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An Analysis of Cost Overruns and Time Delays of INDOT Projects

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16. Abstract

A commonality among state Departments of Transportation is the inability to complete projects on time and within budget. This project assessed the extent of the problem of cost overruns, time delays, and change orders associated with Indiana Department of Transportation (INDOT) construction projects, identified the reasons for such problems, and finally developed a set of recommendations aimed at their future reduction. For comparison purposes, data from other states were collected and studied using a questionnaire instrument. The analysis of the cost overrun, time delay and change order data was done using an array of statistical methods. The literature review and agency survey showed that time delays, cost overruns and change orders are generally due to factors such as design, unexpected site conditions, increases in project scope, weather conditions, and other project changes. The results of the agency survey showed that with regard to the problem of cost overruns, INDOT has an average rank compared to other states. Between 1996 and 2001, the overall rate for cost overrun amounts for INDOT projects was determined as 4.5%, and it was found that 55% of all INDOT contracts experienced cost overruns. It was determined that the average cost overrun amount and rate, as well as the contributory cost overrun factors differ by project type. The average cost overrun rates were as follows: bridge projects -- 8.1%, road construction -- 5.6%, road resurfacing -- 2.6%, traffic projects -- 5.6%, maintenance projects -- 7.5%. With regard to time delays, it was found that 12% of all INDOT contracts experience time delays, and the average delay per contract was 115 days. With regard to change orders, the study found that the dominant category of reasons for change orders is "errors and omissions", a finding which is suggestive of possible shortcomings in current design practices The statistical analyses in the present study showed that the major factors of cost overruns, time delays, and change orders in Indiana are contract bid amount, difference between the winning bid and second bid, difference between the winning bid and the engineer's estimate, project type and location by district. Besides helping to identify or confirm influential factors of cost overruns, time delay and change orders, the developed regression models may be used to estimate the extent of future cost overruns, time delay and change orders of any future project given its project characteristics and any available contract details. Such models can therefore be useful in long-term budgeting and needs assessment studies. Finally, the present study made recommendations for improving the management of projects and the administration of contracts in order to reduce cost overruns, time delays and change orders.

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CHAPTER 1: INTRODUCTION

1.1 Background and Problem Statement

A commonality among state departments of transportation is the inability to complete transportation projects on time and within budget. This is a chronic problem for the Indiana Department of Transportation (INDOT). Time delay, cost overruns and change orders are generally due to factors such as design errors, unexpected site conditions, increases in project scope, weather conditions, and other project changes. A *cost overrun* may be generally expressed as a percent difference between the final cost of the project and the contract award amount. When this value is negative, it is called a *cost underrun*. A *time delay* is simply the difference between a project's original contract period at the time of bidding and its overall actual contract period at the end of construction. In 2001, INDOT incurred approximately $17,028,000 in cost overruns, representing approximately 9% of the total amount for all contracts in 2001. Time delays may or may not resulting liquidated damages. Contractors are liable for liquidated damages to the agency when their contracts incur time delays for which they are responsible. In this regard, a total of approximately $59,000 was incurred by INDOT's contractors in 2001 for liquidated damages, which represent part of the consequences of construction delays. It does not reflect unrealized benefits due to construction delays.

1.2 Objectives of the Present Study

The aim of the present study was to investigate the increasing frequency of cost overruns and time delays on INDOT projects, and to provide recommendations for addressing the situation. In the course of such investigations, it is expected that the following specific objectives will be addressed:

- Identification of the distribution and trends of the cost overruns and time delays of INDOT contracts. (For instance, what kinds of contracts are more susceptible to cost overruns or time delays? In which year? Do cost overruns depend on project size?)
- Investigation of the reasons and the responsibilities for cost overruns and time delays by collecting, reviewing, processing and analyzing change order and contract information data.
- Comparison of the extent and causes of the cost overrun and time delay problem of INDOT projects with those of other highway agencies.

- Statistical analyses for identifying the factors that significantly influence cost overruns and time delays.
- Development of a set of recommendations to help INDOT manage the problem of cost overruns, time delays, and change orders.

1.3 Scope of the Study

The scope of the study included the following.

Project Type: Major INDOT contract types that were considered for the study are as follows:

- Road and bridge construction and rehabilitation projects.
- Maintenance projects, with road maintenance and resurfacing contracts.
- Traffic and traffic maintenance contracts.

Analysis Period: A contract was selected for the present study if its last day of work fell between January 1, 1996 and December 31, 2001.

Geographical Extent: The study considered all contracted projects from the six highway administration districts in Indiana.

Geo-climatic Region: In utilizing data for facilities located in the six highway districts, the study implicitly considered the climatic variations across the entire state. Detailed weather data, such as daily precipitation, snowfall, temperature, and ground snow thickness, were available on a county basis.

1.4 Overview of Study Approach

The overall approach of the study followed the steps shown in Figure 1.1. After establishing the objectives, the study carries out a literature review and agency survey, and follows a study framework that includes data collection and analysis. The data analysis is carried out using an array of statistical methods that include descriptive statistics, correlation analysis, analysis of variance, pair-wise tests, and statistical modeling. The study concludes with a set of recommendations for reducing the problem of cost overruns, time delay and change orders associated with INDOT construction projects.

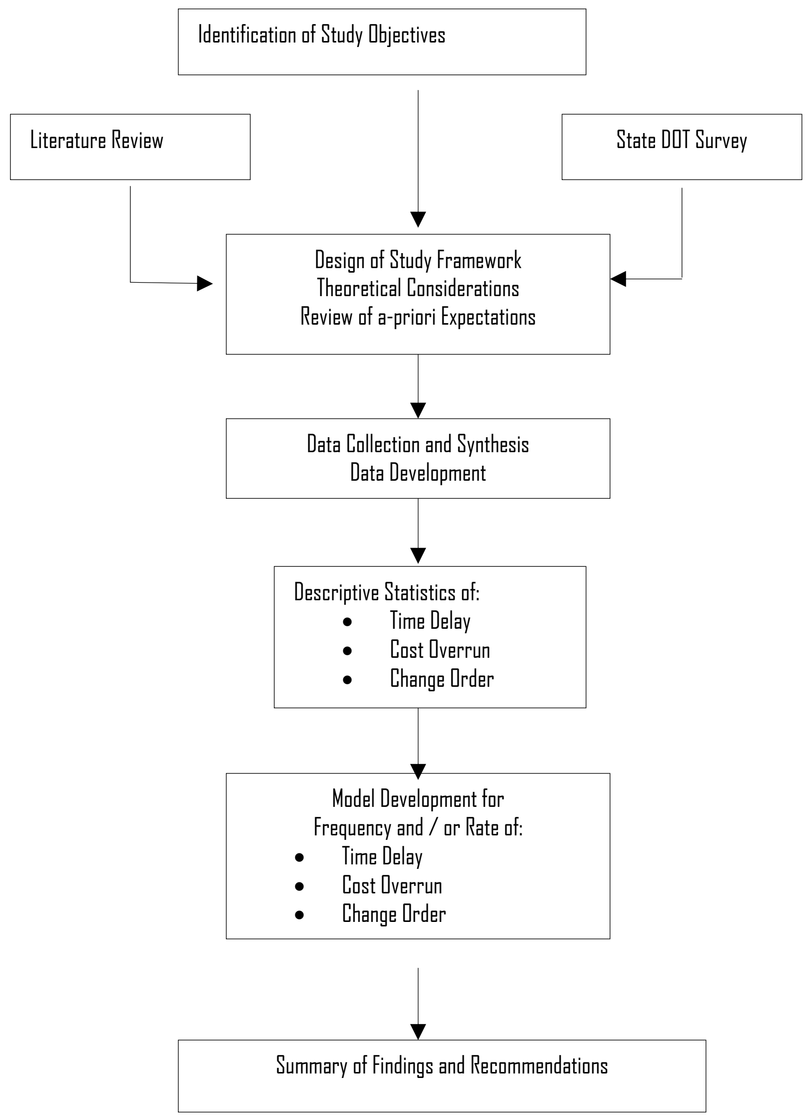

Figure 1.1: Overall Study Approach

1.5 Organization of this Report

Chapter 1 of this report provides a general overview of the situation in Indiana concerning cost overruns and time delays for INDOT projects. This section also highlights the objectives and scope of the present study and provides a brief overview of the approach used in realizing the study objectives. The literature review in Chapter 2 presents and discusses past findings and experience of previous researchers in the areas related to the present study, such as change orders and root causes for time delays. Chapter 3, which complements Chapter 2, presents and discusses the results of a survey of state DOTs and provides a review of their contract management performances in terms of management of cost overruns and time delays. Chapter 4 presents a framework for the analyses, discusses the various methodologies used, and provides a theoretical basis to concepts used in the analysis for the present study. In Chapter 5, the details of data collection are briefly described, as well as how the raw data was processed and organized into a dataset using a format appropriate for the present (and possible future) analysis of cost overruns and time delays in Indiana. Chapter 6 gives a preliminary overview of the extent of the cost overruns and time delays problem in Indiana, using descriptive statistics. Chapter 7 provides a preliminary statistical analysis of the dataset with, for example, the analysis of variance and other statistical tools that enable an investigation of the trends that will appear in the models. Chapter 8 presents the final results of the modeling process for cost overruns, time delays, and change order prediction. Chapter 9 concludes the study with a summary of the findings. This chapter also discusses the challenges faced during the study, implementation issues, and areas for future investigation. In Chapter 10, recommendations are made for the reduction in the number of cost overruns and time delays and to improve efficiency of project management and contract administration. Implementation issues are discussed in Chapter 11.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter identifies previous literature on the subject of cost overruns and time delays, and provides a brief discussion of past findings. Also, the chapter reviews "standard taxonomy" that has been used in this area. The reasons for cost overruns, time delays, and change orders as found in previous studies are discussed, and examples of audit reports that analyze the problem of cost overruns in past studies are provided.

2.2 Standard Taxonomy

Delay occurs when the progress of a contract falls behind its scheduled program. It may be caused by any party to the contract and may be a direct result of one or more circumstances. A contract delay has adverse effects on both the owner and contractor (either in the form of lost revenues or extra expenses), often raises the contentious issue of delay responsibility, and may result in conflicts that frequently reach the courts.

With regard to remedial measures, there are three types of delay (Rowland, 1981):

Excusable delay: the contractor is given a time extension but no additional money.

Concurrent delay: neither party recovers any damages.

Compensable delay: the contractor recovers monetary damages.

Majid and McCaffer [1998] provided similar categories of delay, on the basis of identified responsible parties:

Compensable delays: responsibility borne by the client.

Non-excusable delays: responsibility borne by the contractor.

Excusable party delays: acts of God or a third party.

Cost overruns in construction contracts involve change orders and claims. Defining a "claim" as the proposed changes to the contract that are being negotiated or litigated, Jahren and Ashe [1990] identified two kinds of rates:

- The *cost overrun rate*, which is the percent difference in cost, (positive or negative) between the final contract cost and the contract award amount,

- The *change order rate*, which is the ratio between the dollar amount of change orders and the award amount.

The “final amount” was defined as the cost of the contract including change orders, and outstanding claims and the dollar award amount is the dollar value at which the contract was awarded.

Change orders are “an indication that something on a construction project has not gone as planned” (Rowland, 1981), and are associated with contract alterations such as additions, deletions, or modifications to the contract. The consequences of change orders are additional cost, additional time or both. Contract change orders can be requested by the owner, the contractor or third parties such as local governments (O’Brien, 1998). Change orders are described as “unilateral” when signed only by the contractor, owner or the party authorized by the changes clause in the conditions of the contract. Change orders are referred to as “bilateral” when it is a mutual agreement or supplemental agreement. The price of a change order can be expressed as a lump sum, a unit price, or the cost plus a fee, which needs to be documented, estimated in terms of price and delay, and approved by both parties. A change order is just as legally binding as the original construction contract. Few construction projects are built without changes being made by the owner or by being necessary due to some unforeseen circumstance (Rowland, 1981). Therefore, it may not be possible for any transportation agency to completely eliminate change orders. Rather, efforts should be made to reduce their occurrence. According to contract law, parties to a contract may modify the contract at any time by mutual agreement. The owner’s right to order changes is offset by the contractor’s right to an equitable adjustment in the contract price and time, to cover the cost of the work as changed. A change order can imply extra or additional work, which are essentially two different concepts: extra work may not be necessary for project completion and can be independent of the contract. Additional work may be necessary because of errors or a change of plans and specifications.

Generally, the primary reasons for actual costs varying from a contractor’s original bid price are changes in the scope of the work to be done and incorrect estimates of the work quantities included in the original bid specifications. Contractor errors include unnecessary work, work that is not according to design plans, and work or materials that do not meet contract specifications. On the other hand, contracting agency errors include planning and design deficiencies such as revisions in the scope of the work, added work, and revisions in quantities in the project design. Unforeseen circumstances include site conditions that differ from those described in the contract documents.

2.3 Causes of Time Delays

Non-excusable delays are generally the responsibility of the contractor, and the agency may be entitled to claim damages. In studying non-excusable delays, Majid and McCaffer [1998] discussed methods to document the factors of non-excusable delays using a fishbone diagram and ranking methodology, the steps for which are explained below. The fish bone diagram, shown in Figure 1, enables the identification of contract problems at a micro level and consequently helps to search for the root causes. Majid and McCaffer defined 12 main causes:

1. Materials-related delays
2. Labor-related delays
3. Equipment-related delays
4. Financial delays
5. Improper planning
6. Lack of control
7. Subcontractor delays
8. Poor coordination
9. Inadequate supervision
10. Improper construction methods
11. Technical personnel shortages
12. Poor communication

Materials-related delays include late delivery, damage, or poor quality of materials. Labor-related delays can be due to low motivation, poor communication or absenteeism. Equipment-related delays can be due to poor equipment planning. Improper planning can be due to a lack of experience. Financial-related delays concern financial planning or delayed payment to suppliers. Lack of control, poor coordination, technical personnel shortage and poor communication are representative of poor management of personnel and the whole agency. Improper construction method is related to items such as a wrong method statement. Subcontractor-related delays include not only items that are the fault of the subcontractor but also of the agency’s employees because of absenteeism or slow mobilization. The problem of inadequate supervision concerns managers who, for instance, have too many responsibilities or few management skills. Each main cause of non-excusable delays comprises several contributing factors. Some factors, such as poor monitoring and control, poor planning, and lack of experience, are common to more than one main cause. A total of 25 factors were identified by Majid and McCaffer [1998] as shown in Table 2.1.

