10	15	10	10	10	10	5	10	100%
Testing the model case 19	REPLCMT:Construction of the White House Siding along the Raritan Valley Line Readington Township, NJ	$1,535,270.00	$2,152,035	$616,765	40%	15	5	10	15	10	10	10	10	5	10	100%
Testing the model case 20	REHAB:Painting of Undergrade Bridges, M.P. 7.07 & M.P. 7.25, Morristown Line, Harrison, Hudson County, NJ	$627,500.00	$776,627	$149,127	24%	18	8	8	7	8	8	5	17	11	10	100%
Testing the model case 21	REHAB:Painting of Undergrade Bridges, M.P. 21.57 (GLD) Chatham & M.P. 22.74 (M&F) Summit, Morris and Union City, NJ	$435,000.00	$491,038	$56,038	13%	15	9	10	9	7	7	9	14	8	12	100%
Testing the model case 22	REHAB:Secaucus Junction Station Improvements Stage 1- Faregate Relocation Project Stage 2 - Crew Quarters Quiet Room	$329,373.00	$431,922	$102,549	31%	16	8	6	7	7	9	7	16	13	11	100%
Testing the model case 23	REHAB:Newark City Subway Portal Curve Trackwork Phase 2, Located in Newark, NJ	$674,700.00	$825,255	$150,555	22%	14	8	8	8	6	11	8	12	12	13	100%
Testing the model case 24	Emergency Repair: Hx Drawbridge, BCL M.P. 5.48 Upper Link Assembly- Emergency Engineering Services	$80,310.00	$133,853	$53,543	67%	14	7	8	7	6	10	8	12	14	14	100%

Table 13: Continuing-Effect of each variable on the Predicted Cost Overrun for the 30 "New" Transit completed contracts, which are different from the contracts used to develop the Model.

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10										
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permit s&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%
Testing the model case 26	HBLR Weehawken Pedestrian Overpass, East Tower	$893,230.00	$1,161,341	$268,111	30%	15	5	10	15	10	10	10	10	5	10	100%
Testing the model case 27	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	$3,572,825.00	$4,520,854	$948,029	27%	13	5	9	7	7	11	6	18	12	12	100%
Testing the model case 28	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$972,062	$190,512	24%	15	5	10	8	6	12	5	18	12	9	100%
Testing the model case 29	REHAB:Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	$2,074,424	$505,424	32%	16	5	16	5	5	11	5	19	10	8	100%
Testing the model case 30	REHAB:Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County, NJ)	2,676,315	$4,272,426	$1,596,111	60%	15	5	15	5	9	10	5	16	11	9	100%

Table 14: Applying the proposed Model using the variables to Predicted Cost Overrun for the 30 "New" completed contracts (different from the contracts used to develop the Model).

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 - 3.008X5 -13.213 X6 - 4.447 X7 - 8.201 X8 + 9.648 X9 -1.521 X10													
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10				
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%	Intercept	270.305	PREDICTED OVERRUN using the proposed model
Testing the model case 1	REHAB:Construction of Submarine Duct Bank, Shark River Draw, North JCL M.P. 30.43	7,999,000	$9,600,709	$1,601,709	20%	7	12	18	17	10	10	10	5	5	6	100%	X Variable 1	0.7082	22.12
Testing the model case 2	REPLCMT:Culvert Replacement Flow Morristown line , M.P. 36.87, NJ	902,510	$1,319,196	$416,686	46%	14	5	10	15	7	12	10	8	7	12	100%	X Variable 2	-12.842	50.16
Testing the model case 3	NEW CONSTRTN:Construction of the 69th Street Grade bridge Project	22,027,109	$27,127,707	$5,100,598	23%	7	5	7	10	15	10	11	13	11	11	100%	X Variable 3	3.755	18.62
Testing the model case 4	NEW CONSTRTN:Final Design and Construction of Palisades Tunnel	258,786,000	$331,507,813	$72,721,813	28%	4	7	11	10	15	9	10	13	11	10	100%	X Variable 4	2.4688	25.01
Testing the model case 5	REHAB: Highland Ave. Rail Station-Pedestrian Tunnel Repairs	479,946	$638,061	$158,115	33%	6	5	16	6	7	10	9	20	12	9	100%	X Variable 5	-3.0082	30.07
Testing the model case 6	REHAB: Construction Improvements to New Brunswick Train Station bridge	1,670,470	$1,870,669	$200,199	12%	14	8	9	4	5	10	7	18	14	11	100%	X Variable 6	-13.214	13.55
Testing the model case 7	REHAB: Repair of Riverline Light Rail Roebling Embankment Failure	7,158,758	$9,137,337	$1,978,579	28%	15	9	14	12	4	8	6	20	10	2	100%	X Variable 7	-4.4471	32.53

Table 14: Continuing-Applying the proposed Model using the variables to Predicted Cost Overrun for the 30 "New" completed contracts (different from the contracts used to develop the Model).

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10													
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10				
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%	Intercept	270.305	PREDICTED OVERRUN using the proposed model
Testing the model case 9	REPLCMT:Replacement of Welch Spur Rod Bridge over Raritan Valley Line	5,336,058	6,976,000	$1,639,942	31%	15	8	10	5	4	9	8	18	14	9	100%	X Variable 9	9.6487	35.30
Testing the model case 10	REHAB:Rehabilitation of Bergen Tunnel - North Tube	56,388,044	$66,084,629	$9,696,585	17%	17	8	2	4	6	10	10	15	16	12	100%	X Variable 1	-1.522	15.42
Testing the model case 11	NEW CONSTRTN: Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	$35,576,980	$7,917,560	29%	4	7	11	10	15	9	10	13	11	10	100%			25.01
Testing the model case 12	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$871,243	$89,693	11%	16	5	6	7	7	11	6	18	12	12	100%			14.04
Testing the model case 13	REHAB:North Retaining Wall Repairs Morristown Line M.P. 8.0 to M.P. 9.1 Newark, NJ	3,521,341	$5,039,200	$1,517,859	43%	16	8	13	4	6	8	5	18	12	10	100%			44.53
Testing the model case 14	REHAB:Repair of the Raritan River Bridge Fender System	104,106	$149,962	$45,856	44%	15	7	10	13	9	9	10	10	7	10	100%			40.51
Testing the model case 15	REHAB:Substructure Repairs to HX Draw Bridge Over Hackensack River-Secaucus, Hudson County, NJ (U.G. Bridge 5.48	1,841,000	$2,717,442	$876,442	48%	13	7	9	14	6	10	7	13	10	11	100%			49.78
Testing the model case 16	REPLCMT: Replacement of the West Parapet and Sidewalk at MP 21.73, Gladstone Branch, New Providence, NJ	$427,215.00	$621,978	$194,763	46%	11	6	10	15	8	12	10	8	8	12	100%			41.83

Table 14: Continuing-Applying the proposed Model using the variables to Predicted Cost Overrun for the 30 "New" completed contracts (different from the contracts used to develop the Model).

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 – 3.008X5 -13.213 X6 - 4.447 X7 – 8.201 X8 + 9.648 X9 -1.521 X10													
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10				
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0%	Intercept	270.305	PREDICTED OVERRUN using the proposed model
Testing the model case 17	REHAB:Substructure Rehabiltation of Beach Thorofare Drawbridge on Atlantic City Line M.P. 57.63 Atlantic City, NJ	$1,469,000.00	$1,900,574	$431,574	29%	13	8	12	7	8	8	6	17	11	10	100%			34.14
Testing the model case 18	REPLCMT:Design, Engineering & Construction Assistance for the Replacement of NJ Transit's Undergrade Drawbridge at NJCL M.P. 30.43 over Big Shark River	$441,346.00	$578,525	$137,179	31%	15	5	10	15	10	10	10	10	5	10	100%			35.61
Testing the model case 19	REPLCMT:Construction of the White House Siding along the Raritan Valley Line Readington Township, NJ	$1,535,270.00	$2,152,035	$616,765	40%	15	5	10	15	10	10	10	10	5	10	100%			35.61
Testing the model case 20	REHAB:Painting of Undergrade Bridges, M.P. 7.07 & M.P. 7.25, Morristown Line, Harrison, Hudson County, NJ	$627,500.00	$776,627	$149,127	24%	18	8	8	7	8	8	5	17	11	10	100%			27.11
Testing the model case 21	REHAB:Painting of Undergrade Bridges, M.P. 21.57 (GLD) Chatham & M.P. 22.74 (M&E) Summit, Morris and Union City, NJ	$435,000.00	$491,038	$56,038	13%	15	9	10	9	7	7	9	14	8	12	100%			15.64
Testing the model case 22	REHAB:Secaucus Junction Station Improvements Stage 1- Faregate Relocation Project Stage 2 - Crew Quarters Quiet Room	$329,373.00	$431,922	$102,549	31%	16	8	6	7	7	9	7	16	13	11	100%			25.06
Testing the model case 23	REHAB:Newark City Subway Portal Curve Trackwork Phase 2, Located in Newark, NJ	$674,700.00	$825,255	$150,555	22%	14	8	8	8	6	11	8	12	12	13	100%			25.87
Testing the model case 24	Emergency Repair: Hx Drawbridge, BCL M.P. 5.48 Upper Link Assembly- Emergency Enigneering Services	$80,310.00	$133,853	$53,543	67%	14	7	8	7	6	10	8	12	14	14	100%			67.23

Table 14: Continuing-Applying the proposed Model using the variables to Predicted Cost Overrun for the 30 "New" completed contracts (different from the contracts used to develop the Model).

						INDEPENDABLE VARIABLEs as % of the the total actual overun of each case study: contingency Y" = 270.304 + 0.708 X1 -12.842 X2 + 3.755 X3 + 2.468 X4 - 3.008X5 -13.213 X6 - 4.447 X7 - 8.201 X8 + 9.648 X9 -1.521 X10													
30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overun ($)	(%) of Actual Overrun at completion	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10				
						Track outage Constraints restricting work schedule	Construction staging (Rehab vs. for bridge Replacement)	Marine outages: Mariners approval, Port authorities, US coast guard	Third parties approval	ROW permits&Site Access (issued vs apply)	non-movable bridge vs movable	Project wide Communication	Unforeseen existing Field condition (Controlled vs undetermined)	Structure Steel work/Material long lead fabrication and delivery time	Labor type (reg vs Tech)	0z	Intercept	270.305	PREDICTED OVERRUN using the proposed model
Testing the model case 25	REHAB:Kings Road Retaining Wall & Elm Street Bridge Repairs M.P. 25.61 to 25.80 and 26.17 Morristown Line, Madison, Morris County, NJ	$1,368,000.00	$1,660,003	$292,003	21%	16	5	6	7	7	11	6	18	12	12	100%			14.04
Testing the model case 26	HBLR Weehawken Pedestrian Overpass, East Tower	$893,230.00	$1,161,341	$268,111	30%	15	5	10	15	10	10	10	10	5	10	100%			35.61
Testing the model case 27	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	$3,572,825.00	$4,520,854	$948,029	27%	13	5	9	7	7	11	6	18	12	12	100%			23.18
Testing the model case 28	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$972,062	$190,512	24%	15	5	10	8	6	12	5	18	12	9	100%		24	29.62
Testing the model case 29	REHAB:Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	$2,074,424	$505,424	32%	16	5	16	5	5	11	5	19	10	8	100%		32	35.70
Testing the model case 30	REHAB:Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County, NJ)	2,676,315	$4,272,426	$1,596,111	60%	15	5	15	5	9	10	5	16	11	9	100%		60	65.15

Table 15: Actual Cost Overrun of contracts grouped by categories of their dollar amount for the 30 "New" completed contracts (different from the contracts used to develop the Model).

	Contracts less than $1M					(%) of Actual Overrun at completion
Testing the model case 24	Emergency Repair: Hx Drawbridge, BCL M.P. 5.48 Upper Link Assembly-Emerge	$80,310	$133,853	$53,543	rehab	67%
Testing the model case 14	REHAB:Repair of the Raritan River Bridge Fender System	$104,106	$149,962	$45,856	rehab	44%
Testing the model case 22	REHAB:Secaucus Junction Station Improvements Stage 1- Faregate Relocation I	$329,373	$431,922	$102,549	rehab	31%
Testing the model case 21	REHAB:Painting of Undergrade Bridges, M.P. 21.57 (GLD) Chatham & M.P. 22.74	$435,000	$491,038	$56,038	rehab	13%
Testing the model case 18	REPLCMT:Design, Engineering & Construction Assistance for the Replacement c	$441,346	$578,525	$137,179	replcmt	31%
Testing the model case 16	REPLCMT: Replacement of the West Parapet and Sidewalk at MP 21.73, Gladst	$427,215	$621,978	$194,763	replcmt	46%
Testing the model case 5	REHAB: Highland Ave. Rail Station-Pedestrian Tunnel Repairs	$479,946	$638,061	$158,115	rehab	33%
Testing the model case 20	REHAB:Painting of Undergrade Bridges, M.P. 7.07 & M.P. 7.25, Morristown Line,	$627,500	$776,627	$149,127	rehab	24%
Testing the model case 23	REHAB:Newark City Subway Portal Curve Trackwork Phase 2, Located in Newark	$674,700	$825,255	$150,555	rehab	22%
Testing the model case 28	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	$781,550	$972,062	$190,512	rehab	24%
Testing the model case 26	REHAB:HBLR Weehawken Pedestrian Overpass, East Tower	$893,230	$1,161,341	$268,111	replcmt	30%
Testing the model case 2	REPLCMT:Culvert Replacement Flow Morristown line , M.P. 36.87, NJ	$902,510	$1,319,196	$416,686	replcmt	46%
	Contracts range $1 To 3 M					(%) of Actual Overrun at completion
Testing the model case 25	REHAB:Kings Road Retaining Wall & Elm Street Bridge Repairs M.P. 25.61 to 25.	$1,368,000	$1,660,003	$292,003	rehab	21%
Testing the model case 6	REHAB: Construction Improvements to New Brunswick Train Station bridge	$1,670,470	$1,870,669	$200,199	rehab	12%
Testing the model case 17	REHAB:Substructure Rehabiltation of Beach Thorofare Drawbridge on Atlantic (	$1,469,000	$1,900,574	$431,574	rehab	29%
Testing the model case 29	REHAB:Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	$1,569,000	$2,074,424	$505,424	rehab	32%
Testing the model case 19	REPLCMT:Construction of the White House Siding along the Raritan Valley Line	$1,535,270	$2,152,035	$616,765	replcmt	40%
Testing the model case 15	REHAB:Substructure Repairs to HX Draw Bridge Over Hackensack River-Secaucu	$1,841,000	$2,717,442	$876,442	rehab	48%
Testing the model case 30	REHAB:Substructure Rehabilitation of Bascule Bridge, NJCL over Manasquan Ri	$2,676,315	$4,272,426	$1,596,111	rehab	60%
	Contracts range $3 To $10 M	Original contract Value	Actual Cost at completion	Cost Overun ($)		(%) of Actual Overrun at completion
Testing the model case 27	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	$3,572,825	$4,520,854	$948,029	rehab	27%
Testing the model case 8	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	$3,572,825	$4,601,488	$1,028,663	rehab	29%
Testing the model case 13	REHAB:North Retaining Wall Repairs Morristown Line M.P. 8.0 to M.P. 9.1 Newa	$3,521,341	$5,039,200	$1,517,859	rehab	43%
Testing the model case 9	REPLCMT:Replacement of Welch Spur Rod Bridge over Raritan Valley Line	$5,336,058	$6,976,000	$1,639,942	replcmt	31%
Testing the model case 7	REHAB: Repair of Riverline Light Rail Roebling Embankment Failure	$7,158,758	$9,137,337	$1,978,579	rehab	28%
Testing the model case 1	REHAB:Construction of Submarine Duct Bank, Shark River Draw, North JCL M.P.	$7,999,000	$9,600,709	$1,601,709	rehab	20%
	Contracts range $10 To $60 M	Original contract Value	Actual Cost at completion	Cost Overun ($)		(%) of Actual Overrun at completion
Testing the model case 3	NEW CONSTRTN:Construction of the 69th Street Grade bridge Project	$22,027,109	$27,127,707	$5,100,598	new constr	23%
Testing the model case 11	NEW CONSTRTN: Main Bergen Connection Project - Secaucus Transfer Program	$27,659,420	$35,576,980	$7,917,560	new constr	29%
Testing the model case 10	REHAB:Rehabilitation of Bergen Tunnel - North Tube	$56,388,044	$66,084,629	$9,696,585	rehab	17%
	Contract above $200M	Original contract Value	Actual Cost at completion	Cost Overun ($)		(%) of Actual Overrun at completion
Testing the model case 4	NEW CONSTRTN:Final Design and Construction of Palisades Tunnel	$258,786,000	$331,507,813	$72,721,813	new constr	28%

Graphical presentation of cost overrun by categories of contract amounts:

1. Original Contract vs. Actual Cost at completion for Original Contract value less than $1 M, as illustrated in Fig.11

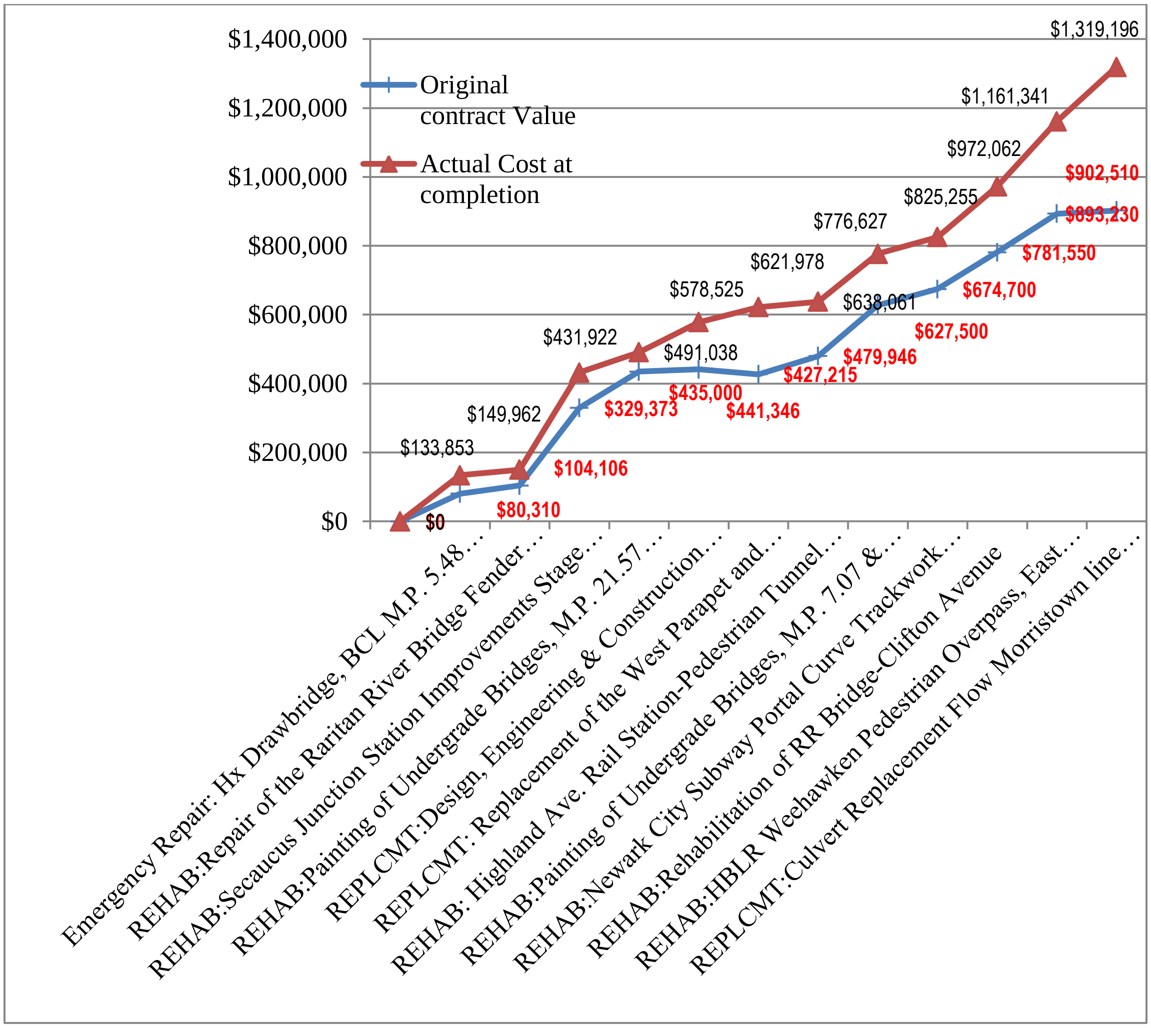


Figure 11: Original Contract vs. Actual Cost at completion for Contracts less than $1 M

2. Original Contract vs. Actual Cost at completion for Original Contract value above $1 M and less than $ 5M, Fig.12.

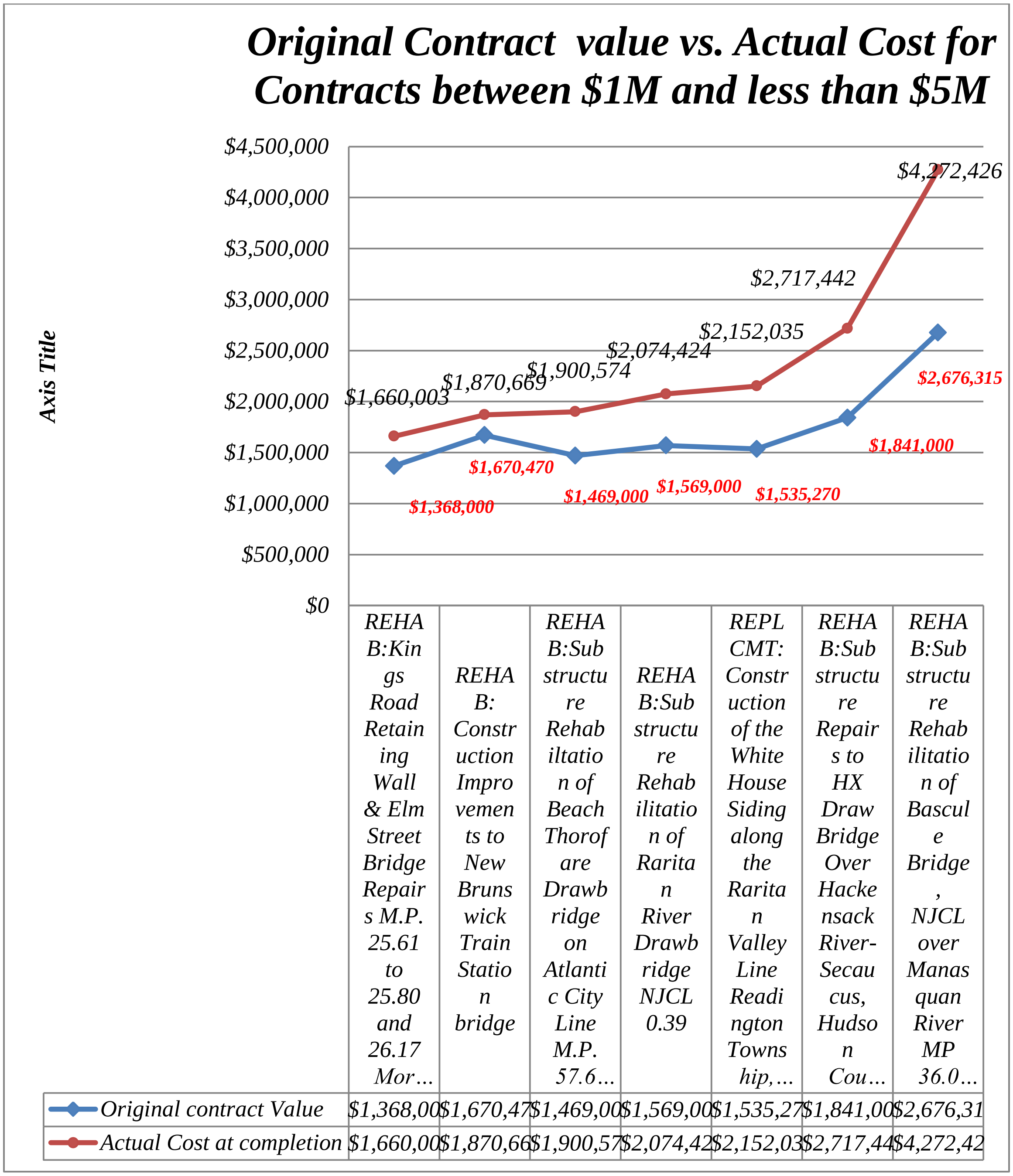


Figure 12: Original Contract vs. Actual Cost for Contracts between $1M and less than $3 M

3. Fig. 13 demonstrates that amount of variance increases when the contract amount increases for Contracts above $3M and less than $10 M,

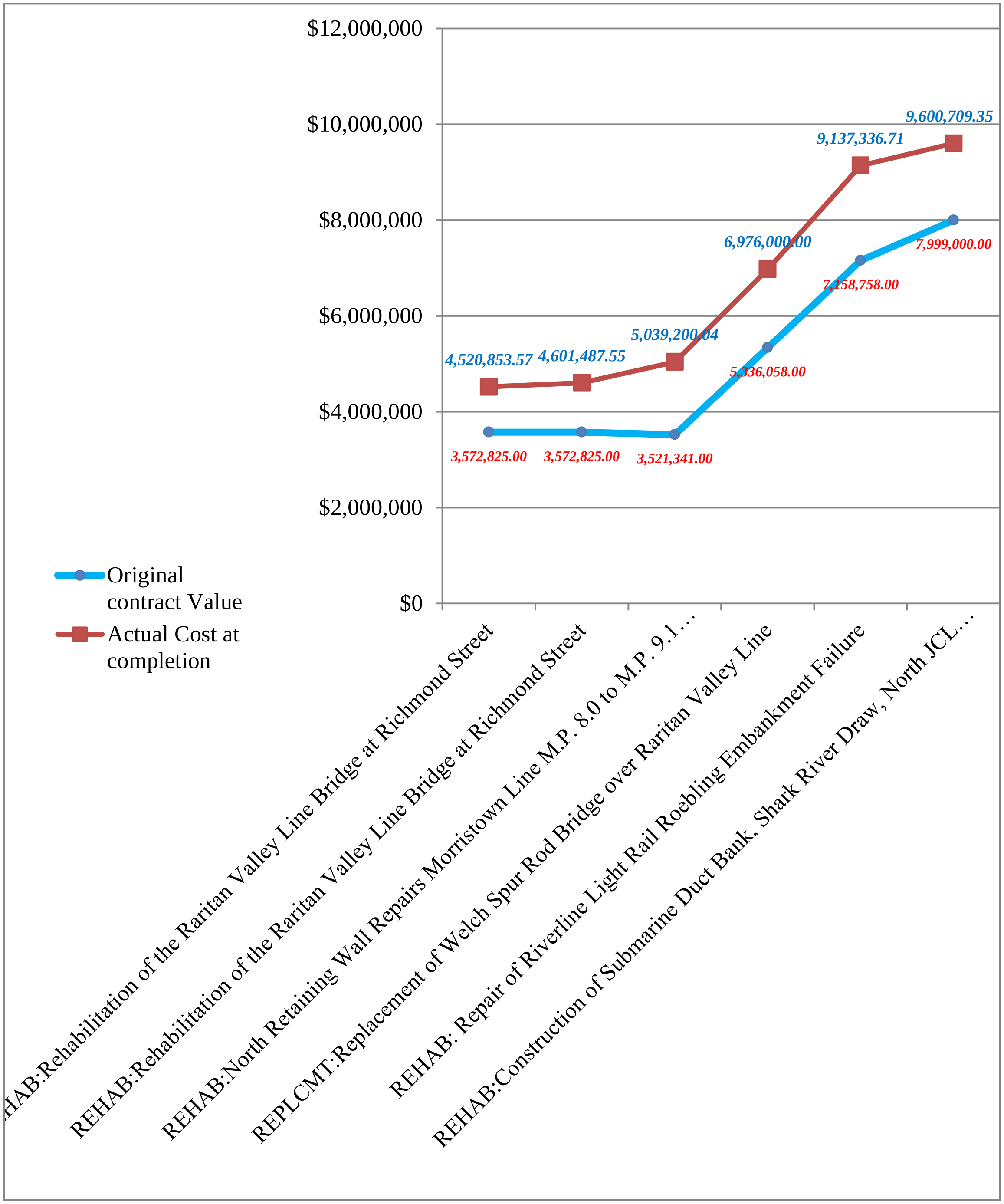
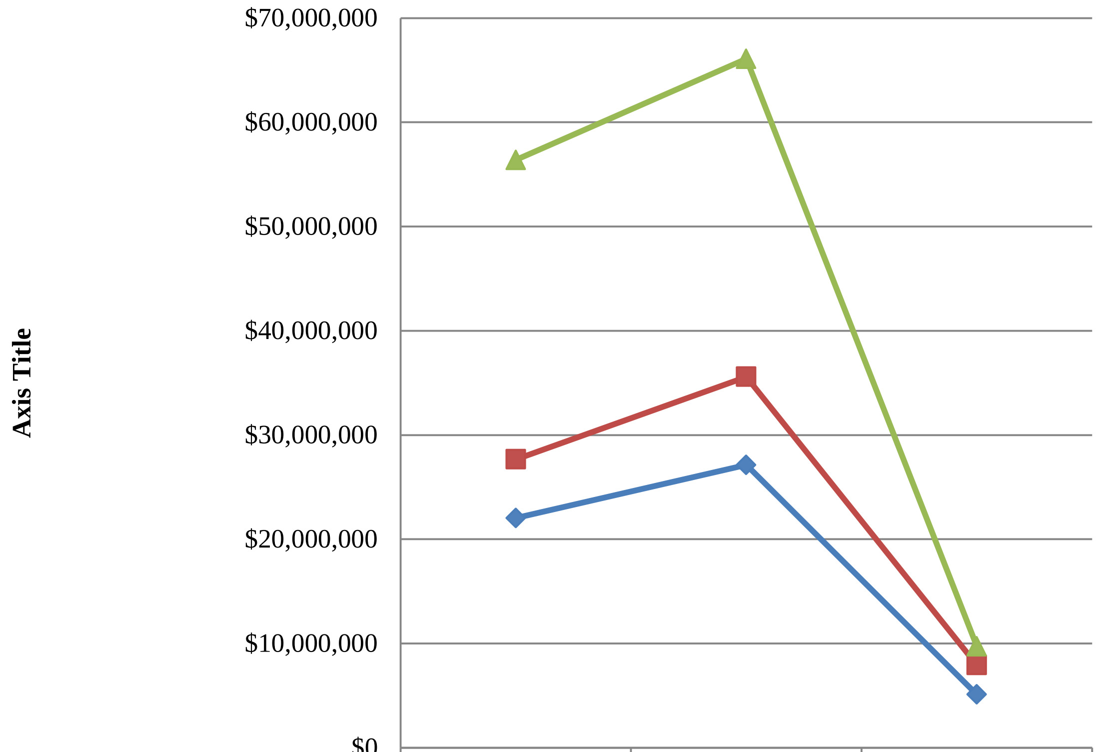


Figure 13: Original Contract vs. Actual Cost for Contracts above $3M and less than $10 M

4. Fig. 14 demonstrates that amount of variance increases when the contract amount increases for Contracts above $20M and less than $100 M,



	Original contract Value	Actual Cost at completion	Cost Overun ($)
NEW CONSTRTN:Construction of the 69th Street Grade bridge Project	$22,027,109	$27,127,707	$5,100,598
NEW CONSTRTN: Main Bergen Connection Project - Secaucus Transfer Program	$27,659,420	$35,576,980	$7,917,560
REHAB:Rehabilitation of Bergen Tunnel - North Tube	$56,388,044	$66,084,629	$9,696,585

Figure 14: Original Contract vs. Actual Cost for Contracts above $20 M and less than $ 100M

5. Fig. 15 demonstrates that amount of variance of Actual Cost from Original Contract for various type of construction

Figure 15: Original Contract vs. Actual Cost for Contracts above $20 M and less than $ 100M

6. Fig. 16 demonstrates that amount of variance of Actual Cost from Original Contract for contracts above $200M

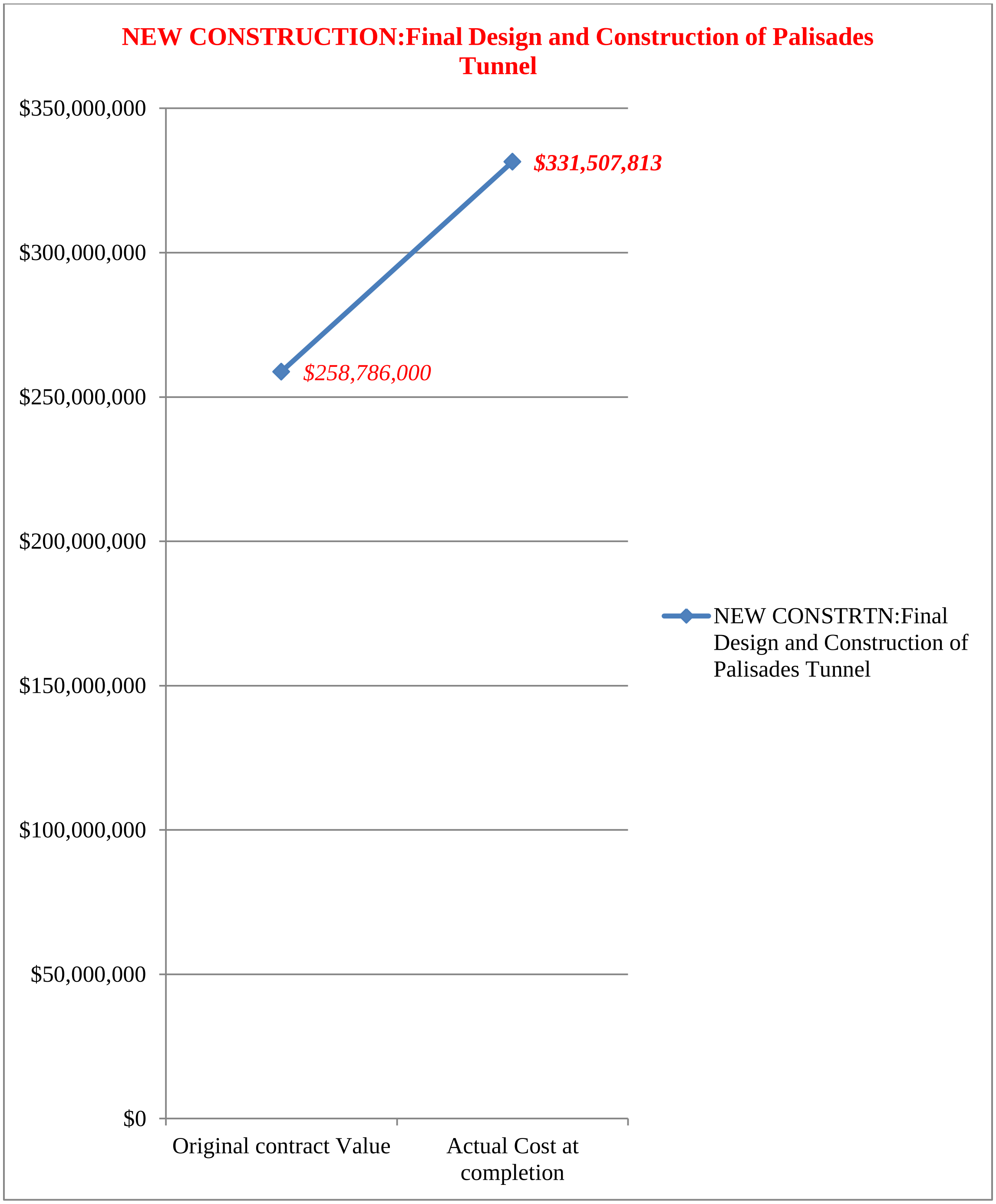


Figure 16: Original Contract vs. Actual Cost for Contracts above than $ 200M

7. Fig. 17 shows the different slope in each type construction which reveals that the cost overrun rates are different, deeper slope represents higher cost variance.