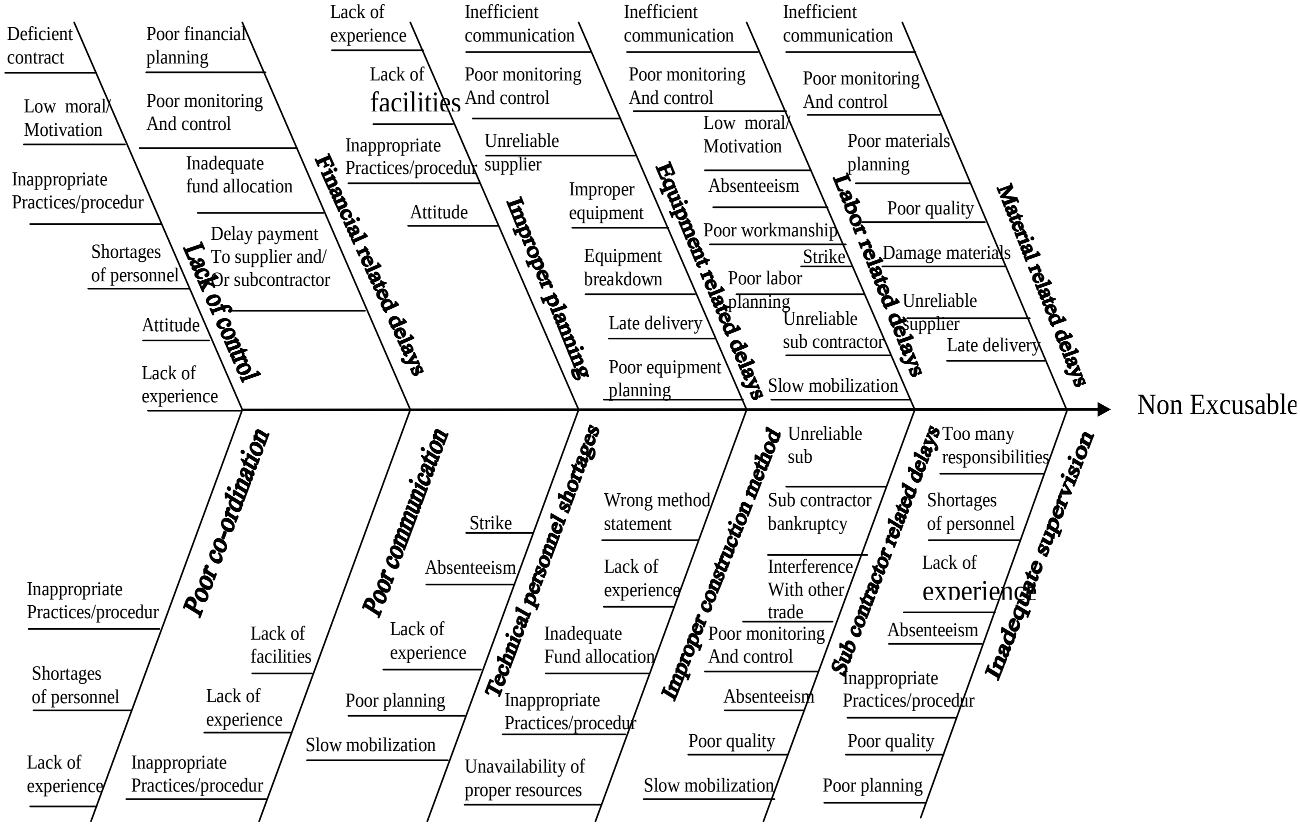

Figure 2.1: Contributory Factors of Non-Excusable Delay [Majid and McCaffer, 1998]

To assign rankings to the 25 factors, Majid and McCaffer utilized findings from eight studies related to construction delays. This involved 900 construction contracting organizations from both developed and developing countries between 1964 and 1995. The study results included the information showed in Table 2.1 which provides the main reasons for non excusable delays sorted by frequency. Table 2.1 shows that “late delivery or slow mobilization” is the main factor that leads to contractors’ poor performance as it was ranked first in the eight studies. Majid and McCaffer recommended that construction managers adopt a systematic approach to identify the factors contributing to non-excusable delays in order to increase awareness of the perennially persistent factors and take the necessary proactive measures.

Table 2.1: Ranking of Contributory Factors of Non-Excusable Delay

Factor	Aggregate Rating Based on Previous Studies	Final Ranking
Late delivery or slow mobilization	8	1
Damaged materials	22	2
Poor planning	27	3
Equipment breakdown	31	4
Improper equipment	34	5
Unreliable supplier/subcontractor	34	5
Inadequate fund allocation	35	7
Poor quality	36	8
Absenteeism	44	9
Lack of facilities	44	9
Inappropriate practices/procedures	46	11
Lack of experience	47	12
Attitude	47	12
Poor monitoring and control	48	14
Strike	48	14
Shortages of personnel	53	16
Delay payment to supplier/subcontractor	53	16
Inefficient communication	57	18
Wrong method statement	59	19
Unavailability of proper resources	59	19
Deficient contract	61	21
Interference with other trades	62	22
Too many responsibilities	63	23
Subcontractor bankruptcy	64	24
Low morale/motivation	66	25

Source: Majid and McCaffer [1998]

Ellis and Thomas [2002] conducted a study to investigate the root causes of delays in highway construction. In their study, both excusable and non-excusable delays are considered. It was found that 31% to 55% of all highway projects experience an average time delay of 44% in excess of their original contract periods. It was observed that time delays occur more frequently for contracts in urban areas. The focus of that study was to identify the root causes of delays (not only for the apparent causes). A root cause is distinguished from an apparent cause by determining if the cause violated a fundamental principle and if the cause is known or developed in sufficient detail to allow corrective action to be taken (Ellis and Thomas, 2002). For example, an apparent cause may be plan errors; however, an in-depth investigation may ultimately determine that the root cause was a violation of the "time-cost" principle leading to easily recognizable mistakes. Generally, apparent causes are relatively many while root causes are relatively few in number. According to the authors, the main root causes of delays include business practices, procedures, utilities, unforeseen site conditions, contractor and State Highway Agencies management of scheduling and planning, maintenance of traffic work zones, and design errors and omissions. Table 2 summarizes the root causes identified by the Ellis and Thomas study [2002].

2.4 Factors Affecting Cost-Overruns

As defined in Section 2.2, the concepts of cost overrun rate and change order rate were used by Jahren and Ashe [1990] to analyze the problem of cost overruns. They considered that both cost overrun and change order rates are influenced by the same kinds of factors as listed below:

- project size
- difference between the selected bid and the government estimate
- type of construction
- level of competition

It was found that other non-quantifiable factors, such as the quality of the contract document, the nature of interpersonal relations on the project and the policies of the contractor, could have a significant impact on cost overruns. Jahren and Ashe's study [1990] also found that a cost overrun rate of 1-11% was more likely to occur on larger projects than smaller ones. The mode for the cost overrun rate for projects over $1,000,000 is approximately 2% rather than near 0%, which is typical for most categories, and the median cost overrun rate increases as the project size increases. A possible explanation for these results is that projects become more complex as they become larger so more cost overruns occur. However, on large projects, managers may make special efforts to keep cost overrun rates from becoming excessively large. Furthermore, Jahren and Ashe [1990] found that contracts with award amounts less than the government estimate were more likely to have cost overrun rates above 5% and that the risk of high cost overrun rates is greater when the amount is less than the government estimate. Finally, the study recommended that data for computation of the percent difference between award amounts and government estimates should be included in construction contract databases since it appears to influence the cost overrun rate. The design of the dataset of the present study was guided by such findings, but other directions were also followed in order to discover new factors that could influence cost overruns and change orders.

Table 2.2: Root Causes of Highway Construction Delays

Major Category	Root Causes
Business Practices	Business as usual
	Most projects are treated alike
	For political and funding reasons, projects often need to be awarded based on an accelerated schedule
	Various team members have different objectives
	Budgets restrict the expenditure of project fund across functional boundaries
Procedures	There lacks team accountability for timely project completion: the decision maker weigh cost benefits more heavily than time benefits; and SHA personnel and consultants called to the project to solve technical problems sometimes do not have an adequate appreciation for the need for a timely decision
	Construction expertise is not incorporated into the design: A shortage of experienced personnel exist within the design industry; and because of time pressure, designers often leave problems to be solved during construction
Utilities	Utilities are unidentified or incorrectly located: Many smaller utilities have no as-built drawings; often, the as-built drawings are incorrect; as-built location information may not include vertical location; utility location information provided on drawings is not clear particularly for complex intersections; and the standard of practice for designers with regard to communicating utility information on drawings is not clearly defined
	Slow response by utilities to improve their processes: smaller utilities are restrained by funding limitations
	Delays in the relocation of utilities: utilities companies may not see SHA work as a priority; and SHA right of way agreements with utilities may not provide adequate terms and conditions to obtain timely response from the utilities
Differing or Unforeseen Site Conditions	The information provided is inaccurate: conditions are known but not incorporated into the design because of funding or time pressure issues; and the view point that site investigation is done for design rather than for construction
	Conditions change after the design is complete: project pre-bid visits not done or ineffective; conditions are unknown and SHA response time is slow; and pressure to get the project bid
	Conditions are unknown but are easily discoverable: constructability reviews are ineffective; and site investigation data is used for design purposes and not for construction planning.
Contractor and SHA Management of Scheduling and Planning	Inadequate planning by contractor: planning horizon is too short; and unit price contract forms encourage work on high pay items that are not critical
	Inadequate scheduling by contractor: project schedules often do not match the way the work is to be done; contractor planning management schedules are often overly complex and not representative of the work plan; and schedule updating is either not done or not done correclty
	Inadequate review and administration by SHA: chosen scheduling format is not an appropriate match for the project; initial review of the contractor's proposed schedule is inadequate; and schedule update provisions are not enforced
Maintenance of Traffic	Maintenance of traffic focus on traffic management and often are lacking with regard to constructability: MOT plans often do not represent the required construction process; MOT plans often do not address worker safety issues; MOT plans often omit critical construction steps
Design Errors and Omissions	Designers are not given sufficient time to produce quality designs; they are not accountable for project performance during construction and there is a shortage of experience personnel within the design industry particularly with regard to construction experience.

2.5 Reasons for Change Orders.

Rowland [1981] found that the change order rate increases with the contract size (in terms of the dollar value of a construction project). Both results can be explained: larger projects are generally more complex, and the complexity may increase the cost overrun rate. Upon analyzing data from 18 contracts, Rowland [1981] found that for large projects, communication channels become significantly longer and information feedback becomes distorted, possibly increasing the likelihood of a high number of change orders. The author contends that these factors could have an impact on project performance: the larger the absolute value of the difference between the owner's fair cost estimate and the low bid on a project, the greater the likelihood that a job will experience more change orders. Also, the greater the difference between the low bid and the next low bid, the greater the number of change orders. According to Rowland, this is logical in a competitive economy where there is an error in a low bid that is significantly lower than the next low bid whether or not the error is intentional. The low bidder who finally gets the job needs to attempt to recover his losses using change orders, and the number of change orders may increase with job complexity. Contracts involving heavy construction experience the greatest number of change orders per job, which is largely attributed to unforeseen conditions. Rowland [1981] found that the change order rate increased when the winning bid was below the government estimate.

From another perspective, it has been hypothesized that because the stakes are higher on larger projects, more care is probably exercised in the building and planning process, leading to a lower likelihood of cost overruns and time delays.

Jacoby (2001) with FHWA carried out a study on construction contract change orders. The study was completed in April 2001 and was based on 74 projects with a minimum cost of $10 million and cost overruns of more than 25%. The reasons cited for the change orders are indicated in Table 3.

Table 2.3: Reasons for Change Orders Identified by FHWA

Reason	Number of Projects	Remarks
Packaging of project	1	Project bundled with another
Design revisions between FHWA approval and actual advertisement.	6	3 projects in one state
Engineer's estimate was low/bids high.	27	Some fuel price adjustments, 1 project cited market conditions, some citations that size of project or uniqueness of work affected bid prices or state's ability to estimate project.
Differing site conditions – geotechnical issues (hazardous waste, muck excavation, additional shoulder rehab required, additional pavement patching)	20	–
Environmental and legal injunction with construction delay costs	1	–
Low design-build estimates	3	_
Delays/accelerated roadway openings or work in general	10	–
Design issues corresponds to construction changes	5	Omissions, issues that carried over to construction
Payment of incentives	2	
Construction Changes and miscellaneous or no reasons cited	13	Minor scope changes or additional work orders
Work zone traffic control	1	_

Source: Jacoby, 2001

2.6 Audit Reports

An audit of construction contracts in the State of Washington established that the average cost overruns of 10% for 1998 highway projects were similar to other states (Korman and Daniel, 1998). However, 33% of the total number of change orders (which represents $35.4 million) could have been avoided. The cited causes were inadequate field investigation, unclear specifications, plan errors, design changes, or mistakes by a construction engineer. This audit revealed "modest areas of potential savings" (Korman and Daniel, 1998). It was found that the costs of larger projects tended to run over frequently, compared to smaller ones. Furthermore, about $3 million a year could have been saved by cutting back on "no added value" change orders. Early project redesign was found to yield significant savings of money and time and was therefore advocated by the researchers.

In a study by the Office of Program Policy Analysis and Government Accountability that investigated the problem of cost overruns in the State of Florida, it was found that that state suffered from cost overruns of 9.5% between July 1, 1995 and December 31, 1995, within 102 contracts and a total original bid amount of $302,700,000 (Turcotte, 1996). However, the report did not indicate whether these contracts represented all contracts within that period or whether they were a random or representative sample. $15.6 million of the $28.6 million of cost overruns were considered "avoidable" costs. Furthermore, approximately $4.2 million of the avoidable costs were considered wasted money because they did not add value for citizens. The Florida study sought to identify the responsibility for such "wasted money," which was supposedly shared among consultants (32%), third parties (utility companies, permitting agencies, and local governments (55%), and the highway agency staff (13%). The report stated that cost overruns are perceived as being avoidable when they occur due to design plan or project management problems that were reasonably foreseeable and preventable. The reported further asserted that cost overruns may add value to projects by producing a better product, but duly noted that in many cases, cost overruns do not add value and are therefore considered as "wasted money." It was found that consultants and third parties in the Florida study were responsible for more avoidable cost overruns (38% for both) than agency staff (24%), but the part of cost overruns that do not add value to the project was less for consultants than for agency staff. Finally, in a bid to minimize cost overruns from occurring and to hold responsible parties accountable, Turcotte (1996) made the following recommendations for the Office for Program Policy Analysis and Government Accountability:

- Develop statewide criteria to assess the effectiveness of pursuing recovery of cost overruns that are attributable to consultants that do not add value to projects.
- Develop criteria for including avoidable cost overruns that do not add value in the selection process for awarding future contracts to consultants.
- Develop criteria for including avoidable cost overruns that do not add value in determining the constructability grades for design work.
- Provide an interim constructability grade during the construction process in addition to a final grade.
- Monitor responses to the monthly report of consultant performance grades.
- Modify DOT personnel policies and procedures to include evaluating DOT design staff for the impact of avoidable cost overruns that do not add value.
- Continue implementing strategies to improve the quality of construction plans to resolve plan problems prior to letting contracts for bid and monitor progress toward reducing cost overruns.
- Continue improving coordination with third parties to incorporate design changes and to identify utility lines as plans are developed to minimize cost overruns due to delays in making design changes during construction.