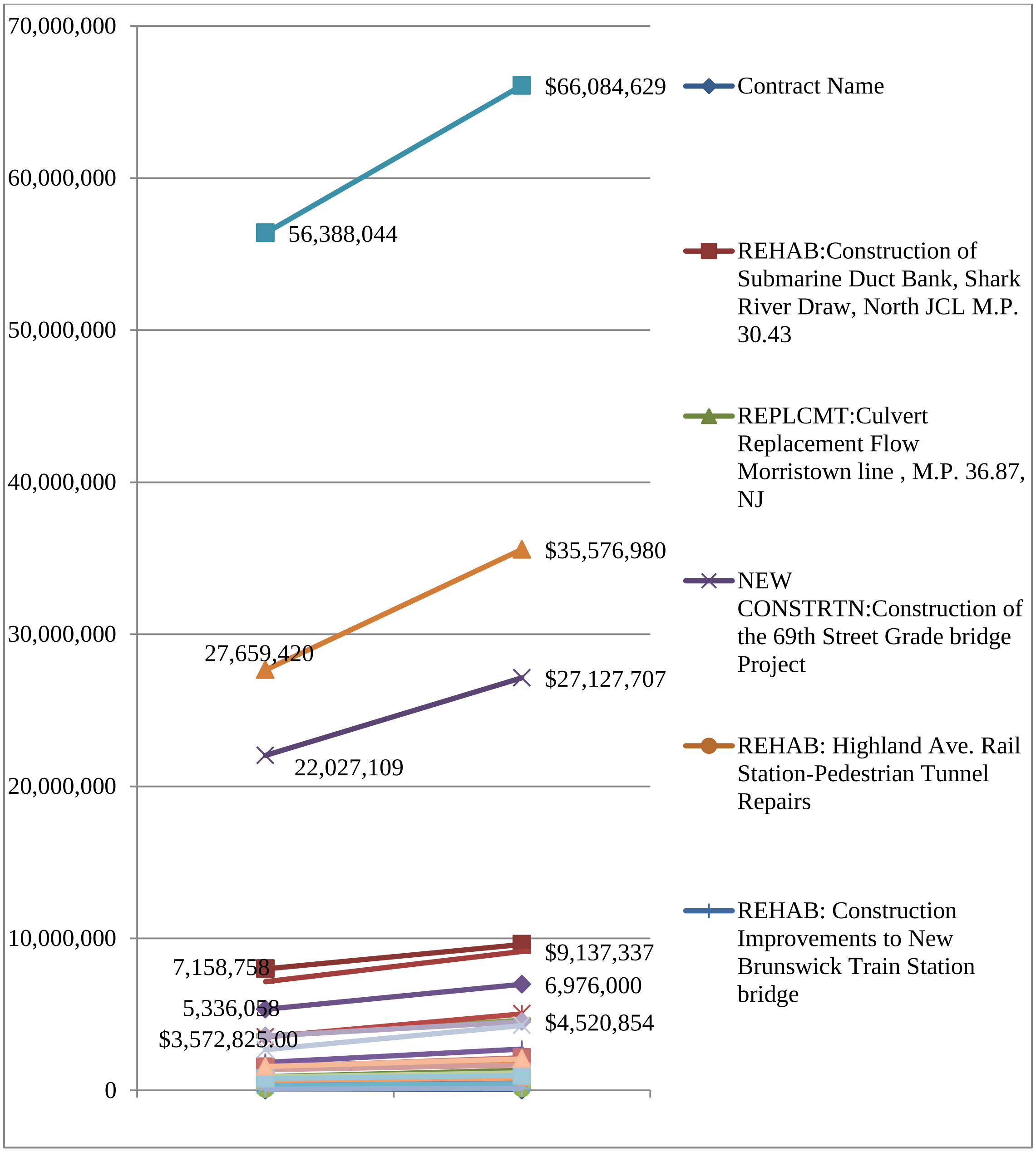


Figure 17: Based on Type of Construction: Comparison between Original Contract vs. Actual Cost for Contracts below than $100M

8. Fig.18.Cost overrun varies based on type of Construction: It reveals that there is no correlation between overrun and construction type

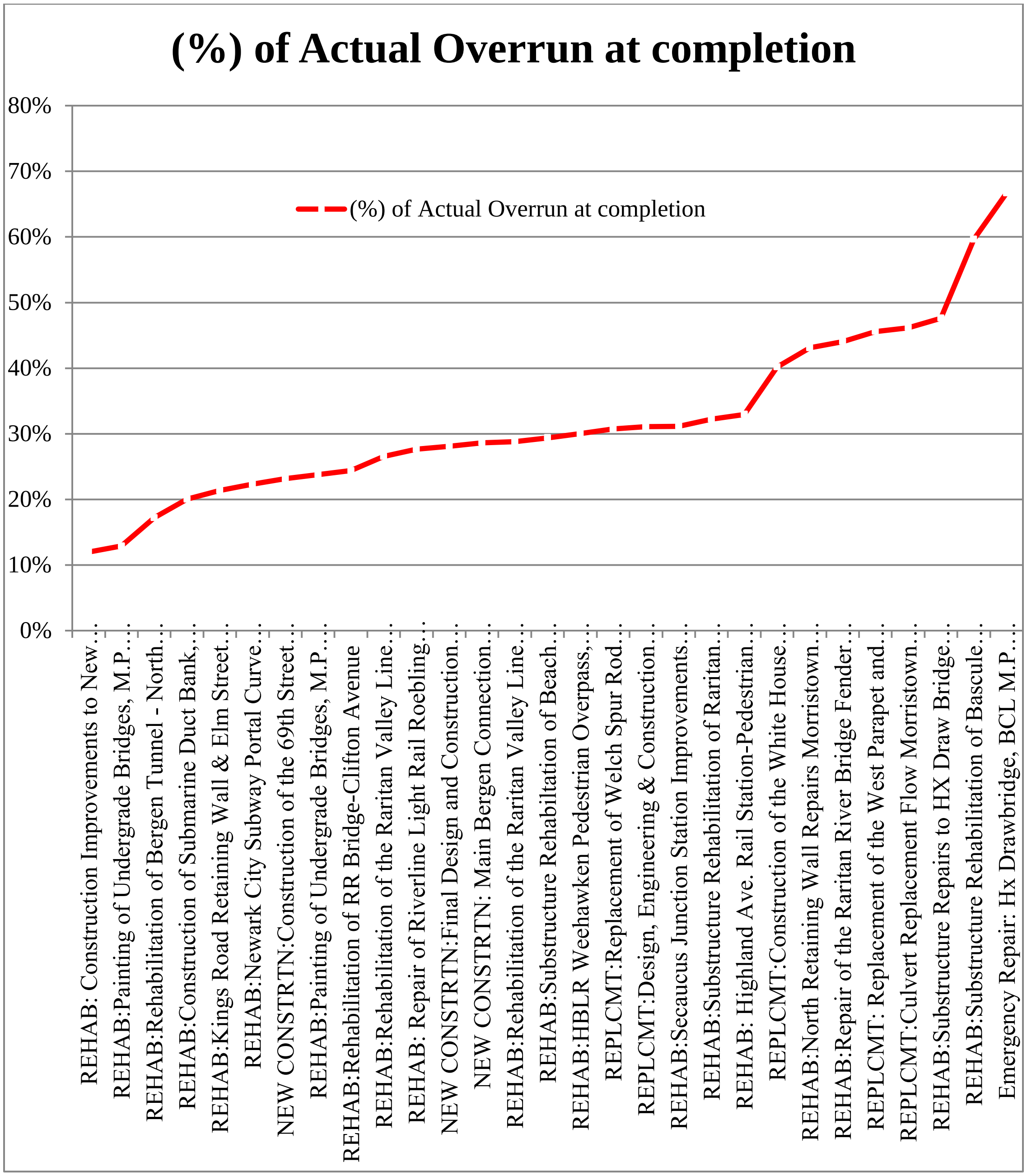


Figure 18: Percentage of Cost overrun vs. Type of Construction: (No correlation between overrun and construction type)

9. Fig 19 shows Cost overrun vs. Type of Construction for contracts range between $1m and $350M: No correlation between overrun and construction type

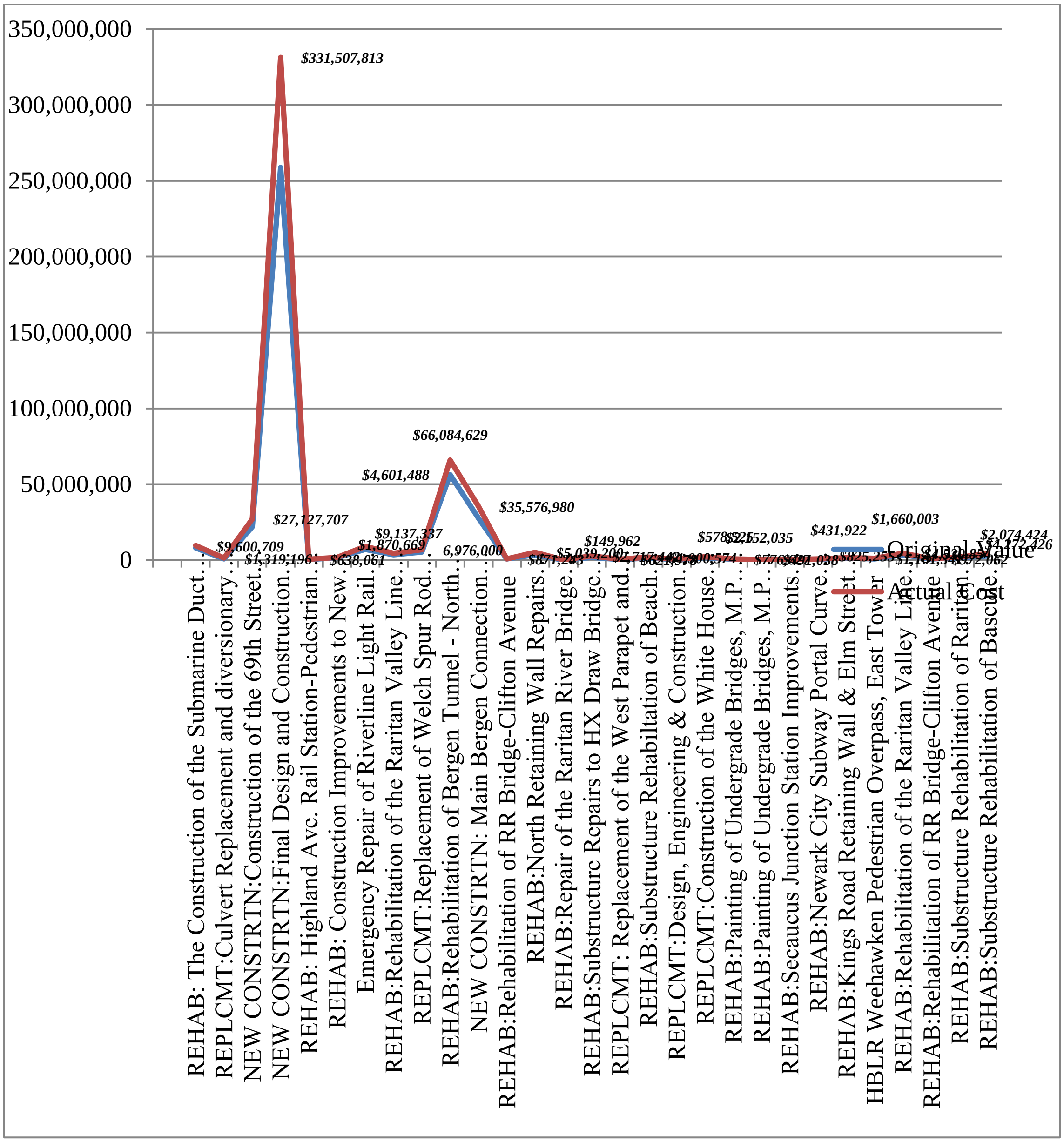


Figure 19: Based on Type of Construction: Comparison between Original Contract vs. Actual Cost for contract values between $50K to $350 M

10. Fig 20 shows percentage of Cost overrun vs. Type of Construction: No correlation between % of overrun and construction type.

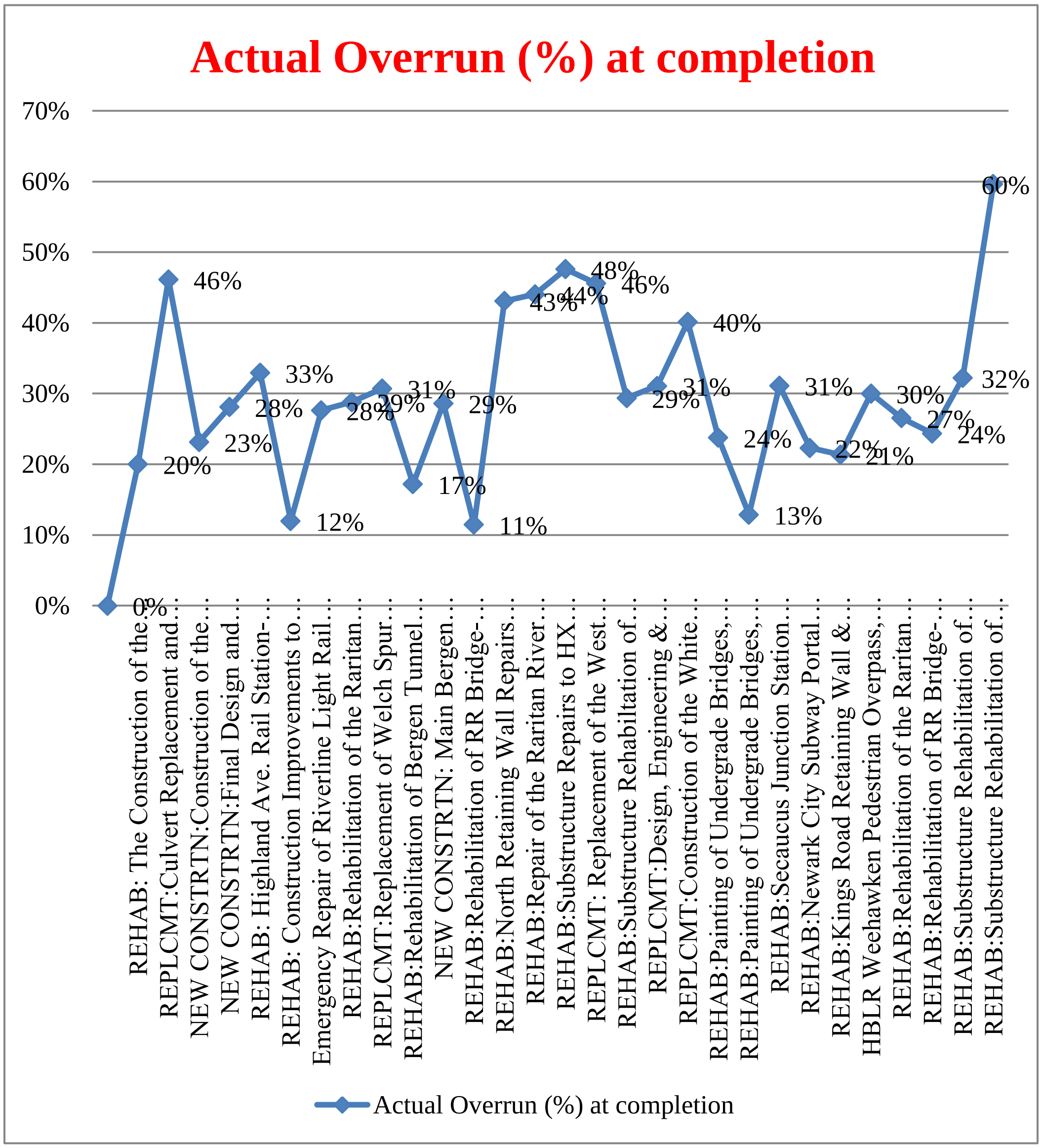


Fig. 20: Percentage of Actual Overrun based on Type of Construction.