In Delaware (Wagner, 1998), the state DOT (DelDOT) experienced 13.9% cost overruns between 1994 and 1996 with a total bid amount of $114,200,000 for 148 contracts. From an economic and efficiency audit study commissioned by the state, Wagner [1998] found that the main causes were changes in the work scope and incorrect estimates of the work quantities in the original bid specifications. According to the author, these reasons are probably due to contractor error (unnecessary work, design plans, poor contract specifications), contracting agency error (planning and design deficiencies: scope of work, added work, and revisions in quantities) and unforeseen circumstances (archeological discovery). The report for that study concluded with a set of recommendations (Table 4) covering issues such as considering alternative options for higher cost-effectiveness, developing bid a analysis system and a tracking system for project payment revisions, evaluating contractors, developing other performance measures, and updating the procedure manuals.

Table 2.4: Recommendations for Addressing Cost Overruns at DelDOT [Wagner, 1998].

Number	Recommendations
1	Evaluation of the need for alternative contracting options to ensure that statutory and other regulatory restrictions do not significantly impact the efficient use of taxpayers funds. For example, DelDOT could consider a policy that would allow re-negotiation of unit prices in certain instances even though the threshold for a Supplement Agreement is not reached.
2	Completion of the development of the bid analysis system.
3	Completion of all aspects of the Project Payment Tracking System so that management has comprehensive, reliable information regarding change orders.
4	Revision of contracts to allow the State to recover additional costs incurred as a result of errors and omissions of consultants.
5	Continued establishment procedures that will ensure more accurate contract design quantities which will provide better engineer estimates of costs before the project goes out to bid.
6	Continued formal tracking both preliminary design requests and input from plan reviewers. The plan reviewers should be held accountable for non-compliance review deadlines.
7	Continued implementation of a formal budgetary control process which ensures that each change order is afforded an appropriate level of management review.
8	Review of post construction contract review process to insure that its stated objective of decreasing plan revisions, change orders, and construction claims is attained and resulting improvements to contract economy and efficiency are documented.
9	Completion of contractor evaluations and use as part of the pre-award evaluation process.
10	Implementation of a plan to ensure that highway construction contracts are afforded sufficient audit coverage.
11	Development of additional performance measures to provide management with more comprehensive data to assess performance.
12	Ensuring that DelDOT processes provide for appropriate reporting of performance measurement, such as, consistent reporting periods.
13	Update of DelDOT’s Highway Construction Manual and the Contract Administration Procedures Manual.

In response to the above recommendations, DelDOT indicated agreement with only some of them, adding that some were already being implemented and needed time for their effectiveness to be manifest. For instance, Recommendation #7 would be addressed with Recommendation #3 by completing the Project Payment Tracking System. Regarding Recommendation #9, DelDOT stated that a decision had been made several years ago to carry out contractor evaluation. In Recommendation #11 DelDOT considered that there was no "correct" number of performance measures and the fact that other states used more performance measures did not mean that the DelDOT system was deficient. Finally, for Recommendation #13 DelDOT agreed with the need for regular updating of performance measures.

2.6 Discussion of the Literature Review

2.7

Figure 2.2 summarizes the main elements of the literature review and indicates how the findings of the review relate to the framework of the present study. First, the literature review enabled definition of key terms for the present study. Rowland's study [1981], for example, provided some terms and identified some influential factors affecting change orders. The discussions in Sections 2.3, 2.4, and 2.5 are the basis for comparing the results of the present study to the previous ones. The information in the present chapter provides an indication of issues faced by transportation agencies in managing cost overruns and time delays. While preparing the recommendations for INDOT, it may be helpful to make the distinction between root causes and apparent causes as defined in the Ellis and Thomas' study [2002].

2.8 Chapter Summary

The literature review identified the problems of cost overruns and time delay with some new and external points of view and provided definitions of the key concepts. Previous studies identified some factors that influence cost overruns or time delays and developed tools that help address such problems.

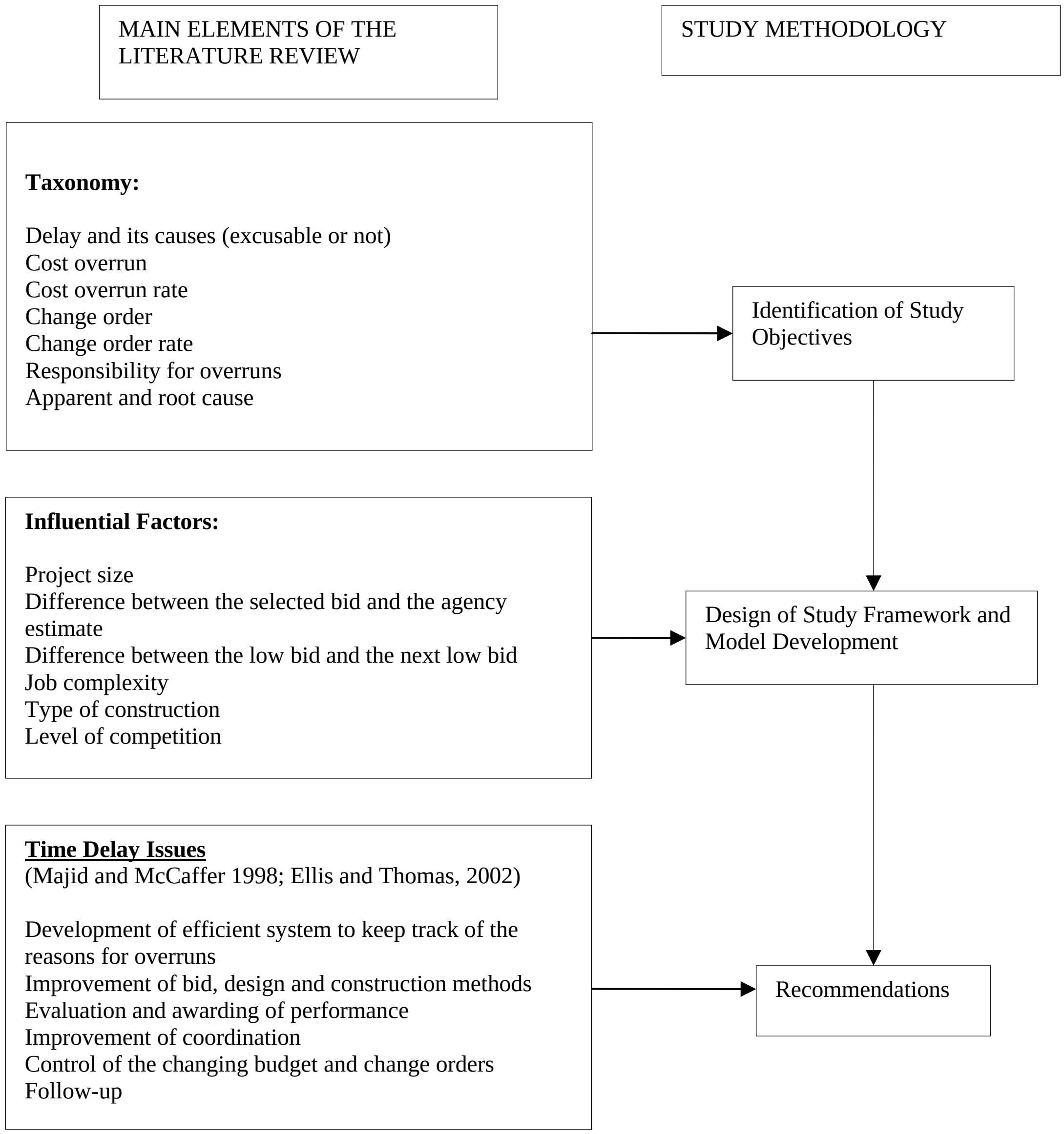

Figure 2.2: Relationship between Literature Review and Other Aspects of the Study

CHAPTER 3: AGENCY SURVEY

3.1 Introduction

An agency survey was carried out to complement the findings from the literature review and to acquire current state of practice perspectives on the problem of cost overruns, time delay and change orders. The agency survey was also motivated by the success of a fairly recent similar effort by Jacoby (2001) who conducted an AASHTO-FHWA sponsored nationwide survey to ask DOTs about the various methods they use to manage cost overruns and time delays through their change order classifications. The experience of other states would therefore be helpful in establishing appropriate recommendations for INDOT. Two aspects of overruns were compared: the frequency and amount of cost overruns and time delays, and how such problems are addressed. An email solicitation (Appendix B) was distributed through the Research Division of INDOT and posted on a national DOT research list requesting information on cost overruns and time delays. This solicitation yielded 11 responses from other state DOTs in the form of either direct responses to email questions or provision of attached electronic documents. This chapter presents and discusses the responses to the agency survey conducted as part of the present study. The cost overrun amounts herein presented constitute an average of several contracts in any single year and therefore may not reveal variations of cost overruns and underruns across individual contracts. In subsequent chapters, both cost underruns and overruns, rather than their combined average, are presented separately using Indiana data.

3.2 Cost Overruns and Time Delays: Results of the Agency Survey

Eleven state transportation agencies responded to the e-mail request: Arkansas, Idaho, Illinois, Iowa, Maryland, Missouri, New Mexico, Ohio, Oregon, Tennessee, and Texas. The respondent from Arkansas indicated that his state is increasingly experiencing cost overruns, with a record cost overrun rate of over 10% occurring in 2001. Table 3.1 shows the trends in cost overruns and time delays for Arkansas DOT projects from 1997 to 2002.

Table 3.1: Cost Overruns and Time Delay in Arkansas

Year	1997	1998	1999	2000	2001	2002
Total Number of Contracts	281	271	289	229	213	94
Number of Time Overrun Contracts	83	94	81	98	50	11
Percentage of Time Overrun Contracts	29.54%	34.69%	28.03%	42.79%	23.47%	11.70%
Number of Cost Overrun Contracts	155	165	178	114	118	56
Percentage of Cost Overrun Contracts	55.16%	60.89%	61.59%	49.78%	55.40%	59.57%
Cost Overrun	$13,271,341	$27,316,195	$17,624,444	$3,277,792	$23,024,593	$1,671,183
Bid Amount	$292,472,031	$406,309,328	$344,829,578	$241,155,482	$219,641,022	$40,940,105
Cost Overrun Rate	4.54%	6.72%	5.11%	1.36%	10.48%	4.08%

Source: Arkansas DOT (2002), email correspondence

Table 3.1 shows that within the time period under consideration, the percentage of Arkansas DOT contracts with time overruns was between 11.7 and 42.8%, while 49.8% to 61.1% of contracts had cost overruns. Generally, over 50% of all contracts experienced cost overruns in that state. The situation at the state of Idaho is similar: 9.19% of contracts had overruns in the year 2001. Table 3.2 shows that 54.7 to 67.5% of Idaho DOT contracts had cost overruns between 1997 and 2001 and state highway contracts at that state experienced increasing problems with cost overruns.

Table 3.2: Cost Overruns in Idaho between Fiscal Years 1997 and 2001

Year	1997	1998	1999	2000	2001
Bid Amount	$95,922,292	$115,486,029	$138,517,432	$64,304,580	$90,222,751
Final Cost	$100,566,782	$121,428,479	$147,168,090	$71,315,274	$98,515,323
Cost Overrun Rate	4.84%	5.15%	6.25%	10.90%	9.19%
Average Overrun	$67,311	$57,139	$113,824	$107,587	$113,597
Total Annual Overrun	$4,644,490	$5,942,450	$8,650,659	$7,010,694	$8,292,572
Percentage of Contracts with Cost Overruns	54.70%	67.53%	62.30%	67.70%	64.60%

Source: Idaho DOT (2002), email correspondence

In the state of Illinois, 42 closed-out projects in 2001 had liquidated damages (which are associated with time delays) that amounted to approximately $400,000. No information was given about cost overruns.

The Iowa Department of Transportation estimated that 75% of their contracts have cost overruns and/or time delays. The respondent for that agency stated that the average cost overrun is approximately 5%, and that the annual amount of cost overruns depends on the amount of work accomplished, and typically ranges between $16 million and $25 million. Cost overruns and time delays were largely attributed to inaccurate plan quantities, plan changes, and site conditions.

Cost overruns on Maryland projects typically range from 4% to 6%. At that state, a large percentage of time overruns are resolved through "justified" time extensions.

For the State of Missouri, the survey respondent stated that, between 1999 and 2002, cost overruns fluctuated over the period, ranging from a low of 1.33% to a high of 5.22%. The 2001 fiscal year had only 1.33% cost overruns (Table 3.3).

Table 3.3: Cost Overruns at Missouri DOT between Fiscal Years 1999 and 2002

	Fiscal Year 1999	Fiscal Year 2000	Fiscal Year 2001	Fiscal Year 2002	Total
Number of Contracts	220	227	152	71	670
Beginning Date	7/1/1999	7/1/2000	7/1/2001	7/1/2002	7/1/1999
Ending Date	6/30/2000	6/30/2001	6/30/2002	11/14/2002	11/14/2002
Total original contract amount	$380,447,304	$406,692,618	$217,039,579	$154,961,759	$1,159,141,260
Total current contract amount	$396,508,590	$427,928,541	$219,930,439	$157,218,314	$1,201,585,883
Total difference for all contracts	$16,061,285	$21,235,923	$2,890,860	$2,256,555	$42,444,623
Total Percentage of change, all contracts	4.22%	5.22%	1.33%	1.46%	3.66%
Number of Contracts with Cost Overruns	131	142	98	44	415
Percentage of Contracts with Cost Overruns	59.55%	62.56%	64.47%	61.97%	61.94%

Source: Missouri DOT (2002), email correspondence

Table 3.3 shows that about sixty percent of Missouri DOT contracts experienced cost overruns. While the cost overrun rate seems rather high, the amount of cost overruns at Missouri DOT is generally lower than for other states because Missouri probably incurs relatively lower expenditure on transportation projects.