11. Fig 21 illustrates the Percentage of contribution of each variable to the total cost overrun for each type of Construction. No correlation between the type of construction to any of the 10 independent variables.

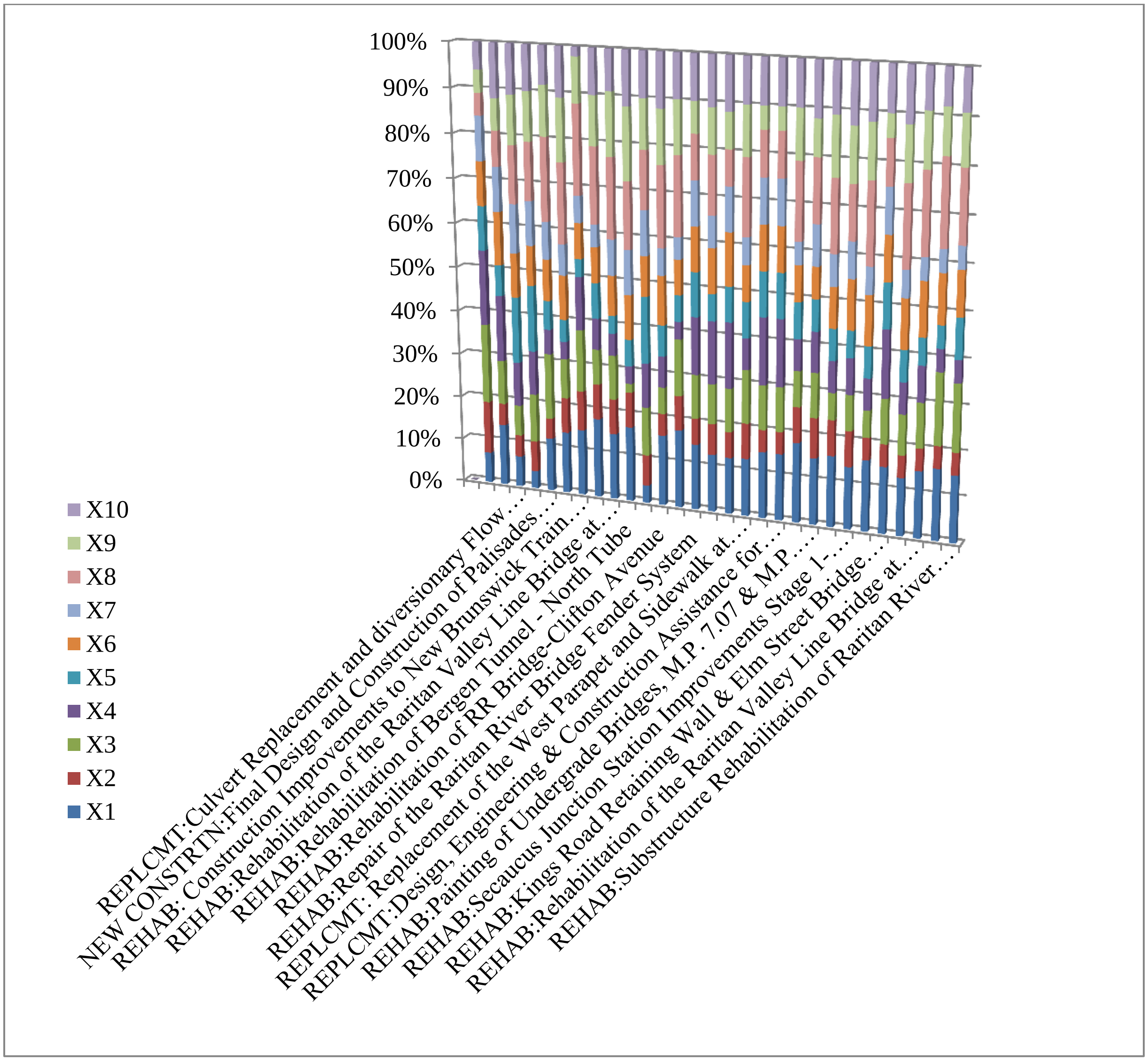


Figure 21: Percentage of contribution of each variable to the total cost overrun for each type of Construction.

12. Figure 22 demonstrates that no correlation between type of Construction with any of the variables impacting the total cost overrun through varieties of RR bridge construction types.
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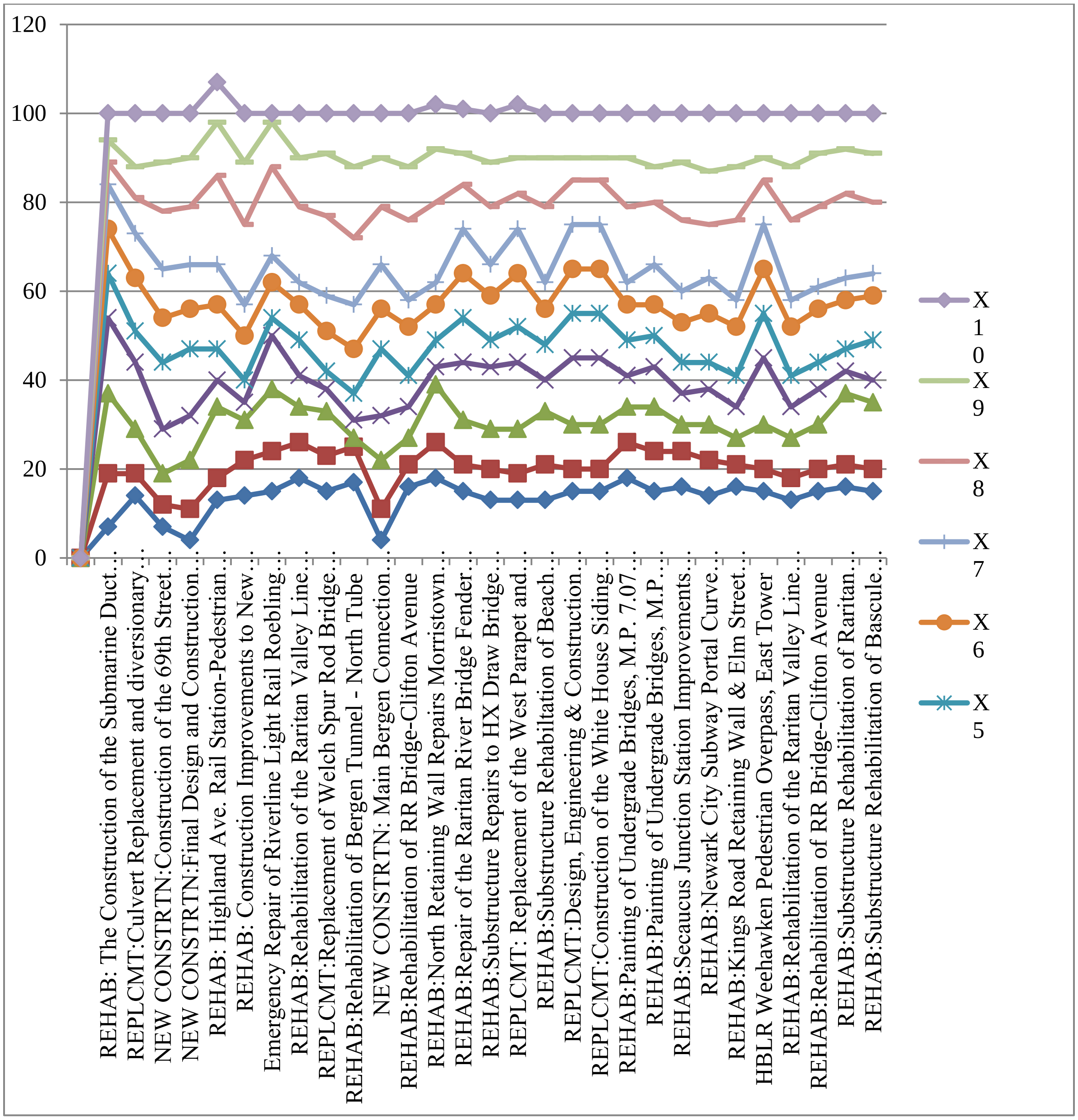

Figure 22: Cumulative percentage of contribution of each variable to the total cost overrun for each type of Construction.

13. Figure 23 shows no correlation of the variation of % of overrun based on various type of construction

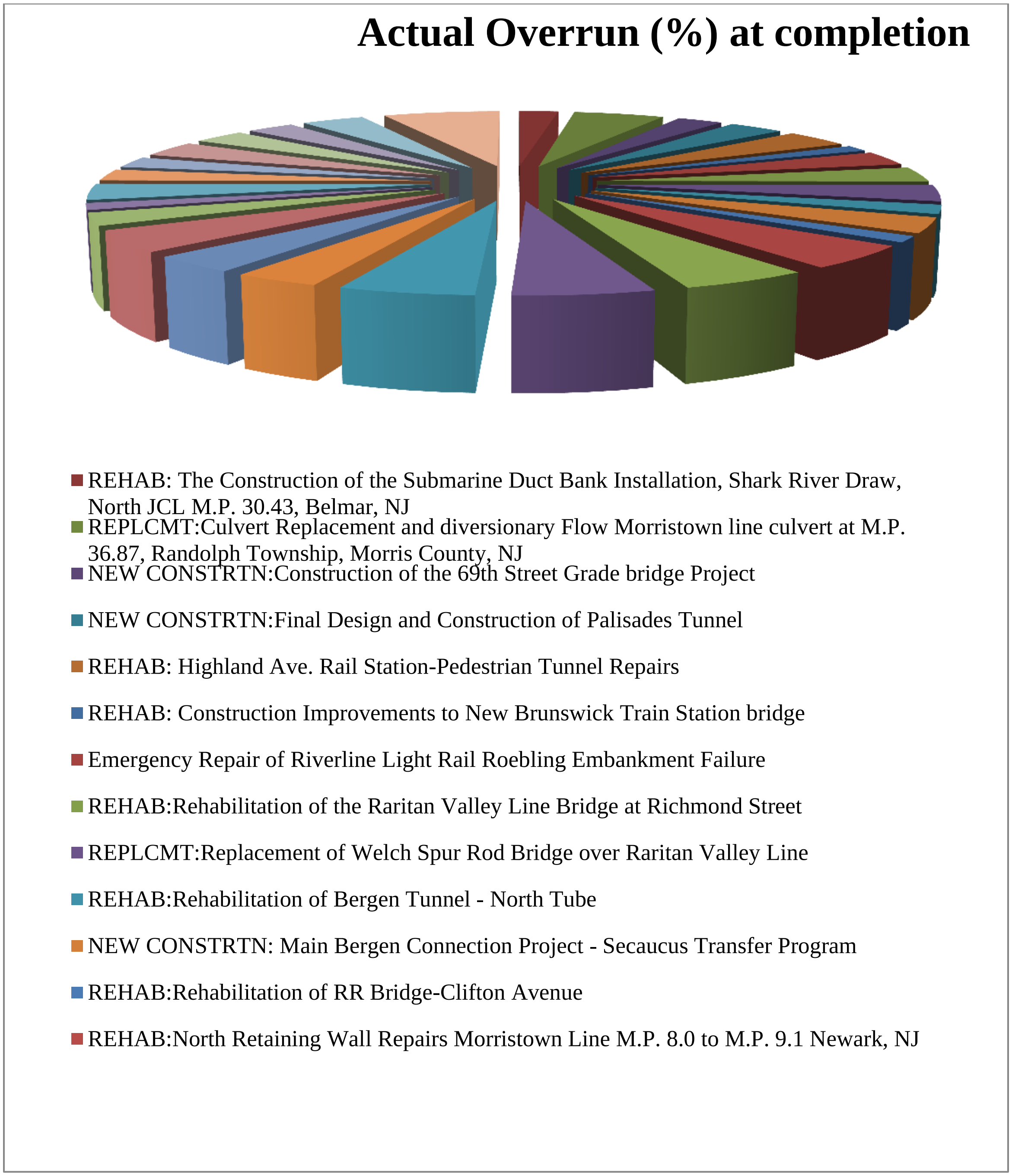

Figure 23: Percentage of cost overrun for each completed contract classified by Construction type.

Figure 24 through Figure 34 shows the degree of variation of each variable has no direct correlation with the type of Construction (Repairs, Replacement, New Construction)

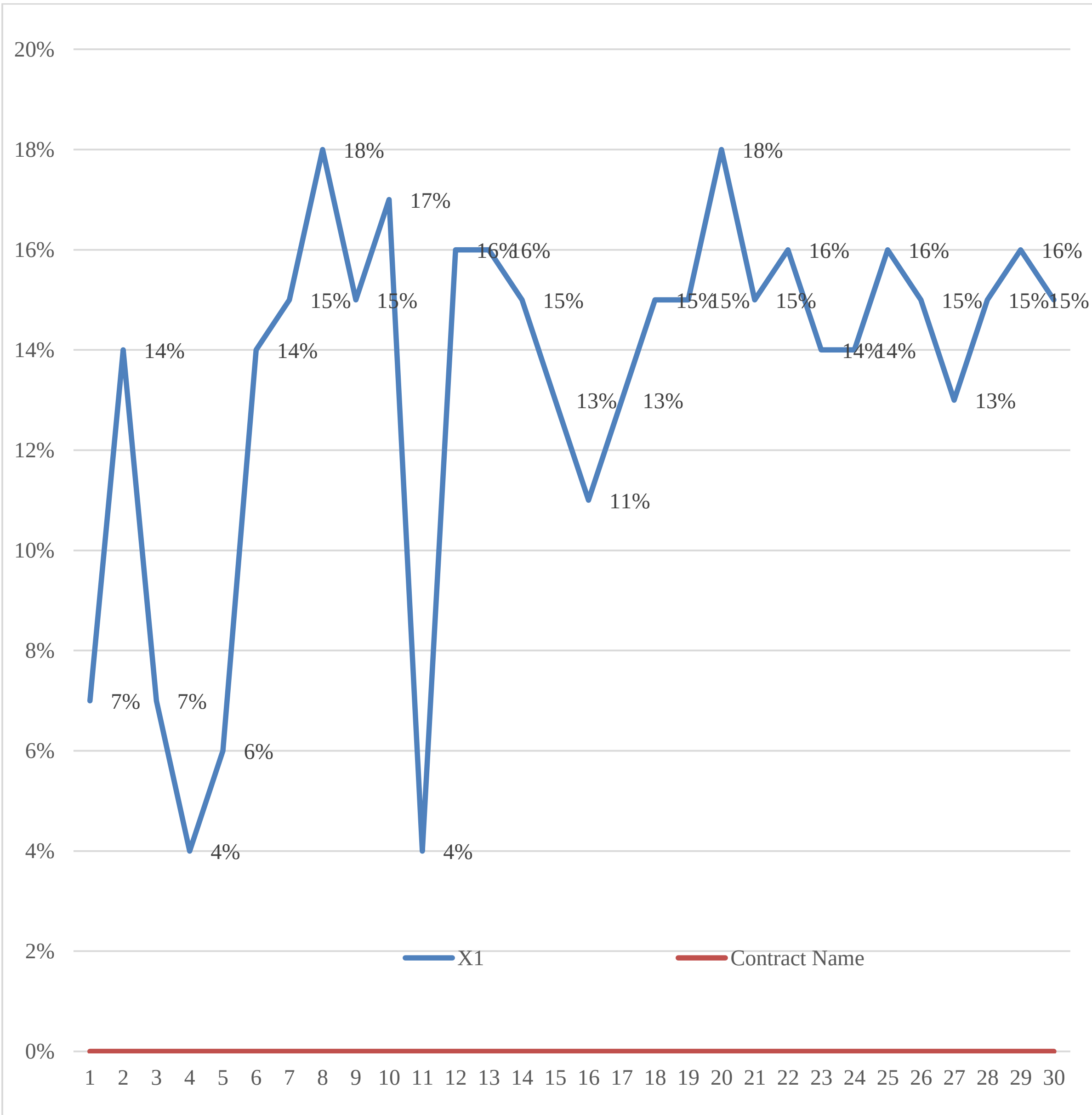

Figure 24: Percentage of "X1" variable contribution to the total cost overrun for each completed contract of the 30 new construction contracts.