At New Mexico DOT, 73 projects were completed in 2002 fiscal year. The total original bid amount was approximately $304 million and the total final contract amount was about $316 million. Consequently, the difference was approximately $12 million, representing an overall average overrun of 3.9%. Forty-five contracts (61.1%) experienced cost overruns; seven contracts (9.6%) experienced time overruns (those for which liquidated damages were applied); and 33 contracts (45.2%) experienced time extensions. The average cost overrun was about $162,000 per project. The New

Mexico Department of Transportation incurred approximately $16,493,000 on overruns and "saved" $4,607,578 on underruns. The net annual overrun amount in 2002 was therefore approximately $12 million. The major causes of overruns in percentage of annual net overrun amount were identified as follows:

Extra work (40%)

Traffic control modifications (6%)

Design oversight (16%)

Miscellaneous adjustment to bid quantities (6%)

Incentive/disincentive payments (21%)

Claim settlements (6%)

At Ohio DOT, cost overrun and time delay projects ranged between 80% to 92% and 45% to 55%, respectively, for all projects. The annual cost averages range from a low of approximately $76 million in 1995 to a high of over $196 million in 1999. Not only do these numbers seem rather high compared to other states, but they also indicate an increasing trend of average cost overruns. According to the respondent, the cost overruns are attributed to the difference between planned and actual construction quantities (approximately $2.6 billion over eight years) and work changes that were deemed unpreventable (approximately $1 billion over eight years).

Table 3.4: Ohio DOT Cost Overruns, 1994 – 1997

Year	1994	1995	1996	1997
Total Number of Projects	793	665	783	778
Number of Projects with Cost Overruns	719	610	720	716
Proportion of Projects with Cost Overruns	90.67%	91.73%	91.95%	92.03%
Number of Projects with Time Extensions	355	361	435	373
Proportion of Projects with Time Delays	44.77%	54.29%	55.56%	47.94%
Annual Cost Overruns	$96,383,928.04	$76,335,671.89	$94,600,976.99	$136,787,513.53
Average Cost Overrun per Contract	$121,543.41	$114,790.48	$120,818.62	$175,819.43

Source: Ohio DOT(2002), email correspondence

Table 3.5: Ohio DOT Cost Overruns 1998 - 2001

Year	1998	1999	2000	2001
Total Number of Projects	758	796	604	574
Number of Projects with Cost Overruns	685	720	535	456
Proportion of Projects with Cost Overruns	90.37%	90.45%	88.58%	79.44%
Number of Projects with Time Extensions	372	385	309	302
Proportion of Projects with Time Delays	49.08%	48.37%	51.16%	52.61%
Annual Cost Overruns	$118,682,969.33	$196,520,134.89	$154,992,070.17	$136,187,887.81
Average Cost Overrun per Contract	$156,573.84	$246,884.59	$256,609.39	$237,261.13

Source: Ohio DOT (2002), email correspondence

The management of cost overruns at Oregon is quite sophisticated. After a project is awarded, an authorized spending limit is set. This limit is called the *original authorization,* and includes bid item amounts, estimated engineering, anticipated items, and a small amount of contingency funds. As the project progresses, the estimated project cost is tracked, which includes change orders and overrun of bid items. Authorization is delegated to various levels to approve overruns of the project. When it is imminent that a project would overrun its authorization by $500,000 or more, ODOT staff are required to make a request to the Oregon Transportation Commission to have the authorization increased. If the authorization is increased, then they have a "new authorization level." If there no request to increase the authorization, then the original (or previously approved) authorization level remains. Because the current authorization is greater than or equal to the original authorization, the total project cost can only exceed the current authorization by an amount less than or equal to the amount over original authorization. For example, if the original authorization is $1,500,500, the current authorization is $2,000,000, and the total project cost is $2,320,000, then the amount over original authorization would be $2,320,000 less $1,500,500 or $819,500 and the amount over current authorization becomes $2,320,000 less $2,000,000 or $320,000. Among the surveyed state agencies, Oregon DOT appears to be the only state that processes a corrective action on project cost when major additional investments are needed.

Table 3.6: Cost Overruns at Oregon DOT, 1998 – 2002

		1998	1999	2000	2001	2002
Percentage of Projects Exceeding	Original Completion Date	65.00%	54.80%	51.40%	42.00%	14.80%
	Original Authorized Amount	32.60%	31.30%	34.30%	36.20%	18.50%
	New Authorized Amount	26.30%	26.70%	28.60%	33.30%	18.50%
Average Amount Over	Original Authorization	$200,445	$249,822	$111,146	$54,547	$82,636
	New Authorization	$124,680	$75,035	$52,066	$54,645	$82,636
Total Amount Over	Original Authorization	$11,425,382	$10,242,701	$4,001,246	$1,363,667	$413,178
	New Authorization	$5,735,277	$2,626,236	$1,561,981	$1,256,843	$413,178

Source: Oregon DOT (2002), email correspondence

For contracts at Tennessee DOT, cost overrun rates have averaged approximately 6% over the years 1998-2002, and approximately 14% of their projects have experienced time delays. This translates to increased contract costs of almost $40 million a year (Table 3.7).

Table 3.7: Cost Overruns for Paid-off Tennessee DOT Projects, 7/01/98 to 9/13/02

Category	Amount or Percentage
Original Contract Amount	$2,642,879,835.72
Contract Expenditure	$2,857,739,999.82
Supplemental	$58,282,515.63
Supplemental Rate	2.21%
Cost Overrun	$156,577,648.47
Cost Overrun Rate	5.92%
Total Average	$214,860,164.10
Rate for Total	8.13%
Total Number of Contracts	2196
Number of Contracts with Liquidated Damages	306
%Percentage of Contracts Not Completed on Time	13.93%

Source: Tennessee (2002), email correspondence

The Texas data indicate a consistency in cost and time overruns over the years. Tables 3.8 and 3.9 show that between 1998 and 2002 the percentage of cost overruns at Texas varied between 4.5% to approximately 7%. The percentage of contracts with cost overruns varied between 66% and 75%. The percentage of contracts with time delays indicated a steady trend, ranging from 52% to 56%.

Table 3.8: Cost and Time Overruns at Texas DOT, 1998 – 2000

	Year 1998	Year 1999	Year 2000
Number of Contracts	938	1006	973
Total Original Contract Amount	$1,794,584,651.23	$2,027,903,107.51	$2,293,376,095.56
Total Final Contract Amount	$1,874,255,325.59	$2,128,140,882.90	$2,395,615,416.08
Total Difference for all Contracts	$79,670,674.36	$100,237,775.39	$102,239,320.52
Total Percentage of Change, all Contracts	4.44%	4.94%	4.46%
Percentage of Contracts with Time Overruns	51.81%	51.89%	52.72%
Percentage of Contracts with Cost Overruns	66.52%	66.90%	72.15%

Source: Texas DOT(2002), email correspondence

Table 9: Cost and Time Overruns at Texas DOT, 2001, 2002 and 1998 - 2002

	Year 2001	Year 2002	1998-2002 (Total)
Number of Contracts	939	474	2917
Total Original Contract Amount	$1,961,075,393.58	$1,084,532,144.86	$6,115,863,854.30
Total Current Contract Amount	$2,096,861,510.82	$1,153,147,241.27	$6,398,011,624.57
Total Difference for all Contracts	$135,786,117.24	$68,615,096.41	$282,147,770.27
Total Percentage of Change, all Contracts	6.92%	6.33%	4.61%
Percentage of Contracts with Time Overruns	53.57%	56.54%	52.93%
Percentage of Contracts with Cost Overruns	75.19%	72.57%	70.42%

Source: Texas DOT(2002), email correspondence

3.3 Cost and Time Overruns: Comparison among States

A comparative analysis of cost and time overruns between the responding states was carried out (Table 3.10), and revealed interesting trends. The majority of DOT contracts experience cost overruns and the cost overrun amounts vary between states and are dependent on the volume of contract. Causes are described in general terms. The distribution of time delays exhibits a wider range of variation – this may be attributed to a lack of precision in the definition (and consequently, estimation) of time delays. For instance, INDOT time delays are computed on the basis of liquidated damages which may not representative of all kinds of time delays. However, INDOT is at the lower end of the range for both cost overruns and time delays.

Table 3.10: Comparison of Cost Overruns at Selected States

State	Period	Percentage of Projects with Cost Overruns	Annual Amount Spent on Cost Overruns	Percentage of Projects with Time Overruns
Arkansas	1997 to 2002	NI	NI	NI
Idaho	1997 to 2001	55% - 67%	$5 - 9 million	NA
Illinois	NI	NI	NI	NI
Indiana	1996 to 2002	55%	$26 - 45 million	12%
Iowa	NA	NA	$16 - 25 million	NA
Maryland	NA	NA	NA	NA
Missouri	1999 to 2002	60% - 64%	$2 - 42 million	NI
New Mexico	2002	62%	$11.9 million	10%
Ohio	1994 to 2001	80% - 92%	$76 - 196 million	44% - 56%
Oregon	1998 to 2002	18% - 33%	$0.4 – 5.7 million	15% - 65%
Tennessee	1998 to 2002	61%	$40 million	14%
Texas	1998 to 2002	66% - 75%	$68 - 282 million	52% - 55%

NA – Not Available (the survey respondents stated that the information was not available)
NI – Not Indicated (the survey respondents did not say whether the information exists)

The following four figures summarize the findings concerning performance in terms of cost overruns (amounts and rates) of the survey respondents. Few states are represented because the responding states did not provide information in a consistent format.

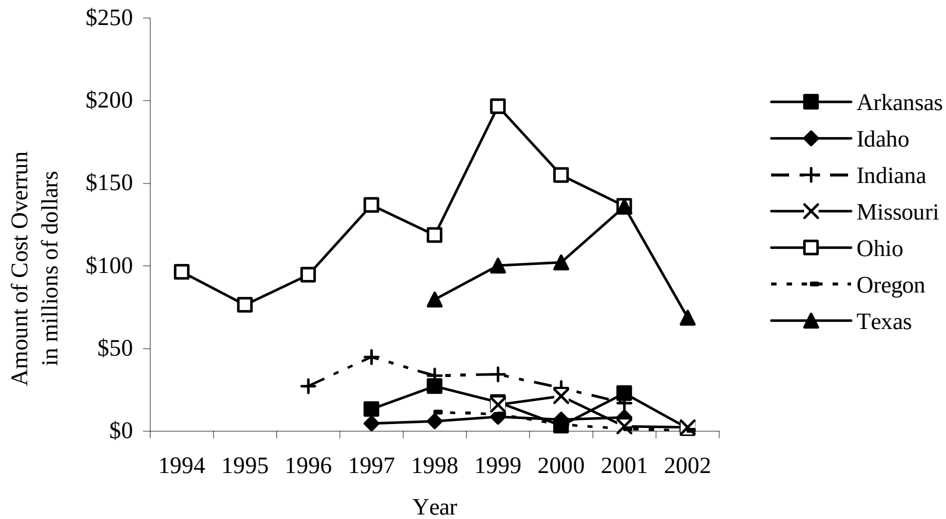

Figure 3.1: Amount of Cost Overruns at Selected States

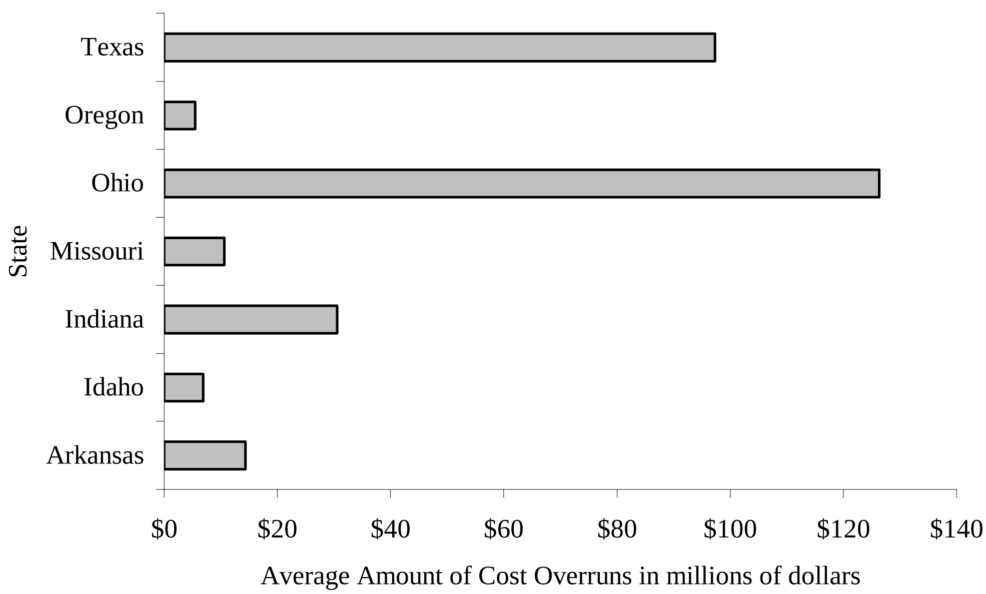

Figure 3.2: Average Annual Amount of Cost Overruns at Selected States

Figure 3.1 shows that Texas and Ohio DOTs experience the most significant amount of cost overruns each year, but the figure also shows that since 1999 (for Ohio) and since 2001 (for Texas), this annual amount of cost overruns has decreased. Indiana is actually in a relatively “good” position in terms of cost overruns. Figure 33 presents the relative average rate of cost overruns, taken over the years 1997 to 2001.