Figure 25 shows the impact of each cost overrun risk factor (independent variable "X1" contribution to the total cost overrun for each completed contract classified by Construction type.

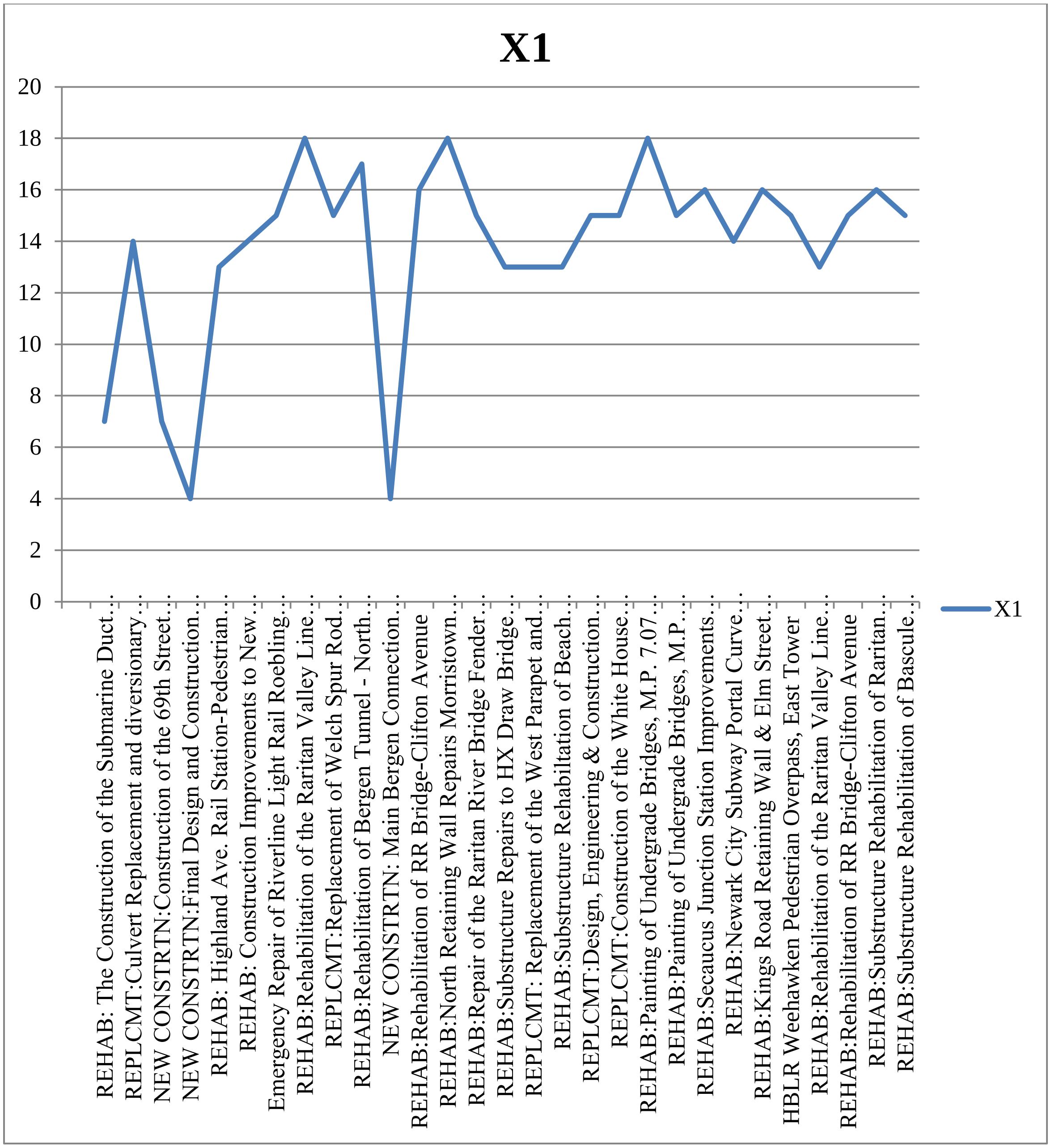

Figure 25: Percentage of "X1" variable contribution to the total cost overrun for each completed contract classified by Construction type.

Figure 26 shows the impact of each cost overrun risk factor (independent variable “X2” contribution to the total cost overrun for each completed contract classified by Construction type.

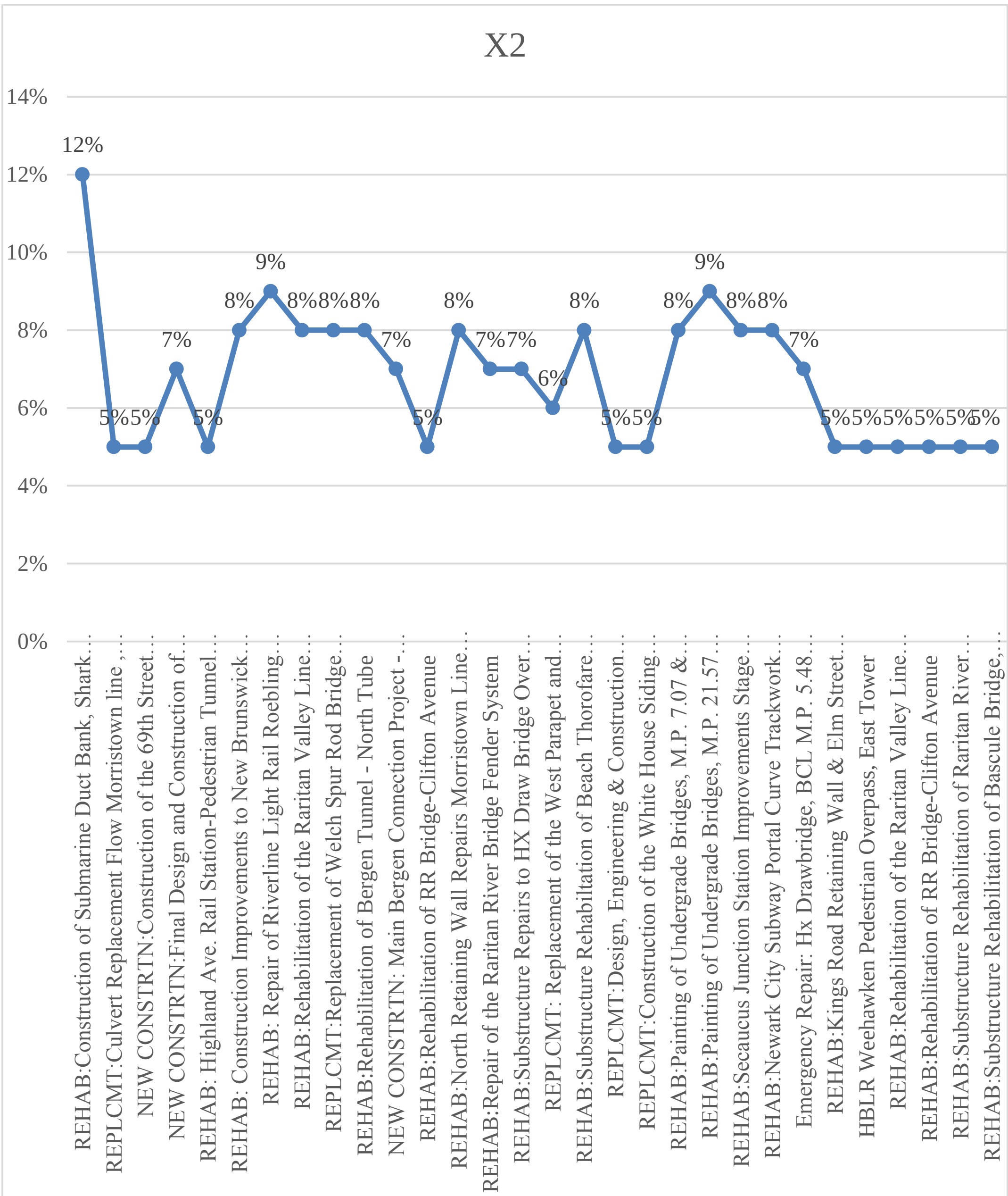

Figure 26: Percentage of “X2” variable contribution to the total cost overrun for each completed contract classified by Construction type.

Figure 27 shows the impact of each cost overrun risk factor (independent variable "X3" contribution to the total cost overrun for each completed contract classified by Construction type.

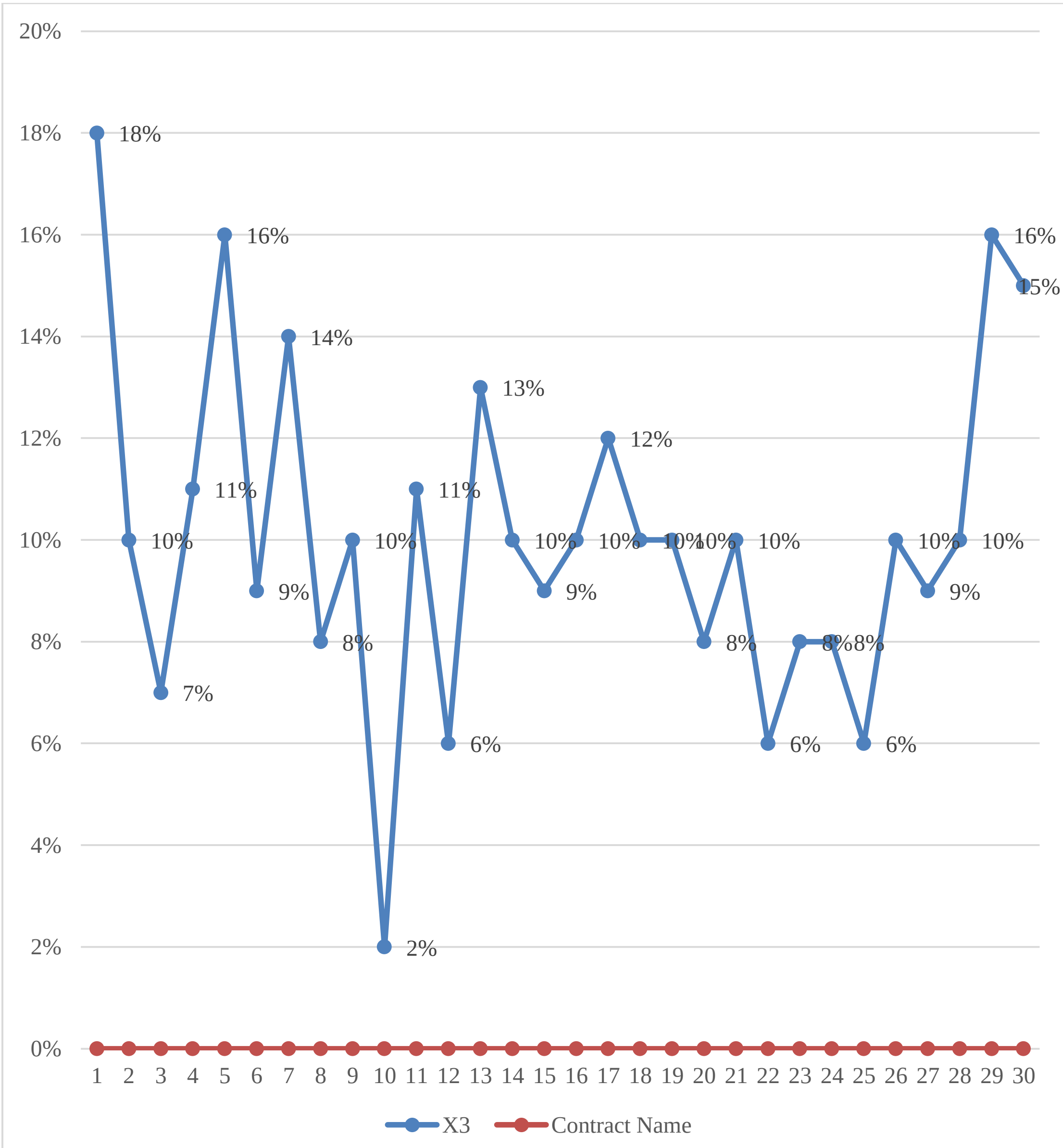

Figure 27: Percentage of "X3" variable contribution to the total cost overrun for each completed contract classified by Construction type.

Figure 28 shows the impact of each cost overrun risk factor (independent variable “X1” contribution to the total cost overrun for each completed contract classified by Construction type.

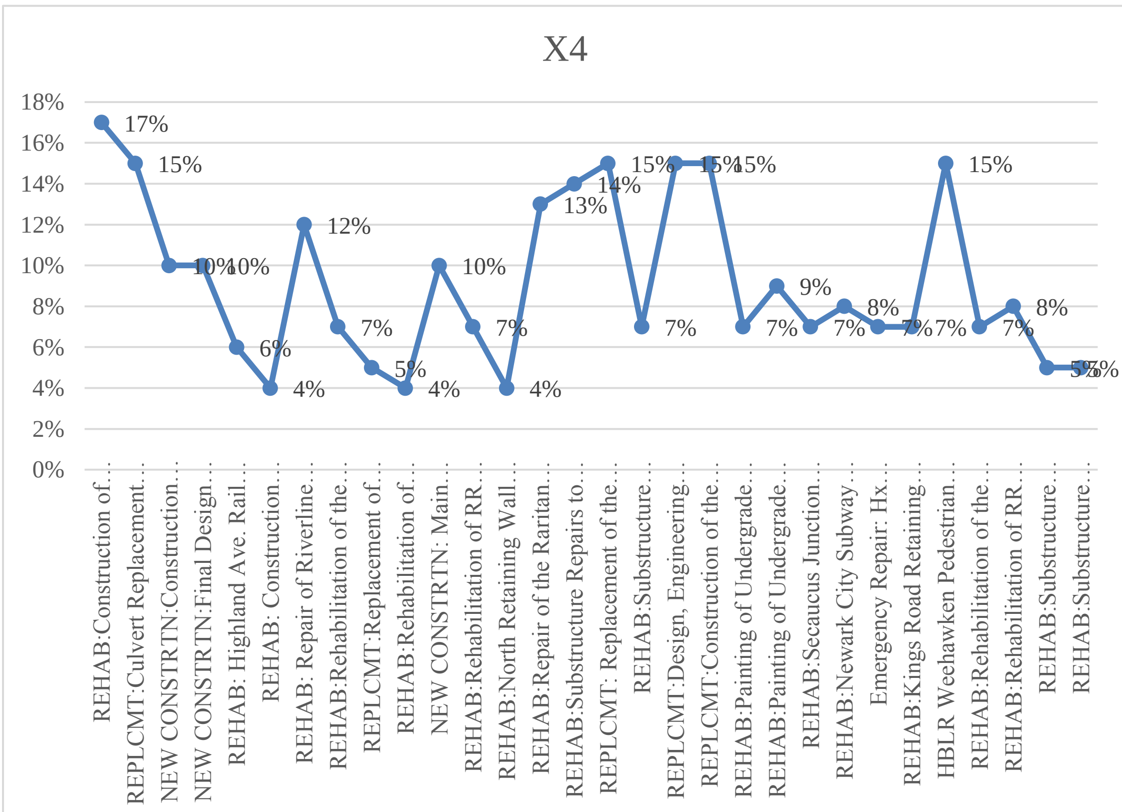

Figure 28: Percentage of “X4” variable contribution to the total cost overrun for each completed contract classified by Construction type.

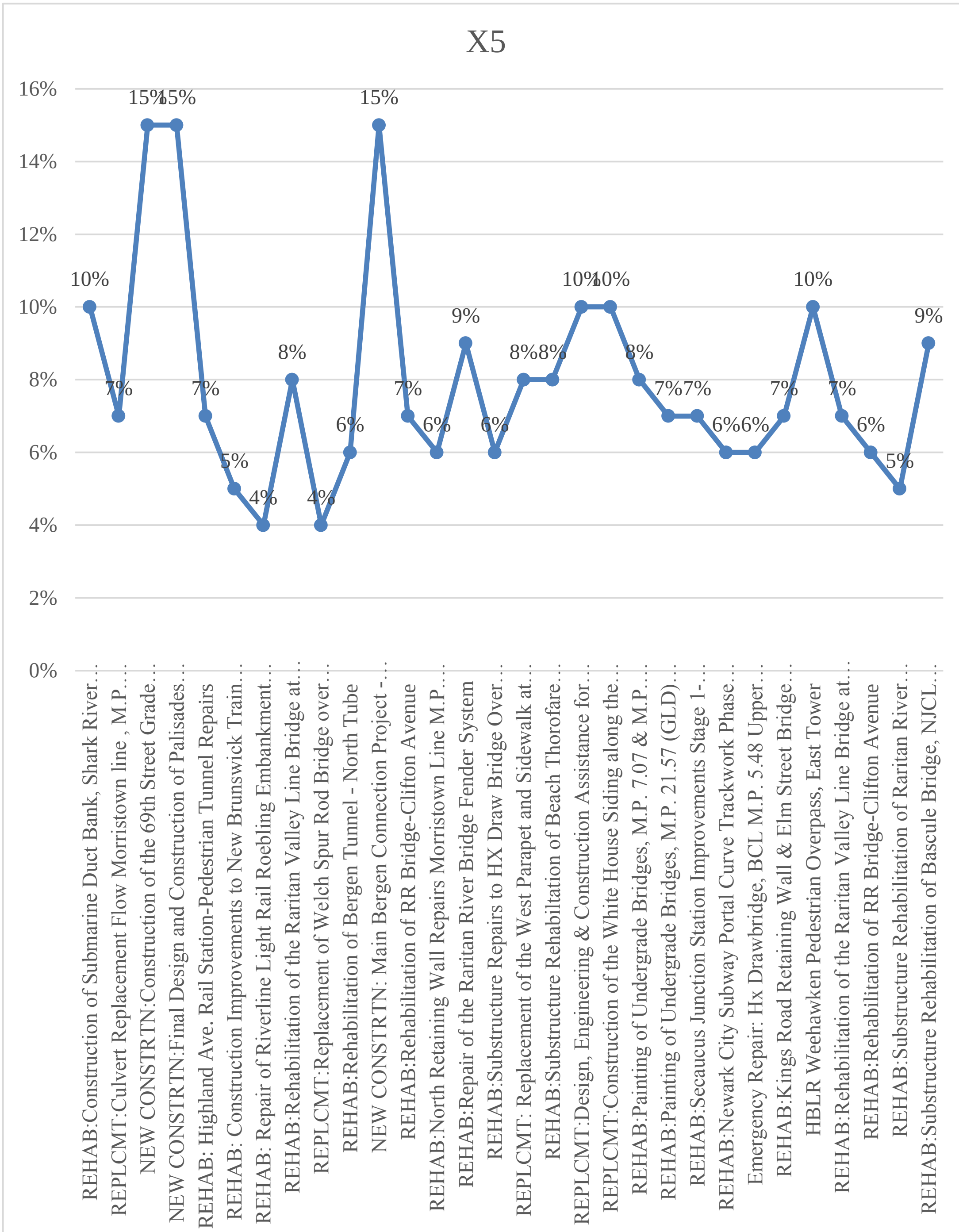

Figure 29:Percentage of “X5” variable contribution to the total cost overrun for each completed contract classified by Construction type.

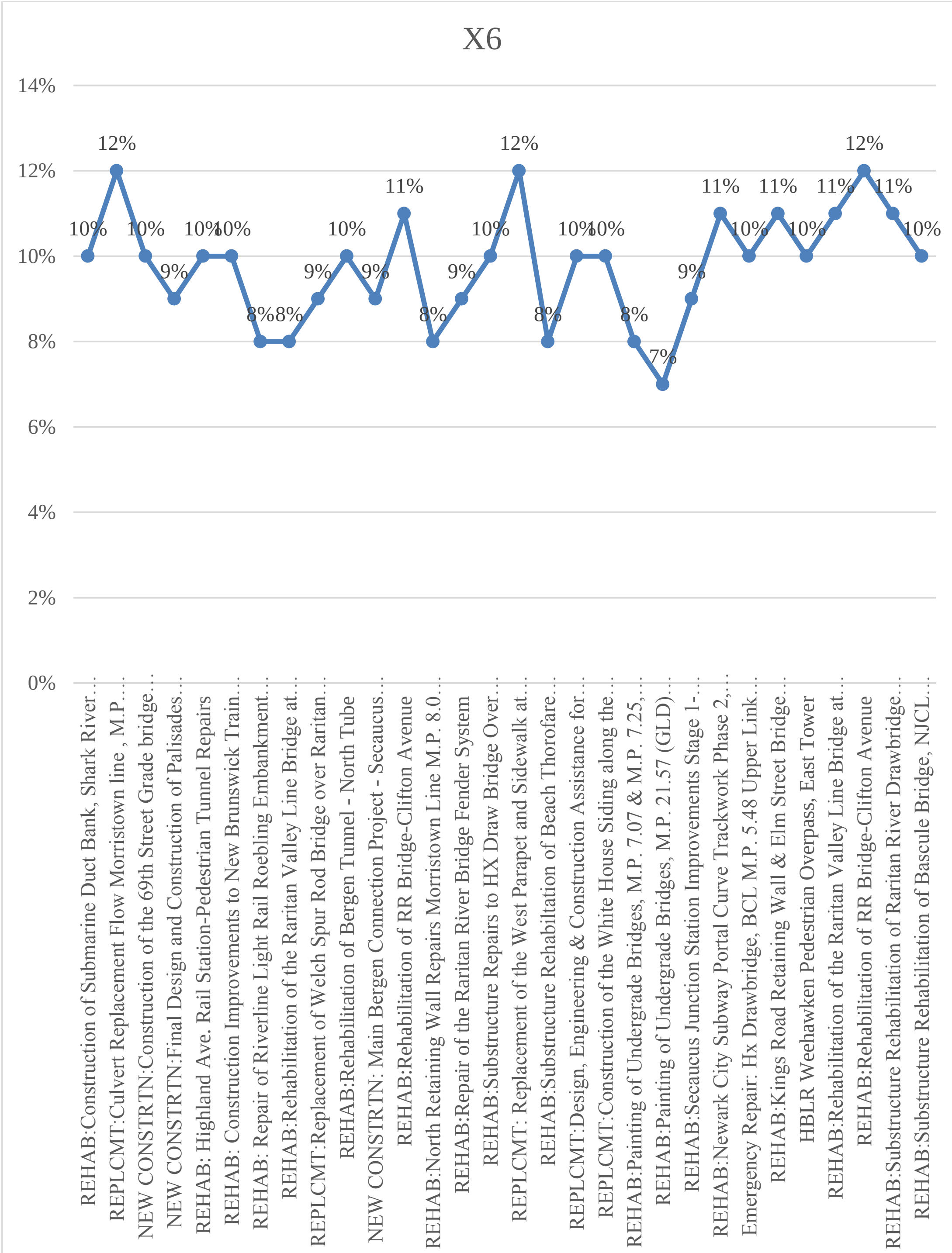

Figure 30: Percentage of "X6" variable contribution to the total cost overrun for each completed contract classified by Construction type.

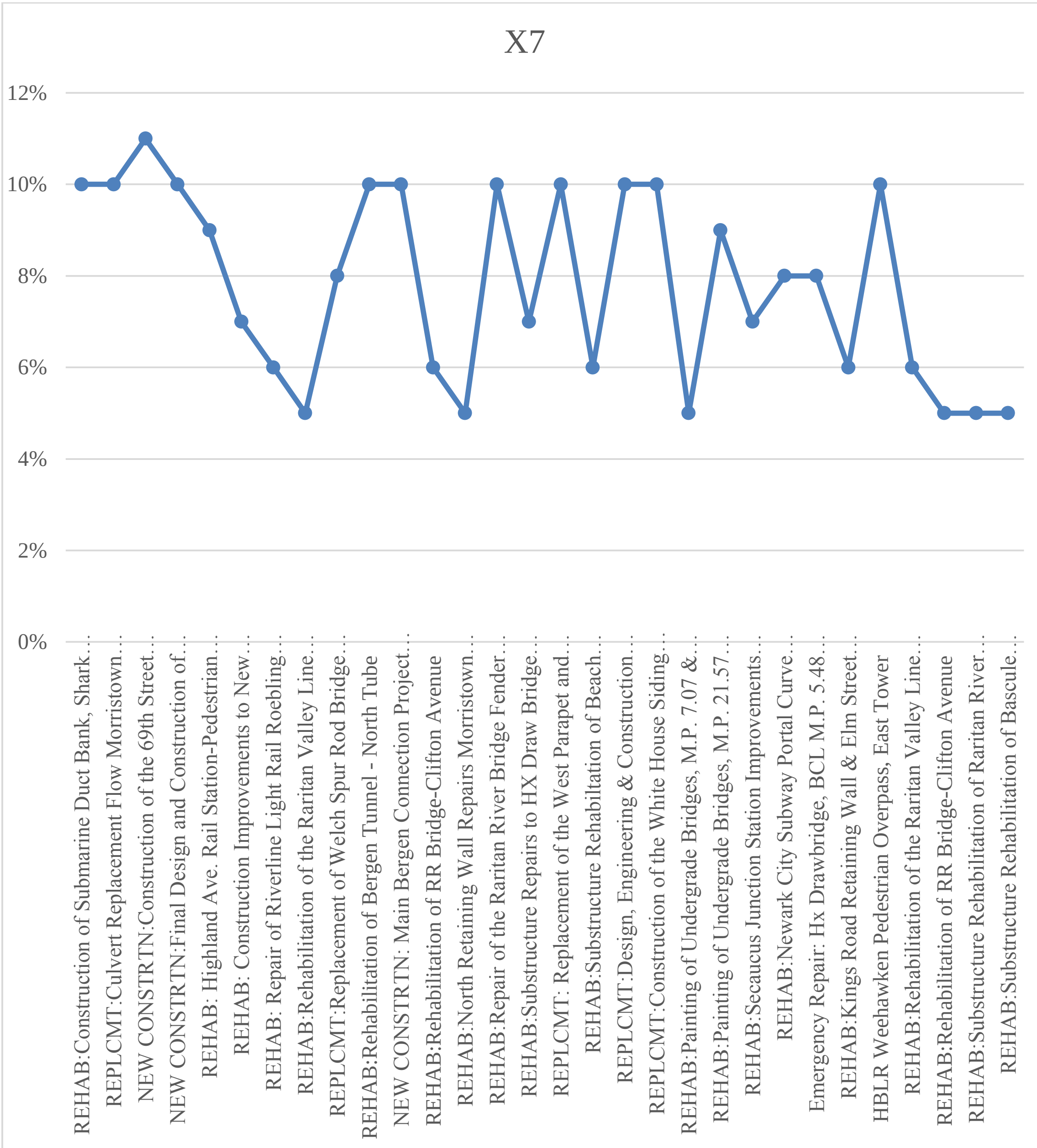

Figure 31: Percentage of "X7" variable contribution to the total cost overrun for each completed contract classified by Construction type.

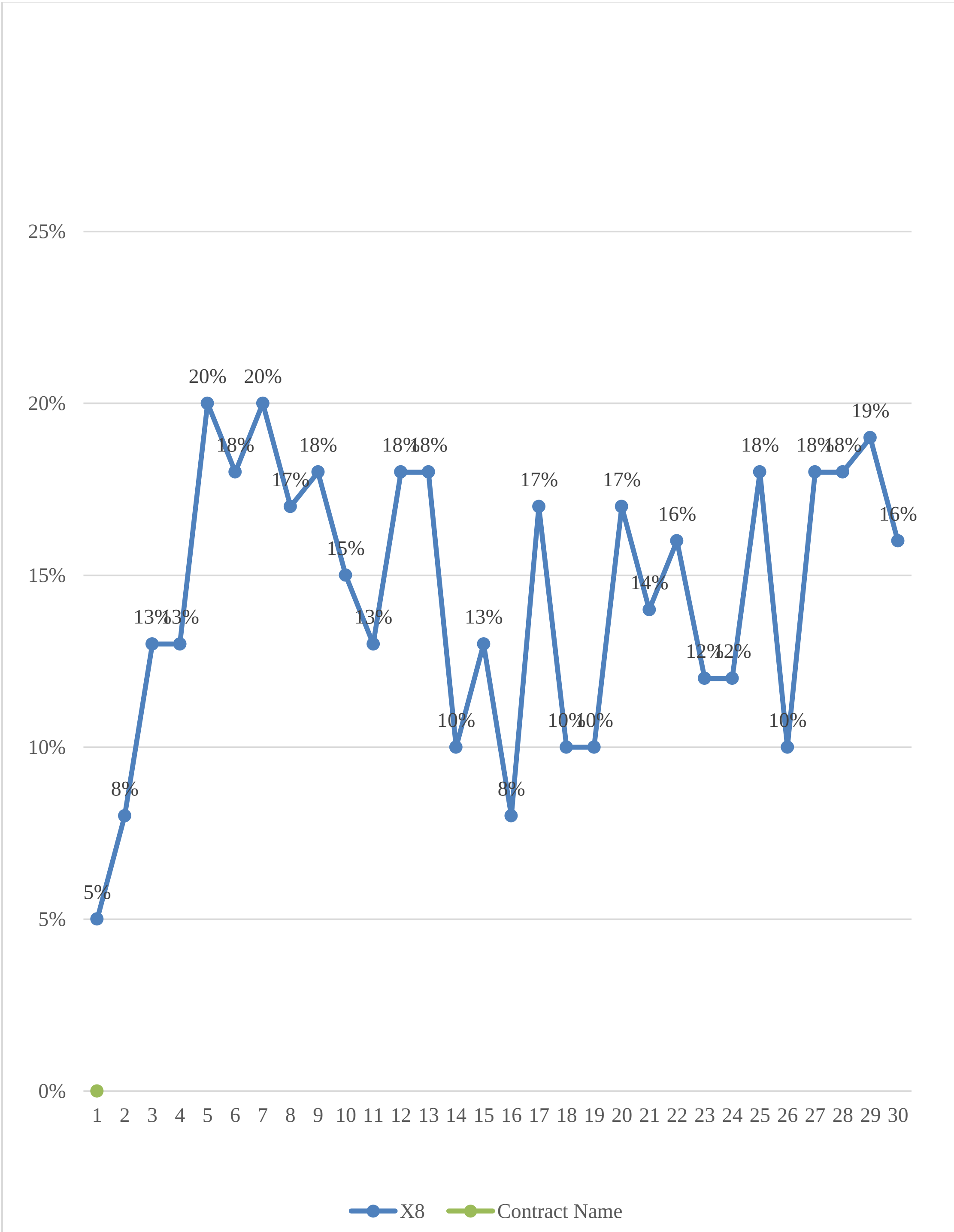

Figure 32: Percentage of "X8" variable contribution to the total cost overrun for each completed contract classified by Construction type.

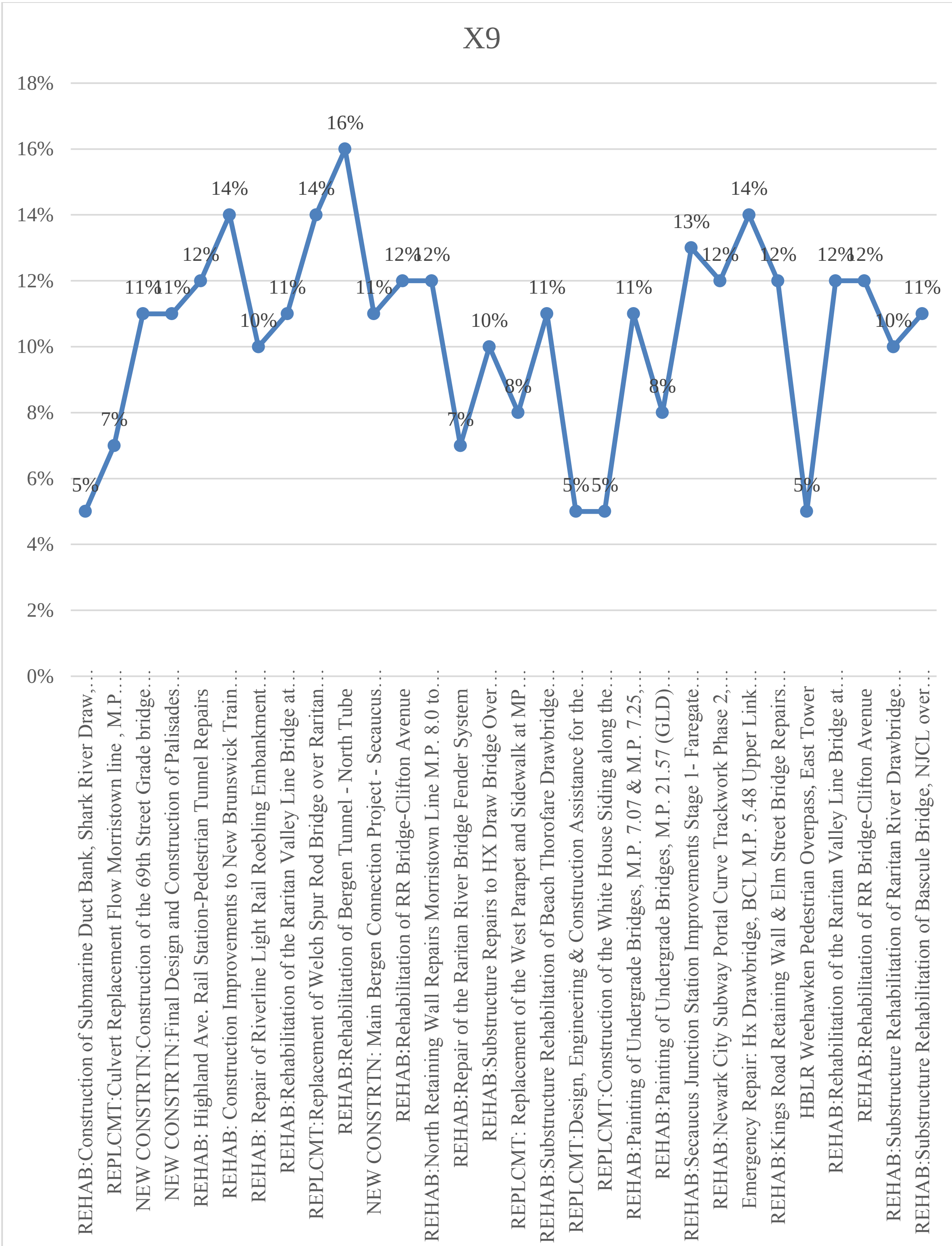

Figure 33: Percentage of "X9" variable contribution to the total cost overrun for each completed contract classified by Construction type.