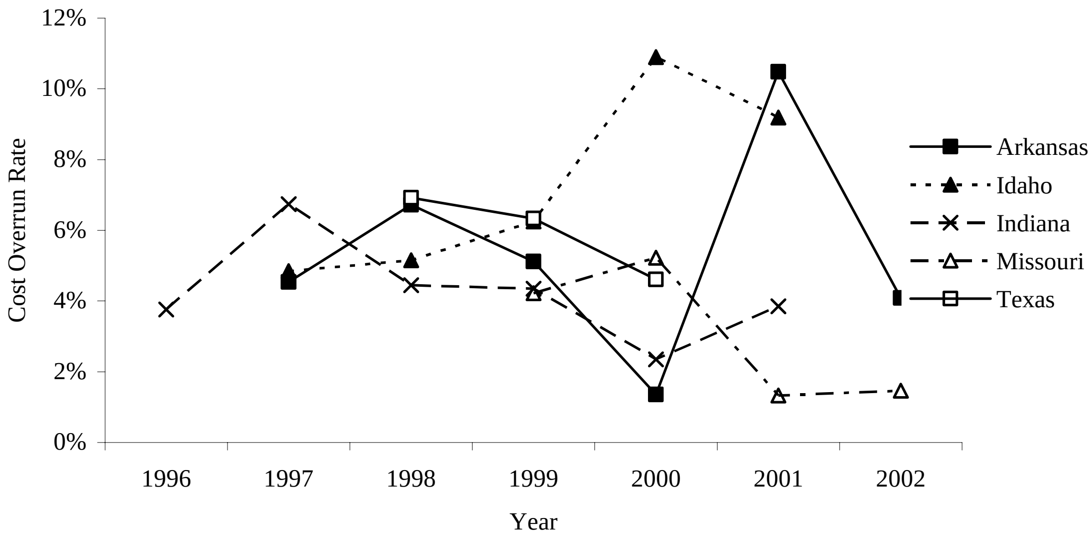

Figure 3.3: Cost Overrun Rates at Selected States

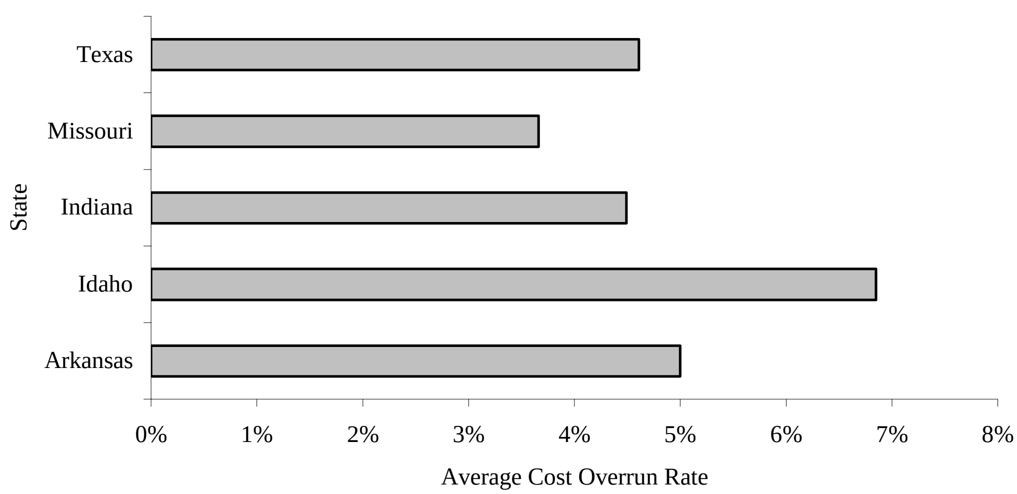

Figure 3.4: Average Annual Cost Overrun Rates at Selected States

Figures 3.3 and 3.4 represent fewer states than Figures 3.1 and 3.2 because information concerning cost overruns rates was not made available by some respondents. The average cost overrun rate varies between approximately 3.4 and 6.8%. It is seen from the figures that Idaho has the least total cost overrun amount but has the highest cost overrun rate (cost overrun amount per bid amount). With regard to cost overrun rates, it is seen that Indiana is in a relatively good position ranking, fourth out of the five states in order of cost overrun rate (or severity).

3.4 Tracking Change Orders: Comparison among States

Some states have developed a precise method to classify their change orders. For such states, change orders constitute vital clues in the identification of reasons for cost and time over/under runs. At the time of reporting, twenty-four states had in place a process for classifying change orders (Alaska, Arizona, Arkansas, California, Connecticut, Florida, Indiana, Iowa, Kentucky, Louisiana, Michigan, Minnesota, New Hampshire, New Jersey, New Mexico, New York, North Dakota, Ohio, Pennsylvania, South Dakota, Texas, Utah, Washington and Wisconsin). The FHWA (Jacoby, 2001) has developed a model which could be used to classify change orders, the basic structure as follows:

1. Physical Work Categories (Additional or extra work out of scope, Contract document revisions and oversights, Contract term adjustments, Changed and unforeseen condition).

2. Administrative Category

INDOT follows the above basic structure suggested by FHWA. The specific method developed by INDOT to classify and track its change orders is given in Appendix A. Methods for other states are shown in Appendix C. The relative degree of simplicity of each state's approach is shown in Table 3.11.

Table 3.11: Relative Simplicity of Change Order Classification at Selected State DOTs

Very Detailed Classification	Simple but Effective Classification	Simplest Classification
California	Arizona	Alaska
Indiana	Arkansas	Iowa
Minnesota	Connecticut	Louisiana
New Jersey	Florida	Michigan
Ohio	Kentucky	New Hampshire
South Dakota	New Mexico	North Dakota
Utah	New York	
Texas	Pennsylvania	
Washington	Wisconsin	

Source: Jacoby, 2001, email correspondence

DOTs of states such as Washington, Ohio, and Texas have developed very detailed classification systems for tracking change orders. It would be useful to ascertain how such agencies use their classifications to improve project management. It can be assumed, therefore, that states with fewer problems in terms of cost and time overruns typically do not have detailed classification system as is available at Washington and Texas.

3.5 Chapter Summary

100% of all respondents indicated concern about the issue of cost overruns, time delays and change orders. It may be argued that such concern is reflective of state DOTs nationwide. Indiana seems to be in an “average” position in terms of the percentage of projects with cost overruns and time delays, even though the state incurs significant amounts ($26-45 million per year) due to these problems. The relatively good performance at INDOT can be attributed to the existence of an effective classification and tracking system for the change orders. However, it is obvious that there is still room for improvement, and in a subsequent chapter, the present study identify avenues for such further enhancements to the existing system.

CHAPTER 4: STUDY METHODOLOGY

4.1 Introduction

This chapter explains the overall framework, methods, and underlying assumptions for analyzing the problem of cost overruns, time delays and change orders in Indiana. Figure 4.1 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, pair-wise tests, analysis of variance, and statistical modeling. The methodologies include definitions of dependent variables (cost overrun amounts and rates, time delay and change orders) and potential influential factors (independent variables), and selection of model categories and appropriate mathematical forms. Also, techniques used for model calibration and validation are discussed in the present chapter. The methodology was designed to yield statistical models with a view to predict cost overruns and time delays, but more importantly, to identify significant factors that influence cost overruns, time delays and the frequency of change orders.

4.2 Descriptive Statistics

The present study seeks to identify the main reasons and responsibilities for change orders, among others, and it is expected that a descriptive statistical analysis would throw more light on this issue. For cost overruns and time delays, descriptive statistical analysis in terms of their frequency and amounts was carried out. Simple descriptive graphs (histograms) may show any variations in such attributes by geographical location, type of project or year of implementation. Moreover, descriptive figures such as pie charts easily and readily show the relative significance of various categories of cost overruns. A description of the distribution and frequency of each type of change order can help understanding the extents and root causes of the problem.

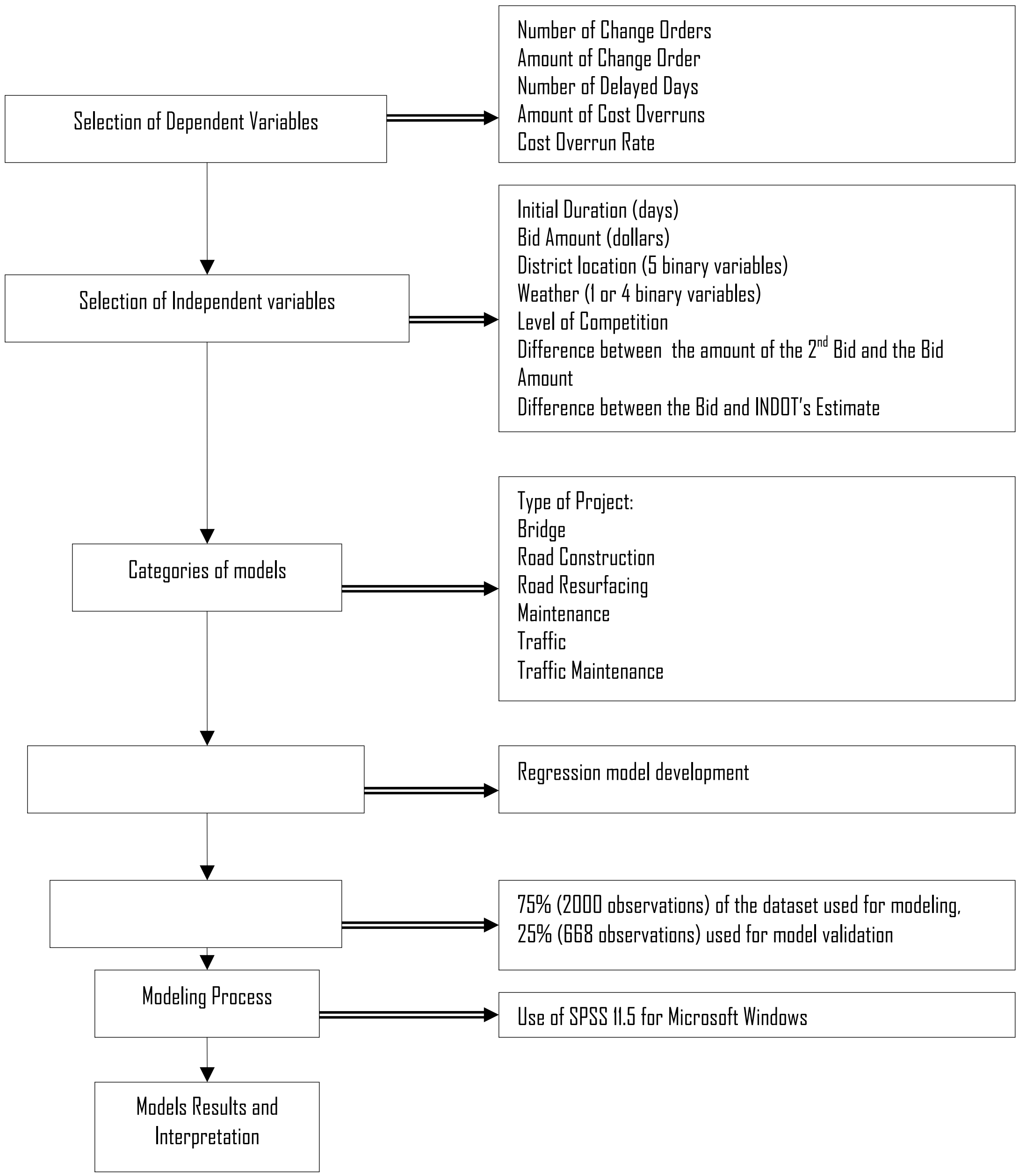

Figure 4.1: Approaches Used in the Statistical Analyses.

4.3 Statistical Analysis

4.3.1 Correlation Matrix Analysis

A correlation matrix analysis of the data was carried out using SPSS 11.5 for Microsoft Windows, in order to identify any possible linear correlations between the independent variables that influence cost overruns, time delay, and change orders. The equation to compute correlation coefficient, r, is shown:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)S_x S_y}$$

Where:
x and y are any pair of variables whose level of correlation is being sought
$\bar{x}$ and $\bar{y}$ are the means of x and y, respectively
S_X and S_Y are the standard deviations of x and y, respectively.

The correlation coefficient lies between -1 and +1. If the coefficient is close to -1 or +1, the two variables are close to a perfect linear relationship, and when the coefficient is close to 0, there is little or no correlation.

4.3.2 Analysis of Variance (ANOVA)

The analysis of variance is conducted to show the overall significance of the independent variables. Two levels were considered for each independent variable, as shown in Table 4.1.

Table 4.1: Selected Levels for Each Independent Variable

Variable	Low Value (1)	High Value (2)
Bid Amount	< \$350,000	> \$350,000
Proportion of Inclement Weather Days	< 0.25	> 0.25
Level of Competition	≤ 3	> 3
Proportion of the Difference between the First and Second Bids	< 0.07	> 0.07
Proportion of the Difference between the Bid and Engineer's Estimate	< 0.22	> 0.22
Project Duration	< 110	≥ 110

Only the first five variables shown in Table 4.1 were used for the analysis of variance of cost overruns, the amount of change orders and the number of change orders. For time delay, only three variables (bid amount, project duration, and proportion of inclement weather days) were considered. The analysis of variance was carried out using SPSS 11.5 for Microsoft Windows [SPSS, 1999].

For each unique combination of the levels of the independent variables, a dummy integer variable was established to facilitate the analysis of variance. For example, as seen in Appendix F, the dummy variable takes a value of 1 when the proportion of inclement days is low (level = 1), bid amount is low (level = 1), level of competition is low (level = 1), *proportion of the difference between the winning and second bid* is low (level = 1), *proportion of the difference between the engineers estimate and the winning bid* is low (level = 1). As such, it is possible to calculate the mean, the standard deviation, and the number of observations for each value of the dummy variable. The analysis of variance was then carried out by comparing the means of cost overruns, time delay, and change orders for each value of the dummy variable. ANOVA yields an F-ratio and a corresponding P-value. The higher the F-ratio, the lower the P-value, and consequently the more significant the difference between the group means.

4.3.3 Pair-wise Tests

A pair-wise t-test analysis was conducted to determine further significance of the independent variables. A more detailed explanation of the method is provided by Harnett [1975]. For each test, it was assumed that the two populations are normally distributed and that the samples are independent random samples. A t-test for the difference between the two samples can be constructed on the basis of the difference for each matched pairs. The matched pairs are a pair of observations that differ from each other for only one variable, and the difference between the other variables must not exceed +/- 10%. x is defined as the difference between x_A and x_B that are matched pairs of the two populations, and is assumed to be normally distributed. The null hypothesis is H_0: $\mu_A - \mu_B = 0$ which is equivalent to H_0: $\mu_x = 0$ and

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2}$$

The test statistic for matched pairs is: $t_{(n-1)} = \dfrac{\bar{x}-\mu_0}{s/\sqrt{n}}$ with $\mu_0 = 0$.

This t-test compares with $\left[-t_{(\alpha/2,n-1)};+t_{(\alpha/2,n-1)}\right]$. If $t_{(n-1)}$ is in this range, H_0 is true and the variable is not significant. $\bar{x}$ is always calculated as the difference between the dependent variable for the high value of the studied variable and for the low value of this variable. In this section, α is defined as 10%, $\alpha = 0.1$.