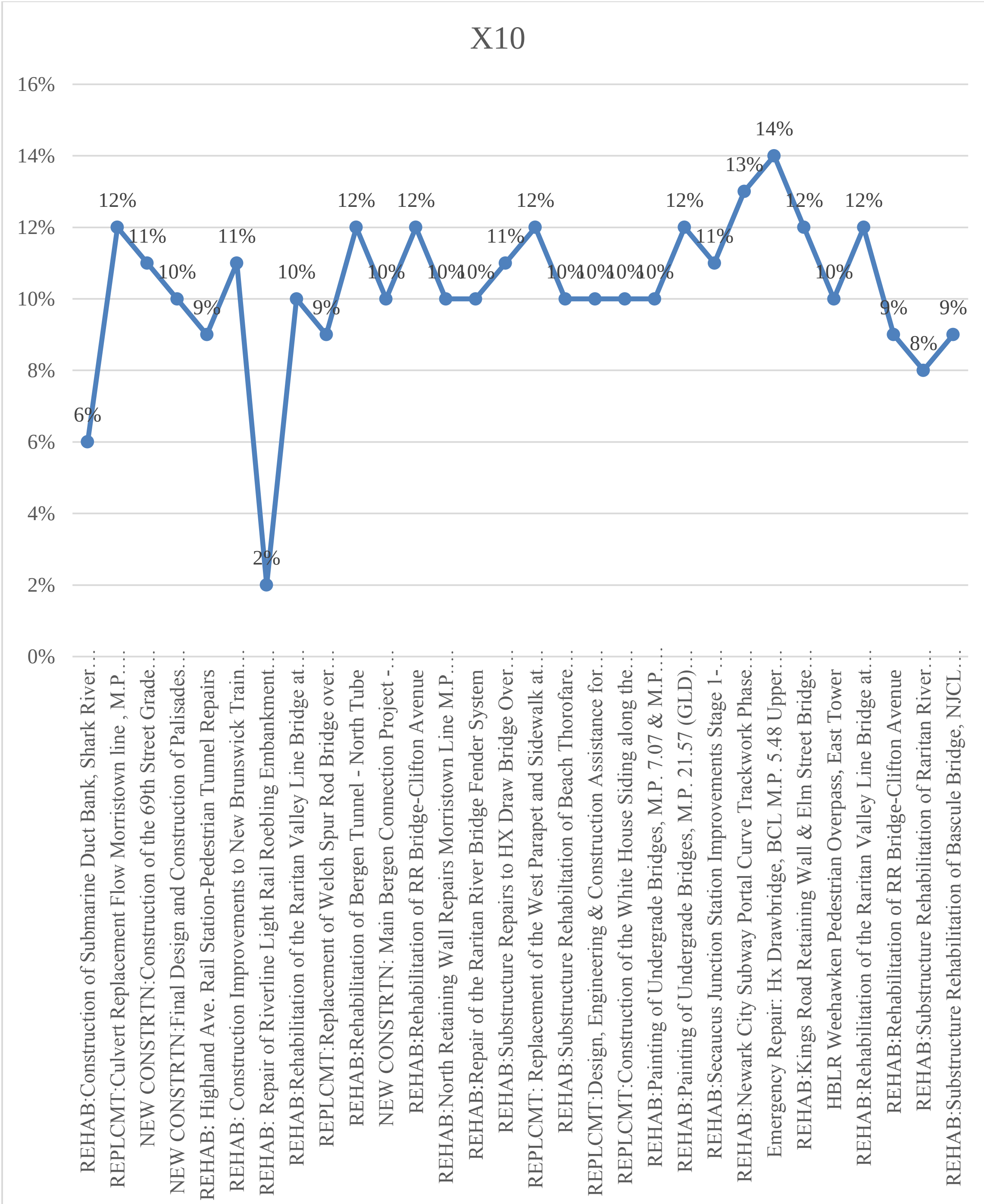

Figure 34: Percentage of "X10" variable contribution to the total cost overrun for each completed contract classified by Construction type.

Predicted overrun by applying the proposed model on the 30 new cases vs. Actual overrun

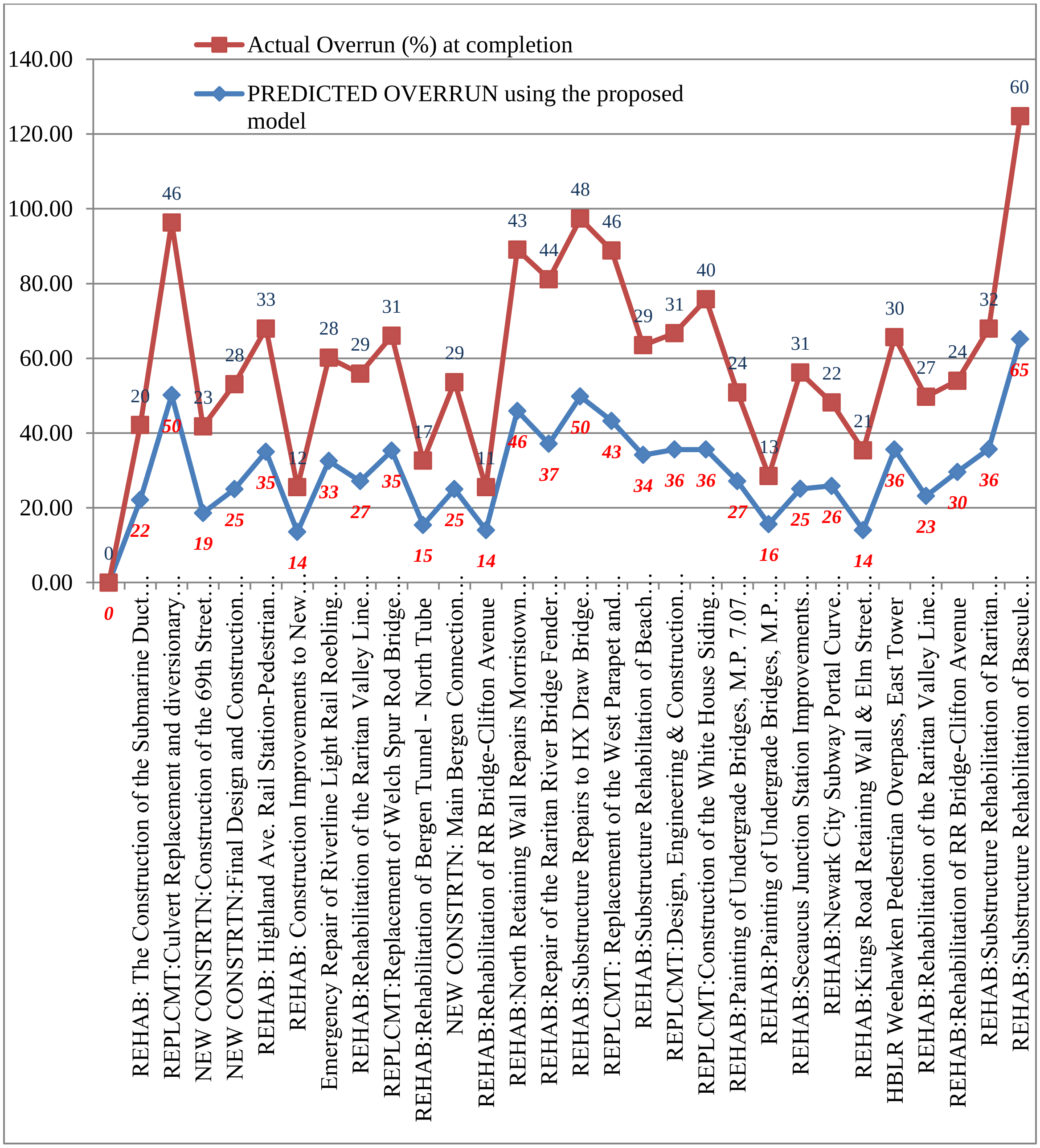

Figure 35: Predicted overrun (%) vs. Actual overrun (%)

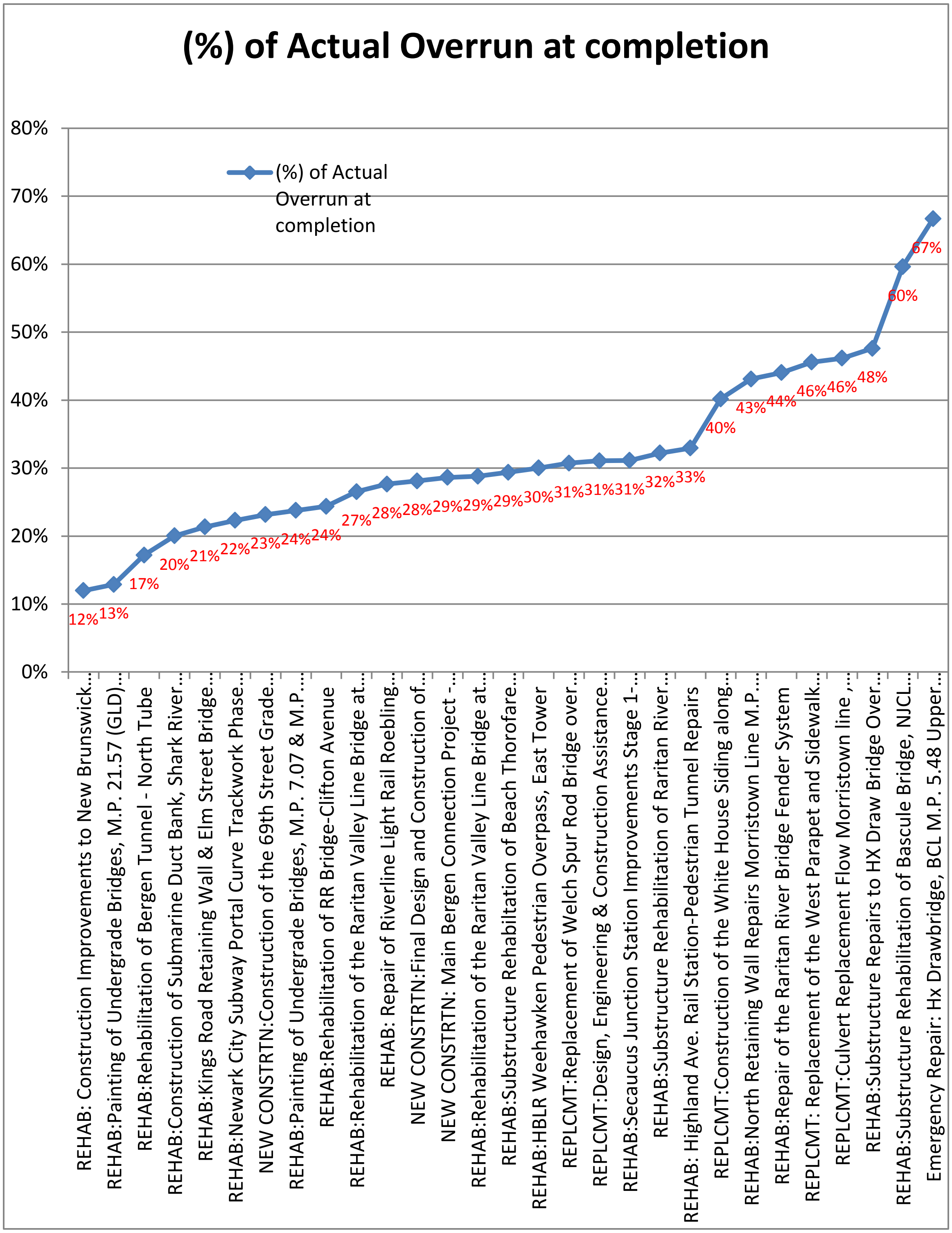

Figure 36: **Ascending percentage of actual cost overrun** for the 30 new construction contracts

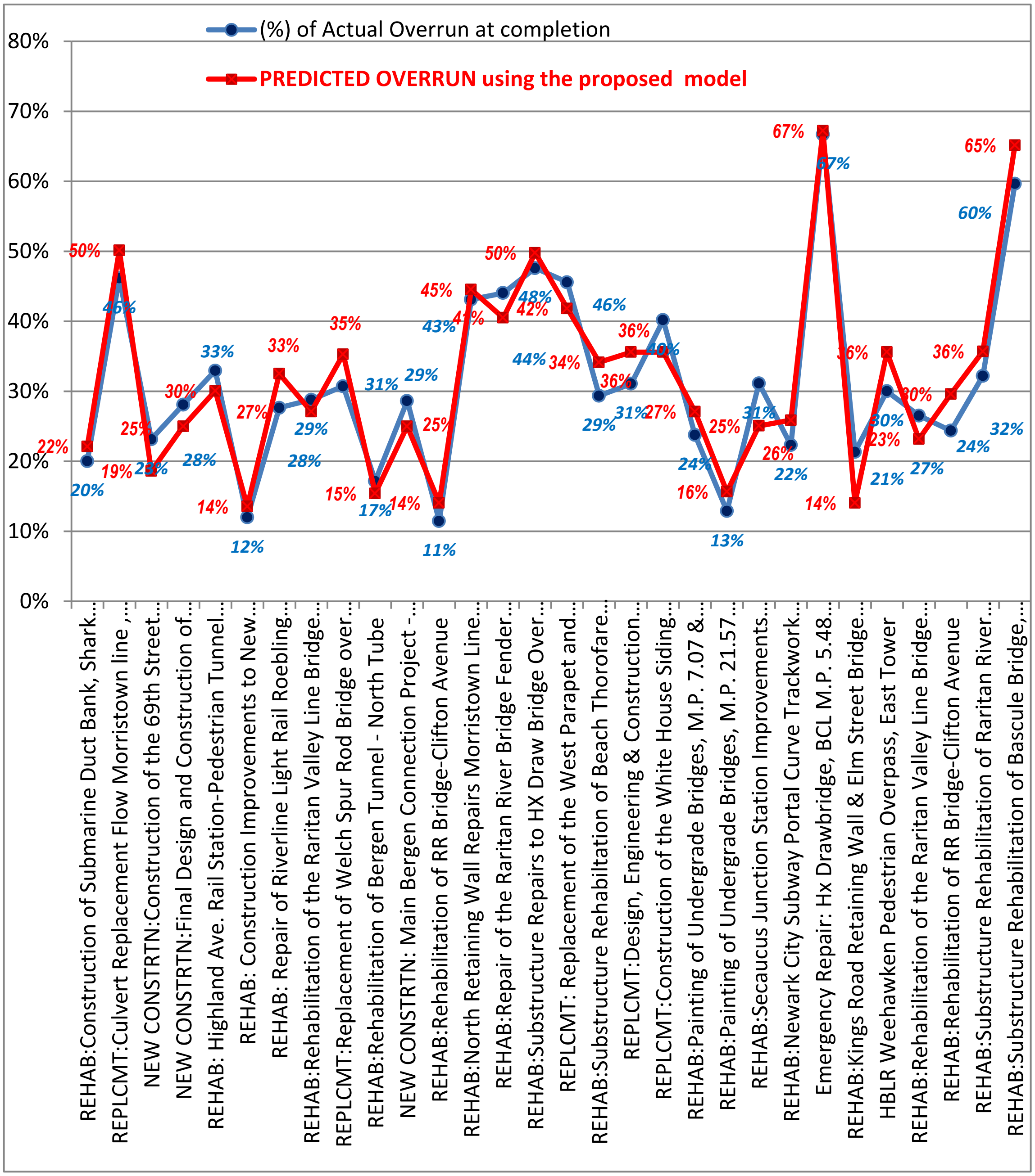

Figure 37: Predicted overrun (%) vs. Actual overrun (%) for the new 30 contracts classified by type of construction

Table 16: Evaluation of the amount of Deviation (%) of Predicted cost overrun from Actual contract Overrun at completion

30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overrun ($)	(%) of Actual Overrun at completion	PREDICTED OVERRUN using the proposed model	% of Deviation of Predicted using the proposed Model Overrun from Actual Overrun
Testing the model case 1	REHAB:Construction of Submarine Duct Bank, Shark River Draw, North JCL M.P. 30.43	7,999,000	$9,600,709	$1,601,709	20%	22%	10%
Testing the model case 2	REPLCMT:Culvert Replacement Flow Morristown line , M.P. 36.87, NJ	902,510	$1,319,196	$416,686	46%	50%	9%
Testing the model case 3	NEW CONSTRTN:Construction of the 69th Street Grade bridge Project	22,027,109	$27,127,707	$5,100,598	23%	19%	-20%
Testing the model case 4	NEW CONSTRTN:Final Design and Construction of Palisades Tunnel	258,786,000	$331,507,813	$72,721,813	28%	25%	-11%
Testing the model case 5	REHAB: Highland Ave. Rail Station-Pedestrian Tunnel Repairs	479,946	$638,061	$158,115	33%	30%	-9%
Testing the model case 6	REHAB: Construction Improvements to New Brunswick Train Station bridge	1,670,470	$1,870,669	$200,199	12%	14%	13%
Testing the model case 7	REHAB: Repair of Riverline Light Rail Roebling Embankment Failure	7,158,758	$9,137,337	$1,978,579	28%	33%	18%
Testing the model case 8	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	3,572,825	$4,601,488	$1,028,663	29%	27%	-6%
Testing the model case 9	REPLCMT:Replacement of Welch Spur Rod Bridge over Raritan Valley Line	5,336,058	6,976,000	$1,639,942	31%	35%	15%
Testing the model case 10	REHAB:Rehabilitation of Bergen Tunnel - North Tube	56,388,044	$66,084,629	$9,696,585	17%	15%	-10%
Testing the model case 11	NEW CONSTRTN: Main Bergen Connection Project - Secaucus Transfer Program	27,659,420	$35,576,980	$7,917,560	29%	25%	-13%
Testing the model case 12	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$871,243	$89,693	11%	14%	22%
Testing the model case 13	REHAB:North Retaining Wall Repairs Morristown Line M.P. 8.0 to M.P. 9.1 Newark, NJ	3,521,341	$5,039,200	$1,517,859	43%	45%	3%
Testing the model case 14	REHAB:Repair of the Raritan River Bridge Fender System	104,106	$149,962	$45,856	44%	41%	-8%
Testing the model case 15	Draw Bridge Over Hackensack River-Secaucus, Hudson County, NJ (U.G. Bridge 5.48	1,841,000	$2,717,442	$876,442	48%	50%	5%

Table 16: Continuing- Evaluation of the amount of Deviation (%) of Predicted cost overrun from Actual contract Overrun at completion

30 New Construction Contracts (that are not used for developing the Model)	Contract Name	Original contract Value	Actual Cost at completion	Cost Overrun ($)	(%) of Actual Overrun at completion	PREDICTED OVERRUN using the proposed model	% of Deviation of Predicted using the proposed Model Overrun from Actual Overrun
Testing the model case 16	REPLCMT: Replacement of the West Parapet and Sidewalk at MP 21.73, Gladstone Branch, New	$427,215.00	$621,978	$194,763	46%	42%	-8%
Testing the model case 17	REHAB:Substructure Rehabiltation of Beach Thorofare Drawbridge on Atlantic City Line M.P. 57.63	$1,469,000.00	$1,900,574	$431,574	29%	34%	16%
Testing the model case 18	REPLCMT:Design, Engineering & Construction Assistance for the Replacement of NJ Transit's	$441,346.00	$578,525	$137,179	31%	36%	15%
Testing the model case 19	REPLCMT:Construction of the White House Siding along the Raritan Valley Line Readington	$1,535,270.00	$2,152,035	$616,765	40%	36%	-11%
Testing the model case 20	REHAB:Painting of Undergrade Bridges, M.P. 7.07 & M.P. 7.25, Morristown Line, Harrison, Hudson	$627,500.00	$776,627	$149,127	24%	27%	14%
Testing the model case 21	REHAB:Painting of Undergrade Bridges, M.P. 21.57 (GLD) Chatham & M.P. 22.74 (M&F) Summit, Morris	$435,000.00	$491,038	$56,038	13%	16%	21%
Testing the model case 22	REHAB:Secaucus Junction Station Improvements Stage 1- Faregate Relocation Project Stage 2 -Crew	$329,373.00	$431,922	$102,549	31%	25%	-20%
Testing the model case 23	REHAB:Newark City Subway Portal Curve Trackwork Phase 2, Located in Newark, NJ	$674,700.00	$825,255	$150,555	22%	26%	16%
Testing the model case 24	Emergency Repair: Hx Drawbridge, BCL M.P. 5.48 Upper Link Assembly-Emergency Enigneering Services	$80,310.00	$133,853	$53,543	67%	67%	1%
Testing the model case 25	REHAB:Kings Road Retaining Wall & Elm Street Bridge Repairs M.P. 25.61 to 25.80 and 26.17 Morristown Line,	$1,368,000.00	$1,660,003	$292,003	21%	14%	-34%
Testing the model case 26	HBLR Weehawken Pedestrian Overpass, East Tower	$893,230.00	$1,161,341	$268,111	30%	36%	19%
Testing the model case 27	REHAB:Rehabilitation of the Raritan Valley Line Bridge at Richmond Street	$3,572,825.00	$4,520,854	$948,029	27%	23%	-13%
Testing the model case 28	REHAB:Rehabilitation of RR Bridge-Clifton Avenue	781,550	$972,062	$190,512	24%	30%	22%
Testing the model case 29	REHAB:Substructure Rehabilitation of Raritan River Drawbridge NJCL 0.39	1,569,000	$2,074,424	$505,424	32%	36%	11%
Testing the model case 30	of Bascule Bridge, NJCL over Manasquan River MP 36.09 (Brielle, Monmouth County, NJ)	2,676,315	$4,272,426	$1,596,111	60%	65%	9%

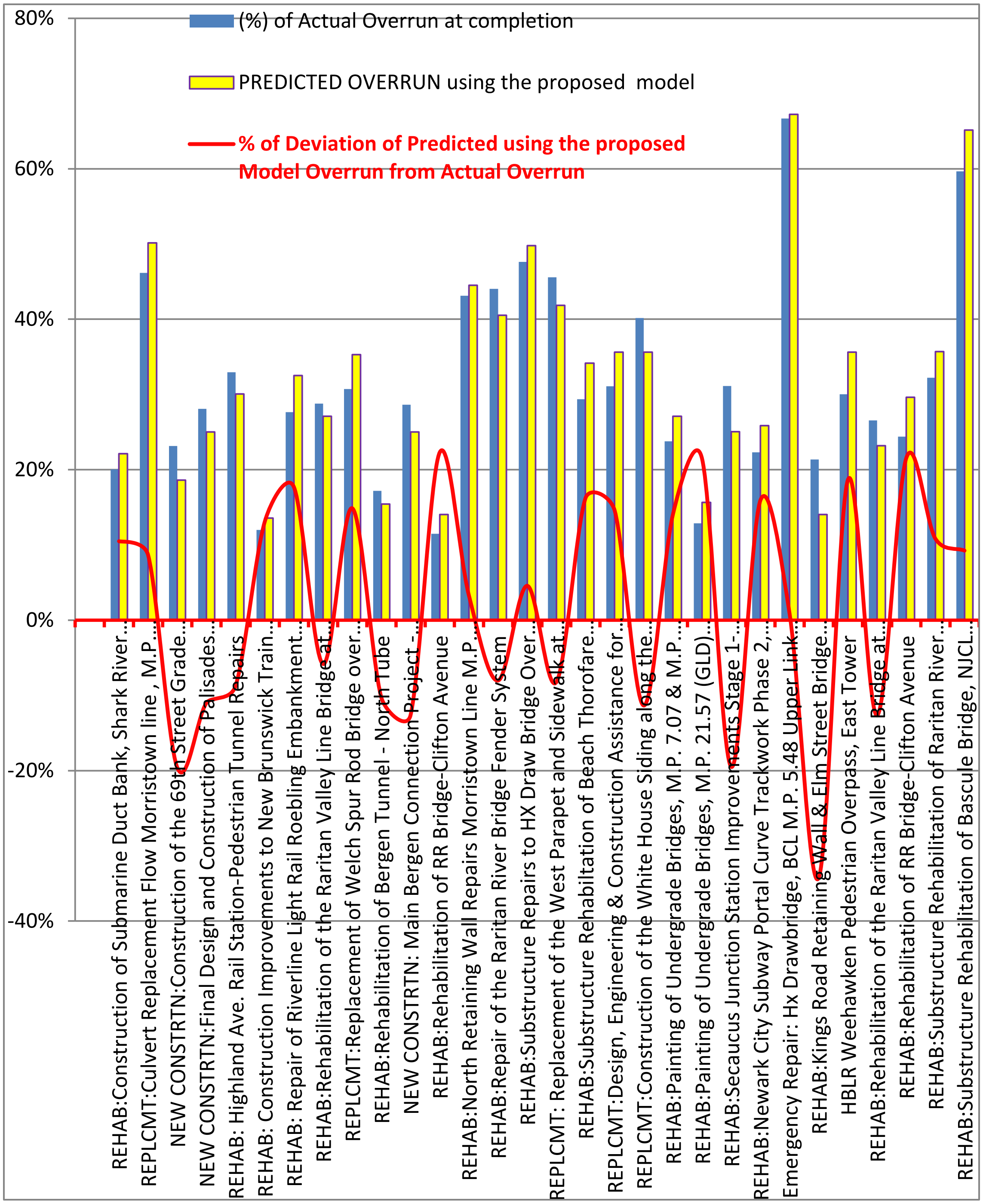

Figure 38: Predicted overrun (%) vs. Actual overrun (%) overlaid by the percentage of deviation of the predicted overrun from the actual overrun at completion for the new 30 contracts classified by type of construction

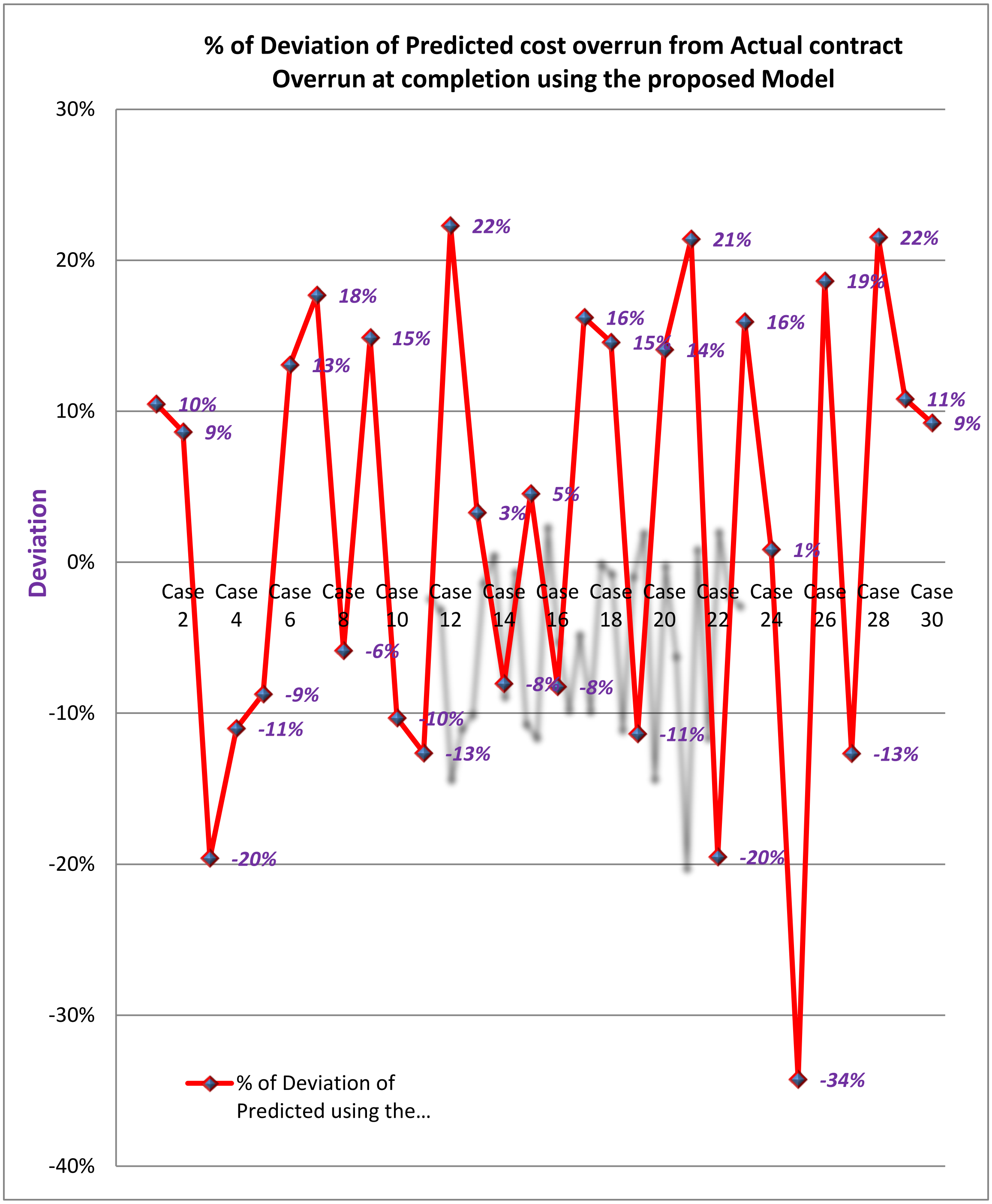

Figure 39: Percentage of Deviation of Predicted cost overrun from Actual contract Overrun at completion

CHAPTER 6: CONCLUSION

This research analysis has produced important findings concerning the major causes behind the significant cost overrun in railroad bridge construction specifically and has provided solid evidences of the most important risks on which railroad bridge agencies need to focus their efforts. Of particular concern are changes in project designs and scope changes during project development. The research process used the extensive in-depth experience in railroad bridge construction and the professional judgment of the researcher to determine the listings of major common risk factors causing cost overrun.

The final stage of the research process involved the investigation into statistical models that can explain the correlation between the cause, effect and other relationships relating to cost overrun in railroad bridge construction projects.

Regression analysis is conducted on only 15 cases study that experienced cost overrun out of 25 Railroad bridge construction projects that have experienced cost overrun and underrun. A proposed model is developed and tested on 30 new cases, which were not part of the cases used in the regression analysis, where the first 3 cases initially tested for the model's level of efficiency followed by the remaining 27 new cases for confirming the model's efficiency and accuracy level in predicting the cost overrun or underrun.

The regression analysis demonstrated a correlation between various specific railroad operation construction constraints of railroad bridge projects, as measured in indexed programmed cost and the size of cost overruns. The correlation evolved after data transformation was carried out to improve the model. It can also be concluded from the research that the arbitrary application of a base contingency percentage figure, to accommodate project risk can lead to those projects reporting substantial budget overrun. Perhaps, cost overruns are primarily due to uncertainty (uncontrollable) than risk (controllable), and therefore, are more difficult to manage.

After successfully testing the developed model, regression analysis proved to be an effective method to adequately predict the cost overrun or underrun in railroad bridge construction.

This study resulted in a multiple linear regression model that outperforms existing contingency funding practices using information available prior to contract award. The proposed model percentage of deviation of predicting the cost overrun is within 1% for 7% from the actual overrun for the first tested 3 projects as shown in Fig 10 and Table 11 before applying it on the 30 new cases that are not used for developing the proposed model as shown in Fig 39.

After testing the proposed model on the 30 new completed construction contracts, the proposed model shows an average percentage of deviations of predicting cost overrun from the actual overrun to be within plus or minus 15% as shown in Table 16 and Figure 35 through Figure 39.

The average difference between predicted and actual cost overruns was only +7% on the 1st case, 1% on the 2nd case and 4% on the 3rd case as described above, Figures 9 and 10. After applying the proposed model to the new 30 completed construction contract which were not used in the original development of the proposed model, the average percentage of the difference between the predicted cost overrun and the actual cost overrun at the project completion is shown to be within the 15% range as per Table 26 and Table 27.

This implies that the current developed model is adequately predicted the cost overrun which will support the allocation of the contingency funds.

The application of this model is a major step in the direction of an adequate budgeting for contingency requirements. While individual project predictions may contain errors, the overall impact of applying the model is a significant achievement in the net effect of under-budgeting for all projects under current practices. Rather than assigning an arbitrary percentage, this model enables the tailoring of contingency funding to correspond with project-specific risks in particular in the railroad bridge industry. Combining the model with appropriate policy and guidance changes would greatly enhance the ability of the transit authority project manager to effectively budget his bridge project, and to support the contractor to prepare an adequate bid estimate which will result significantly in minimizing the project financial risks and rail operation delays associated with change orders and tremendous costly construction claims which will unnecessarily harm the contractors and the owner financially, the rail operations in general and consequently will significantly disturb millions of daily rail commuters.

CHAPTER 7: RECOMMENDATION FOR FUTURE RESEARCH

1. Although this developed model is a major accomplishment towards avoiding cost overrun or extremely minimizing it for the railroad bridge construction, which will significantly benefit the railroad bridge construction industry worldwide, including owners, contractors, consultants and consequently the rail commuters as it will avoid interruption of the rail operation when the bridge construction is not completed as planned, I recommend that the next stage of this research achievement is to expand the cost overrun studies in in railroad bridges construction based on type/configuration of bridges, such as bascule bridges, swing bridges, fixed span bridges, undergrade draw/lift bridges.
2. I also recommend expanding this research on railroad bridges based type of construction material of the bridges, such as reinforced concrete bridges, structural steel, timber brides, precast/prestressed concrete bridges.
3. Expanding this research further to predict schedule contingency which should be an integrated cost-and schedule contingency.
4. Integrating this model with simulation modeling and advanced predicting software's such as SPSS program and others is highly recommended.

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