The following method was followed in the pair-wise testing: first, two categories were established for each independent variable (high and low values). Then, for each level of some independent variables, appropriate pairs of contracts were identified. Then the pairs of contracts were further refined to include only those whose attributes (such as bid amounts) matched closely. The results of such analysis are presented as Tables F.5 – F.15 (Appendix F. For most of the analyses, the bid amount is used for this final step of developing the tables for the analysis, as it is obviously the most significant variable. For the analysis of the bid amount, it was necessary to keep another variable at a fixed level so that the matching pairs could be established. The proportion of inclement weather days was selected for practical reasons for cost overruns and change orders. But project duration was selected for time delay. Then the differences in their cost overruns, time delays or change orders were determined.

4.3.4 Graphical Trend Investigations

In order to discern general trends in the data, each potentially influential factor (independent variable) was categorized into three levels: low, medium, and high. Then the variation of the dependent variable (cost overrun, time delay or change orders) with respect to a selected independent variable was investigated while keeping the other independent variables at a constant level. The medium level was chosen as the level to which the other independent variables were held constant. The range values for each category are defined in Table 4.2.

Table 4.2: Definition of the Proportions for each Variable

Variable	Level		
	None or Low	Medium	High
Proportion of Inclement Days	< 0.15	0.15-0.5	> 0.5
Bid Amount	< 300000	300000-1000000	> 1000000
Percentage of Difference between the First and Second Bids	< 10	10-20	> 20
Percentage of Difference between the Bid Amount and the Engineers Estimate	< 20	20-40	> 40
Original Duration	< 100	100-200	> 200
Level of Competition	≤ 4	=5 or 6	> 6

4.4 Description of the Modeling Process

The next step after examining statistical characteristics was to develop models to confirm the magnitude and direction of the influence of potential factors and to predict the severity cost overruns, time delay, or change order frequency of any future projects. Interestingly, all three dependent variables are potentially influenced by the same set of independent variables which are discussed in Section 4.4.2.

4.4.1 Response Variables

The first step was to identify the response (or dependent variables) to be used in the statistical models. These were as follows:

- Cost overrun amount

- Cost overrun rate (cost overrun amount divided by the bid amount)
- Time delay (in days)
- Number of change orders
- Amount of change orders

4.4.1.1 Cost Overrun

The total amount of cost overrun was calculated by the difference between the final contract cost and the bid amount. In another set of models the response variables was the cost overrun rate, which is the percent difference in cost (positive or negative) between the final contract cost and the contract award amount (Jahren and Ashe, 1990).

4.4.1.2 Time Delay

The response variable for the time delay models was the number of days of time overrun, which is defined as the difference between the actual duration of the project and the original duration (decided in the contract). The dataset provided the following dates: the notice to proceed date, the last day of work, and the estimated date of project completion, which enabled calculation of the time delay.

4.4.1.3 Change Orders

There were two types of change order information: the daily change order that contains all the change orders in a day and the second type is the member of individual change orders. In the present study, the number of individual change orders, as well as the total amount of money involved in change order, was modeled as a function of various independent variables.

4.4.2 Independent Variables

The second step was to identify the factors that potentially influence the amount of change orders, cost overruns and time delays. This step was guided by the findings from the literature review and agency survey (Chapter 2 and 3). The results of the descriptive statistics, pair-wise t test and analysis of variance were instrumental in developing a tentative list of independent variables for use in the statistical models.

An important independent variable is *project duration*, or the initial length (days) of the project, computed as the difference between the estimated last day of work and the notice to proceed date. An initial expectation for this variable would be that longer projects would result in longer delays. Indeed, Rowland [1981] found that the size of the project is a significant variable. Size can be understood as the total cost or duration of the project. It is intuitive that a high-cost project will likely involve a long contract duration. Conversely, a project of long duration is likely to have a high cost. So, these two potential influential variables are obviously related to each other. Rowland [1981] states that a bigger project would have a greater change order amount rate. In the present study, the initial project length was used only for time delay models because this is the most relevant variable for these models.

The *bid amount* (in dollars) may also be a significant variable for all three model types. It is quite possible that correlation may exist between the *bid amount* variable and the *initial length* (days). The *project size* in terms of cost and the size in terms of length may exhibit different levels of influence on the dependent variables. On one hand, it can be hypothesized that an expensive project is often managed more efficiently, resulting in less delay. On the other hand, it may be argued that the involvement of more contractors and subcontractors may result in increased delay certainly because of inevitable lapses in communication between them. The same comment can be made about the impact of *project size* on cost overrun.

To examine the influence of *project type*, six binary variables were created (*bridge, road construction, resurfacing, maintenance, traffic, and traffic maintenance*). Each of these variables takes a value of 1 if the information pertains to the project type, 0 otherwise. Bridge and road construction projects may not suffer from traffic management as much as the other projects, so there may be less risk in terms of safety and delay. However, actual bridge construction is much more unpredictable than the other project types, and unforeseen site conditions or delays in obtaining right-of-way could cause delays and cost overruns. Maintenance and traffic projects are significantly affected by passing traffic, but overall, a lower level of construction delays and cost overruns may be expected for such projects because of their typical small size and short duration. Jahren and Ashe [1990] found that the size of a project is significant in time delays. For models that included the “project type” variable, five binary variables were used (excluding the traffic maintenance variable). As such, a project that shows a zero value for all the binary variables is a traffic maintenance project.

The district at which a project is located may be a significant variable because of variations in weather and administrative practices/culture. Contract locations by districts were represented using binary variables. It is possible that some interaction may exist between the variables representing contract location and those representing weather conditions. The *district* variables are expected to reveal differences in the effectiveness of supervision practices. If these variables are found to be strongly related to the weather variables, they may only represent a climatic and geological variation among the state. However, if this is not the case, other disparities may be revealed among the districts, such as INDOT staff's management efficiency, the performance of the main contractors in the district, etc.

Weather variation was not considered in previous studies. In the present study, four different continuous variables were used to describe the weather conditions during the duration of each project.

- Temperature (in number of days with a temperature less than 0 degree Celsius)
- Rain precipitation (in number of days with rain precipitation)
- Snow precipitation (in number of days with snow precipitation)
- Ground snow conditions (in number of days with snow on the ground)

These variables are expected to reveal the impact of inclement weather conditions on the construction process. It is expected that the coefficients for these variables will have a positive sign for all models. In order to prevent correlation between the four weather variables, another independent variable was considered: inclement weather (in terms of the number of days of the contract duration that experienced either low temperature (less than zero degree Celsius), precipitation, snow, or snow on the ground). This new variable incorporates the four weather variables. It helps avoid the problems of correlation because when the temperature is under zero degree Celsius, any precipitation will be in the form of snow, not rain. The same comment can be made for the variable "ground snow conditions," because it is obviously strongly related to the variable "snow precipitation." These weather variables (expressed in the number of days) are finally reduced to a rate by dividing the number of inclement days by the total number of days worked on the project.

The *level of competition* for each contract is the number of contractors who submitted a bid to INDOT for that contract. The level of competition was found relevant in the Jahren and Ashe [1990] study. Obviously, it is expected that the higher the *level of competition*, the more competitive the bidding, and consequently the higher the number of change orders, cost overruns and time delays likely to be experienced by the contract.

The difference between the *bid amount* and the INDOT engineer's estimate was also taken into account in the present study to ascertain the validity of Rowland's assertion [1981] that the larger the absolute value of the difference between the owner's fair cost estimate and the low bid on a project, the greater the likelihood that a job will experience more change orders, and by extension, more cost overruns.

The *difference between the bid amount and the next low bid* might have an influence on the number of change orders as found by Rowland [1981]. It is expected that when such difference is larger, the number of change orders or cost overrun amounts is greater.

For these variables (i.e., the *difference between the first and second bids and between the bid and the engineer's estimate*) a rate is defined by dividing these amounts by the original bid amount.

4.4.3 Project Types

The *project type* variable was deemed appropriate for categorizing the statistical analyses. The categories consisting of bridge, road construction, resurfacing, maintenance, traffic and traffic maintenance are characterized by significant differences in management practices due to the nature of the categories. Separate models were developed for each category. Also, a general model for all contracts that utilized project type independent variables (rather than having model families based on project type) was developed to further investigate any differences between the impacts of each project type.

4.4.4 Investigation and Selection of Mathematical Forms

All the variables were modeled with the linear regression form, and some typical Box Cox transformations were tried for each dependent variable, depending on the range of these variables.

4.4.5 Model Calibration and Validation

Influential variables were selected on the basis of their relatively high statistical significance, which was ascertained using their t-statistics and P-values given with the model results. The best models were obtained through progressive inclusion and exclusion of various variables in the models. The variables were selected or inclusion if their t-statistics were approximately greater than 1.6. The statistical package SPSS 11.5 for Windows [SPSS, 1999] was used to run the regressions.

Approximately 25% of the data was set aside to validate the models. As such, of the 2,668 projects, a randomly selected set of 2,000 projects were used for the modeling process. The other set of 668 projects were used to determine whether the predictions given by the calibrated model matched the observed values. The following parameters were estimated to evaluate the effectiveness of each model:

$$\text{Root mean square error} = \sqrt{\frac{\sum\left(x_{obs} - x_{\text{mod}}\right)^2}{n}}$$

$$\text{Percentage of deviations} = \sum\left|\frac{x_{obs} - x_{\text{mod}}}{x_{obs}}\right|$$

4.5 Chapter Summary

The present chapter explained the overall framework, methods, and underlying assumptions for analyzing the problem of cost overruns, time delays and change orders in Indiana. The methodology included preliminary descriptive statistics, correlation matrix analysis, pair-wise t tests, analysis of variance, and statistical modeling. The chapter provided a description of the methodologies used in the statistical analysis. Five models types, based on the form of response variable, were considered for development: number of change orders, change order amount, severity of time overrun, cost overrun, and cost overrun rate. The following independent variables were discussed: duration, bid amount, project type, district, weather conditions, level of competition, engineer’s estimate comparison, and first and second bid comparison. Also, appropriate functional forms were discussed. The techniques used for model calibration and validation were also discussed in the present chapter.

CHAPTER 5: DATA COLLECTION

5.1 Introduction

This chapter describes the data collection and the development of the dataset used for the analysis of cost overruns, time delays and change orders in Indiana DOT. Most of the data were obtained from the INDOT contracts division. The study uses data period of approximately five years: between January 1, 1996 and September 6, 2002. There were a total of 2,668 projects during this period.

5.2 Data Collection

5.2.1 INDOT Information

The codes used in the datasets provided by INDOT are indicated in Table 5.1.

Table 5.1: Raw Contract Data Provided by INDOT

Variable Code	Meaning
CONT	Contract ID
PR	Type of Contract (Bridge, Road, Traffic…)
CNFACS	District
CNAWDAMT	(Contract Award Amount) Original Bid Amount
CNDTNTP	Notice to Proceed Date
LASTWRK	Last day of Work
FNLAMT	Final Amount
LIQ/DAM	Liquidated Damages
OCNUM	Original County Number
TOTCO	Total Change Orders Amount
CONUM	Number of Change Orders
COMPLEV	Competition Level
ENGESTIM	Engineer's Estimate
SECLOWBID	Second Low Bid
PSTIMETH	Type of Contract (Available Days or Date)
PSORIGDY	Work Day Completion
PSDTORIG	Calendar Completion Date

INDOT staff members at the Program Development Division, Special Projects Division, Systems Technology Division, were particularly helpful in providing information. The following information was made available on Paradox files easily transferable to Access format:

- Contract ID
- Project type (bridge, maintenance, etc.)
- Project location (district)

- Bid amount
- Final amount
- Dates: Notice to proceed, Acceptance date, Final day of work.
- Liquidated damages

Most of this information is also available at the following website: *http://www.in.gov/dot/div/contracts/letting/oldletting.html*, which is regularly updated. The data concerning the level of competition, the engineer's estimate, and the second low bid was also obtained from this website. The following information on change orders was made available in Access format:

- Description of each change order
- Reason code
- Amount of change orders in dollars
- Expected final date

The following information was provided in Excel files that were exported from BAM files:

- Project location (counties, in order to introduce the weather data into the dataset)
- Amount of change orders in dollars
- Vendor's reference
- Description of the location

A portion of the data could not be used because of a lack of explanation of the codes used in the dataset supplied by INDOT. In some cases, many columns were empty.

Figure 5.1 indicates the geographical location of the various INDOT districts in Indiana. The present study takes into account data from these six districts: La Porte, Fort Wayne, Crawfordsville, Greenfield, Seymour, and Vincennes. The Toll Road district is not represented because no contract data was provided on this district for this study.

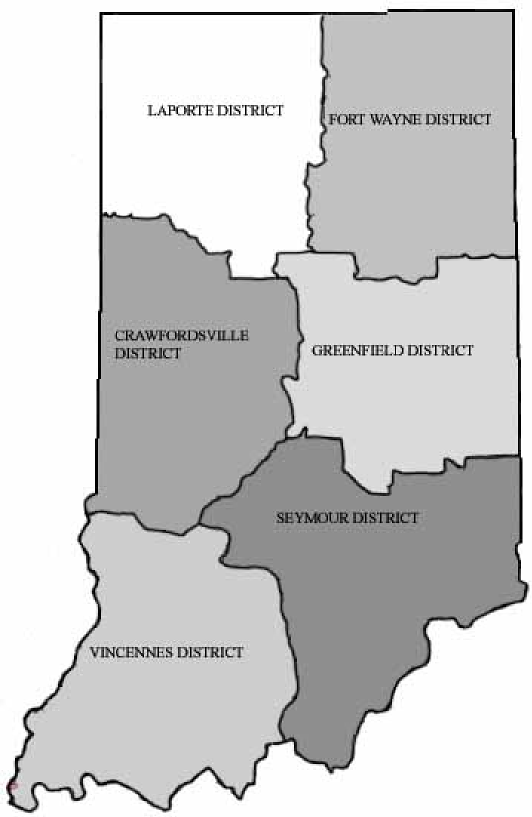

Figure 5.1: Highway Administrative Districts in Indiana

Data regarding change order reasons were not incorporated into the main dataset because they had to be organized differently. The available data provided for each contract a description of each change order: contract number, unit price, quantity, and reason for the change order (code). The final cost of the change order (obtained by multiplying the quantity by the unit price) and the reason for the change order are the most important pieces of information. For this database, six major datasets were created for each project type (bridge, maintenance, etc) and seven different descriptions were done in order to compare the different categories of work in terms of responsibility for change orders. For the analysis, the number of change orders and the amounts of the change orders for a given contract were incorporated in the main dataset.

5.2.2 Weather Data

The weather data were available on the web site: *http://shadow.agry.purdue.edu/sc.index.html*. The county-specific data covered the period between January 1, 1995 and November 1, 2002. The following data were collected:

- Maximum temperature
- Minimum temperature
- Amount of rainfall in inches
- Amount of snowfall in inches only between November and March
- Amount of snow on the ground in inches

5.3 Database Development

5.3.1 Refinement of the Dataset

Contracts with incomplete information because of errors or missing data were deleted from the modeling dataset. Consequently, the dataset used for the three types of models (cost overruns, time delays, and change orders) were slightly different. Moreover, there were a few potentially influential factors (independent variables) for which available data did not cover the entire dataset. As such, it was found prudent to develop two sets of models: one with the entire dataset but with few variables, and the another with a reduced dataset but with many variables. Also, a few outliers were excluded form the modeling dataset,

5.3.2 Weather Database

The present study placed more emphasis on the number of inclement weather days compared to the actual amount of daily precipitation. Therefore, for the duration of each contract, the number of days (with rain, snow, or cold days) was counted. It considered that snow and rain not only preclude a day of work, but also cause the entire process of construction to slow down. The data collection was subsequently simplified In the dataset, weather conditions are presented as the number of days with the following attributes:

- cold temperatures. Cold days were defined with maximum temperature under zero degree Celsius, i.e., 32 degrees Fahrenheit
- rain precipitation
- snow precipitation
- snow on the ground

Information from Figure 5.2 was used in inputting missing weather data by utilizing data from the closest county that had weather data (Appendix D). For a few counties with missing data, the nearest county that had data were used to impute data. A complete dataset of weather conditions for each county was thus established drawn. In order to incorporate the information into the database, the software Microsoft Access was used with Microsoft Visual Studio.NET to develop a program with Visual Basic that counts the number of days in each category given by the county and the beginning and final date of the project. The proportion of inclement days was calculated on the basis of the actual number of working days.

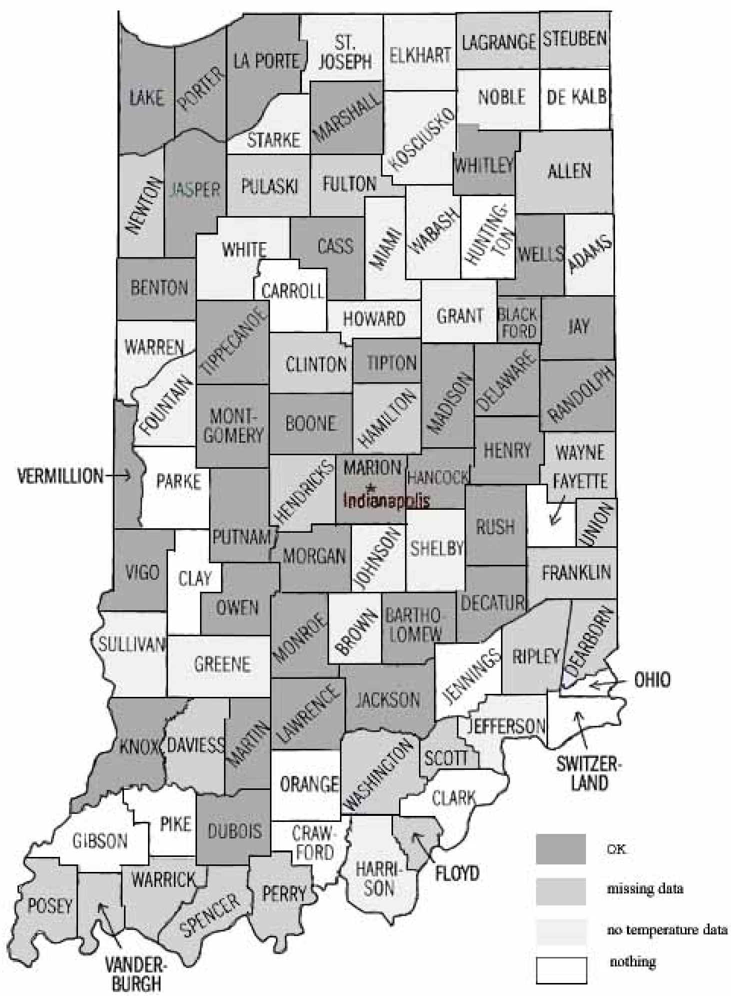

Figure 5.2: Weather Data Availability by County

5.3.3 Construction of the Database

Data items in the database are listed in Table 5.2 and discussed below:

COSOVER: Cost Overrun = Final Amount **-** Original Bid Amount.

COSRATE: Cost Overrun Rate = Cost Overrun / Original Amount.

TIMEDELAY = Time Delay = Last Day of Work – Expected Last Days of Work.

CONLENGTH: Contract Duration = Last Day of Work – Notice to Proceed Date (in days).

PDIFFIRSECBID: Difference between the First and Second Bid = (Second Low Bid – Original Bid Amount) / Original Bid Amount.

PDIFENGBID: Difference between the Engineer's Estimate and the Bid = (Engineer's Estimate – Original Bid Amount) / Original Bid Amount.

PNINCL = Proportion of Inclement Days = Number of Inclement Days/Total Project Duration in Days

Six binary variables were defined: B, M, R, RS, T and TM corresponding to the project type. Year corresponds to the year of the final day of work.

Table 5.2: Items in the Database

Variable Code	Meaning
B	Bridge Project
M	Maintenance Project
R	Road Construction Project
T	Traffic Project
RS	Resurfacing Project
TM	Traffic Maintenance Project
CRAWF	Crawfordsville District
FORTW	Fort Wayne District
GREEN	Greenfield District
LAPOR	La Porte District
SEYMO	Seymour District
VINCE	Vincennes District
PNCOLD	Proportion of Cold Days
PNRAIN	Proportion of Rainy Days
PNSNOW	Proportion of Snow Days
PNSNOWG	Proportion of Days with Snow on the Ground
PNINCL	Proportion of Inclement Days
CNAWDAMT	Contract Award Amount (Original Bid Amount)
COSOVER	Cost Overrun
COSRATE	Cost Overrun Rate
COMPLEV	Competition Level
PDIFFIRSECBID	Proportion of the Difference between the First and Second Bids
PDIFENGBID	Proportion of the Difference between the Engineer's Estimate and the Bid Amount
CONDUR	Contract Duration
LIQDAM	Liquidated Damages
TIMEDEL	Total Time Delay
CHONUM	Number of Change Orders
TOTCO	Total Change Orders Amount
YEAR	Year

As the data came from various sources, consistent sets of data was not available for all necessary items, such as the case of the reasons for change orders or year. Table 5.3 summarizes the number of observations that were found for the variables considered in statistical analysis.

Table 5.3: Number of Observations for Variable

Variable	Number of Observations
Change Order Amount	2650
Time Delay	1975
Number of Change Order	822
Level of Competition	730
Proportion of the Difference between the First and Second Bid	714
Proportion of the Difference between the Bid and the Engineer’s Estimate	674
Other data	2668

5.4 Chapter Summary

This chapter described the methods used to collect and develop the database for the statistical analysis of the cost overrun, time delay and change order data. Most of the data were obtained from the INDOT contracts division. A total of 29 data items were established.

CHAPTER 6: DESCRIPTIVE STATISTICS

6.1 Introduction

This chapter describes trends in the dependent variables used in the various models based on the data obtained from 2,668 projects. It describes time delays both in terms of liquidated damages and in time delays in days. A detailed description of the cost overrun trends classified by categories gives an explicit overview of cost overruns. The chapter also provides a detailed description of the trends in change orders.

In order to describe the dataset, two factors are defined that describe the importance of overruns (time or cost) and the number of change orders:

- When a large percentage of contracts have overruns, it indicates the *extent* (or *frequency*) of the problem.
- When the total overrun is high (in percentage), it indicates the *severity* of the problem.

In any given year, the problem can be extensive but not severe, severe but not extensive, both extensive and severe, or neither extensive nor severe.

All dollar amounts are in current dollars, and no inflation factor was considered because the duration of most projects were small, and the analysis period is rather small.

6.2 General Description

6.2.1 Distribution of Contracts by District

Table 6.1 presents the distribution of the studied projects among districts. There are between 390 and 589 contracts in each category. There are enough contracts in each district for the description statistics and to justify regression analysis. The district with the most contracts was Greenfield, probably because the city of Indianapolis is included in this district. Moreover, there is a correlation between the number of contracts and the population; the most populated district is the one where more contracts were completed. It is interesting to note, however, that there was no relationship between the number of projects in a district and the total road mileage in the district.

Table 6.1: Distribution of Contracts by District

Districts	Number of Projects	Estimated Population in July 2002	Approximate Total Mileage
Crawfordsville	391	646,339	1,936
Fort Wayne	422	1,029,265	1,822
Greenfield	589	1,754,456	1,677
LaPorte	438	1,249,087	2,065
Seymour	438	892,532	1,753
Vincennes	390	587,389	1,947

Source: US. Census Bureau and INDOT

6.2.2 Distribution of Contracts by Project Type

In Table 6.2, it can be noticed that there is a fairly even distribution of contracts across the various project types, each with a large number of observations, with the exception of the category "Traffic Maintenance." As the number of projects in this category was 36, only 27 (75%) could be used for modeling leaving only 9 (25%) for validation. Therefore, this category was not considered for modeling purpose, although descriptive statistics for traffic maintenance were computed.

Table 6.2: Distribution of Contracts by Project Type

Project Type	Number of Contracts
Bridge	621
Road Construction	599
Road Resurfacing	419
Maintenance	607
Traffic	386
Traffic Maintenance	36

6.3 Time Overruns

6.3.1 Analysis of Liquidated Damages

From the 2,668 contracts, 187 were determined to have liquidated damages. Projects that incurred liquidated damages are associated with time overrun, and specific information on the causes of the time delays was sought. Figure 6.1 shows the trend in liquidated damages due to time delays during the analysis period. The year 1997 experienced a relatively high amount of liquidated damages. The causes for this anomaly need to be investigated. Since 1998, these damages have leveled to below $100,000. This level is surprisingly low considering the total number of contracts involved. The same trend was observed for the number of contracts with liquidated damages.

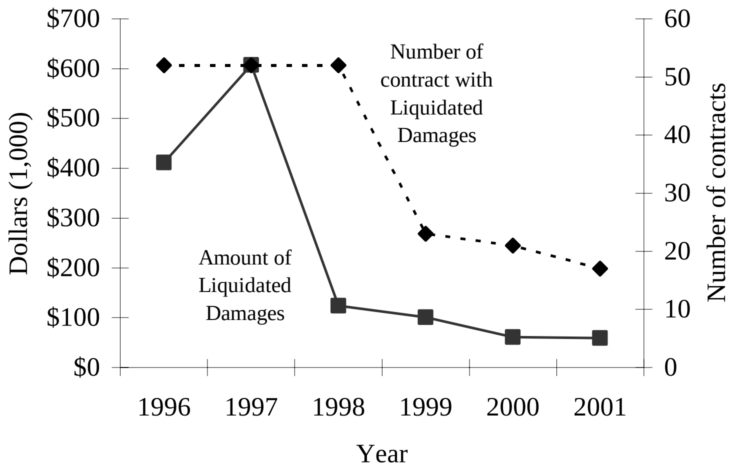

Figure 6.1: Annual Frequency of Contracts with Liquidated Damages and Amount of Liquidated Damages, 1996 - 2001.

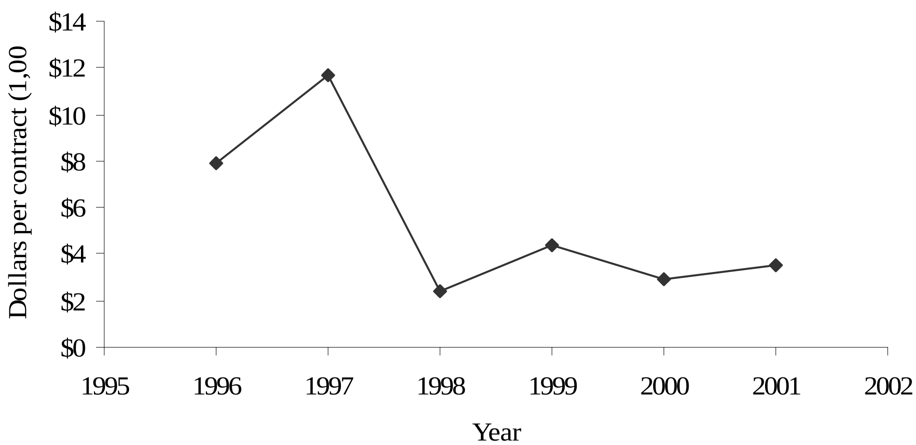

Figure 6.2: Annual Average Liquidated Damage Amounts per Contract, 1996 - 2001.

Figure 6.2 presents the average liquidated damage amounts per contract per year. The year 1997 had the highest level of per contract liquidated damages due to time delay. The problem of liquidated damaged was both extensive and severe in 1997.

6.3.2 Analysis of Time Delays

The analysis of the time delay included only 1,987 contracts of the database because time delay information was not provided for the remaining contracts. Time delay is defined as the difference between the estimated final date and the actual one. It is worth noting that most of these delayed days were actually time extensions that were authorized or requested by INDOT.

Figure 6.3 presents the distribution of time delay in increments of 10 days. The mean time delay is about 120 days and the standard deviation is approximately 153 days. It can be noticed that the distribution is not symmetric. Indeed, there were few projects that were completed before the estimated final date, and for such projects, the time delay was negative.

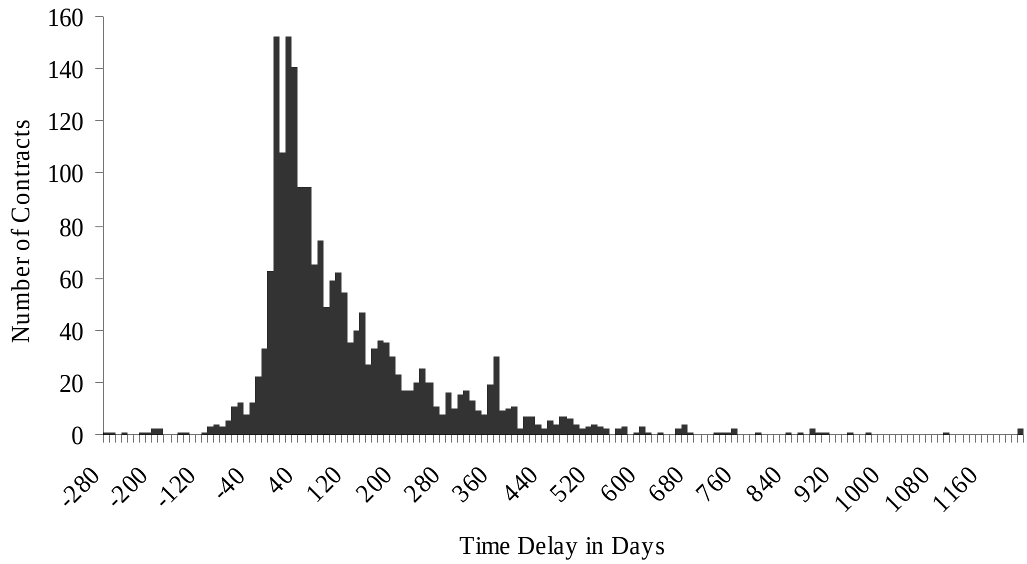

Figure 6.3: Distribution of Time Delays

Table 6.3 presents a summary of average contracts delays by district, project type and project size during the time period, 1996-2001. The values given for the traffic maintenance projects were not taken into account because of the small number of contracts in that category (only three).

Table 6.3: Average Contract Time Delays (in Days)

Project Type	Bid Amount Category	District: Crawfordsville	Fort Wayne	Greenfield	La Porte	Seymour	Vincennes	Any District
Bridge	$0-100,000	132	28	70	57	63	21	73
	$100,000-500,000	92	90	54	73	86	61	72
	$500,000-1,000,000	95	170	91	111	137	90	110
	>$1,000,000	164	124	100	129	175	186	141
	Any Bid Amount	124	104	74	89	108	75	94
Maintenance	$0-100,000	80	112	75	143	163	150	122
	$100,000-500,000	89	90	98	88	123	114	101
	$500,000-1,000,000	184	197	162	174	168	158	174
	>$1,000,000	346	214	187	166	230	266	225
	Total	174	140	135	135	170	166	153
Road Construction	$0-100,000	32	123	131	122	77	103	106
	$100,000-500,000	53	91	68	102	68	93	80
	$500,000-1,000,000	101	103	104	100	100	122	104
	>$1,000,000	119	106	118	196	225	226	172
	Any Bid Amount	78	104	102	129	119	152	114
Resurfacing	$0-100,000	144	40	66	14	74	6	64
	$100,000-500,000	63	62	83	58	77	103	74
	$500,000-1,000,000	159	120	65	104	171	214	132
	>$1,000,000	133	62	253	165	164	120	144
	Any Bid Amount	114	67	110	77	121	110	101
Traffic	$0-100,000	79	99	88	126	152	35	101
	$100,000-500,000	58	98	42	39	97	86	71
	$500,000-1,000,000	84	135	78	69	299	117	118
	>$1,000,000	170	212	193	222	146	185	188
	Any Bid Amount	84	131	90	103	138	107	110
Traffic Maintenance	$0-100,000			89				89
	$100,000-500,000		53					53
	$500,000-1,000,000							
	>$1,000,000		237					237
	Any Bid Amount		145	89				126
Any Project Type	$0-100,000	107	88	88	86	104	76	92
	$100,000-500,000	74	86	67	74	91	91	80
	$500,000-1,000,000	133	137	100	114	161	136	127
	>$1,000,000	195	140	164	170	189	206	177
	Any Bid Amount	119	109	101	107	132	125	115

If the difference between districts in terms of time delay is considered, Seymour experienced most time delays, with an average of 132 days, while Greenfield experienced the least time delay, with 101 days. With regard to project type, maintenance projects experienced the most time delays (an average of 153 days per contract), while bridge and resurfacing projects had the least time delay (averages of 94 and 101 days per contract, respectively,). Also, more expensive projects, on average, generally incurred greater magnitudes of time delay, the only exception being the higher level of delay observed for $0-100,000 contracts compared to 100,000-500,000 contracts. A complete set of figures that illustrate these results are available in Appendix E, while a few selected figures are presented as part of the present chapter. The values given in the following graphs should be interpreted with caution, especially for the years 2000 and 2001. Out of 1,987 contracts, there was information for only 71 contracts in the year 2000 and 13 in the year 2001. For each of the other years, information was available only for 414 – 533 contracts.

Figure 6.5 presents the trends in average time delay per contract, and shows relatively low severity of average time delay until after the year 1999. It is important to note that the high severity of time delays in 2000 and 2001 were based on a small number of observations therefore the relatively high severity of time delays observed for contracts in that period may not be representative of all contracts in those years.

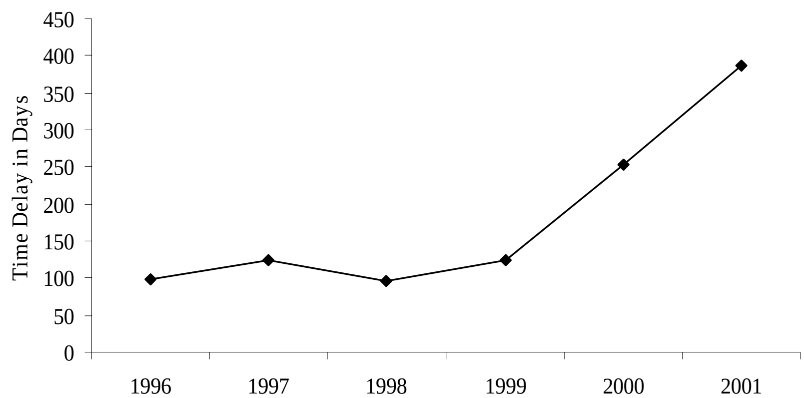

Figure 6.5: Variation of Average Time Delay, 1996 - 2001

Figure 6.6 presents average time delays per contract, by project type. Maintenance projects experienced the most severe time delays. In 1999, time delay for maintenance projects had a sharp increase to approximately 3,244 days. The zero delay value for traffic projects in 2001 was because there was only one project in that category during that year, that project did not experience any time delay.

Figure 6.7 presents trends in the average time delay per contract, for each district, between 1996 and 2001. The figure shows that concerning the average time delay, there are only small disparities among districts between 1996 and 1998. It can be noticed that in 1999, Crawfordsville District experienced more time delays than the other districts, with about 220 days on average per contact. For years 2000 and 2001, it is difficult to reach any conclusions due to lack of adequate data for those years.

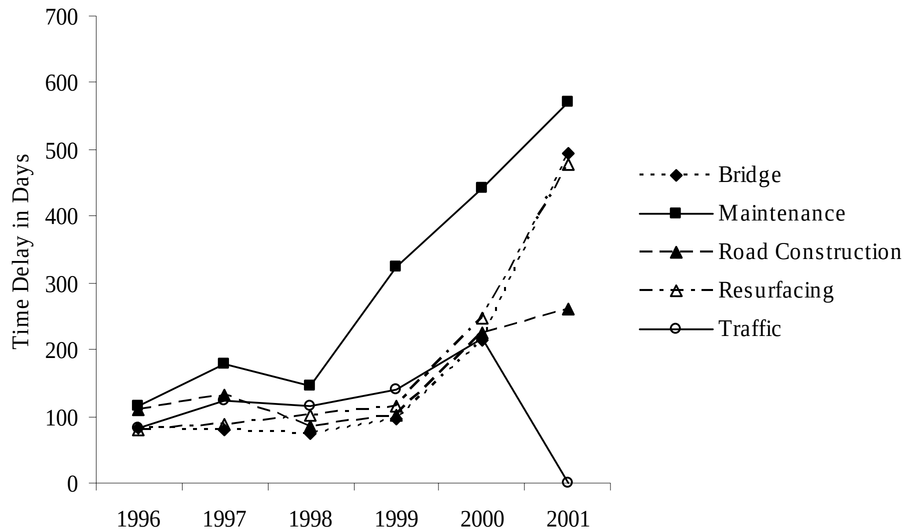

Figure 6.6: Variation of Average Time Delay by Project Type, 1996 - 2001

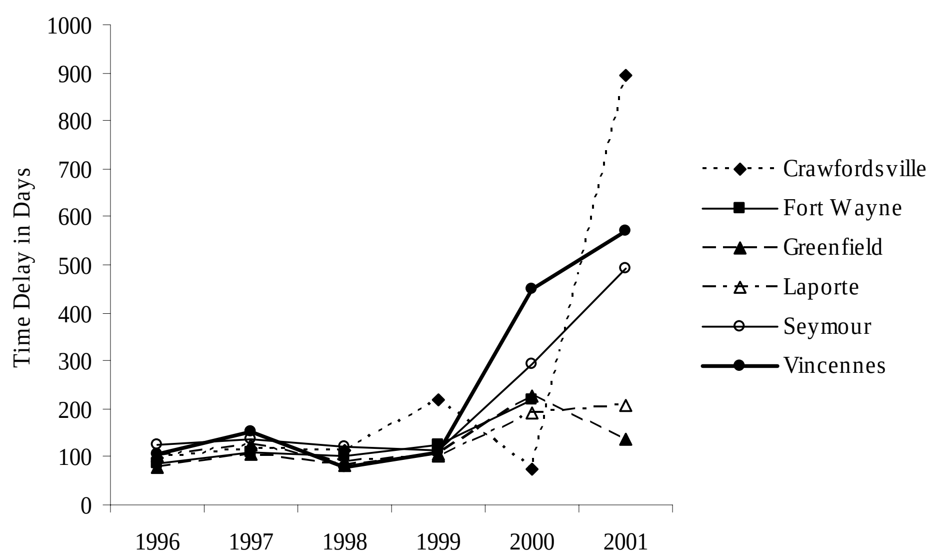

Figure 6.7: Trends in Average Time Delay per Contract by District, 1996 – 2001

6.4 Cost Overruns and Underruns

Figure 6.8 represents the distribution of the cost overrun rates for the 2,668 projects. It shows that most contracts either had a small percentage of cost under or overruns. However, there were several contracts with large overruns. Most contracts (1,889 contracts, i.e., 70.8% of the total number of contracts) had a cost deviation between -10% and +10%.

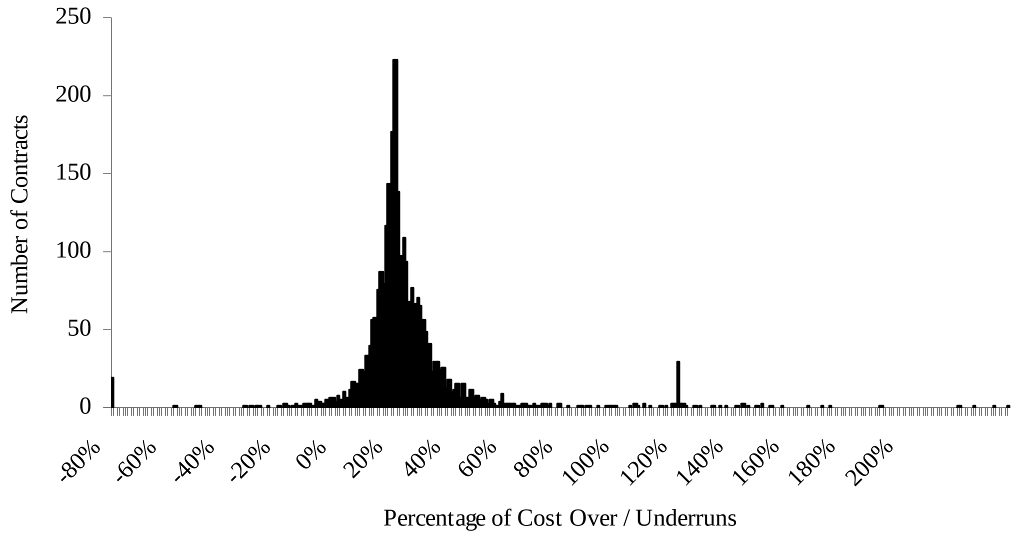

Figure 6.8: Distribution of Contracts with Cost Overruns or Underruns

There were 18 contracts in the database for which no final amount was provided. Therefore, cost under and overrun data were available for 2,650 projects. As seen in Figure 6.8, the data generally appears to be normally distributed, and a chi-squared test was carried out to ascertain the normality assumption for this dataset. The standard value for 95% confidence interval and degree of freedom of 40 is 55.76. The basic statistics of the cost overrun rate are shown in Table 6.4.

Table 6.4: Basic Statistics of the Cost Overrun Rate

Statistics	Value
Valid Observations	2,589
Mean	3.02%
Standard Deviation	14.91%
Range	199.39%
Minimum	-99.54%
Maximum	99.85%

Two tests were done using log-normal distributions. The value for the log-normal was very large (55.76) indicating that the data did not follow a log-normal distribution. The value for the normal distribution was computed as 2.52. As this value was lower than 55.76, the data could be assumed to follow a normal distribution. Figure 6.9 presents the fitted distribution along with the observed data.

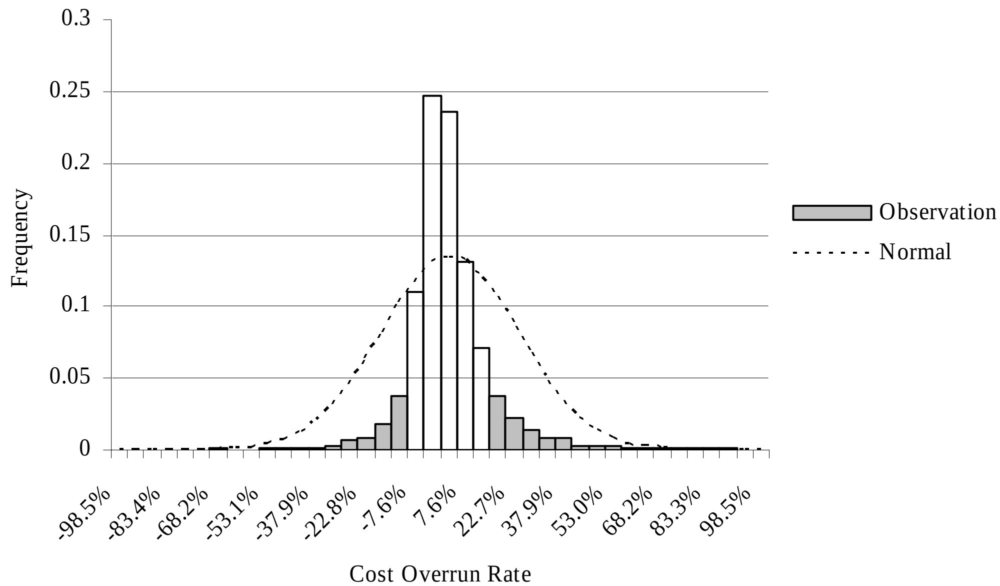

Figure 6.9: Frequency Distribution of Cost Overrun Rates

It is important to note that there were more cost overruns than cost underruns in term of frequency (positive mean) and that the dispersion around this mean of 3.02% was quite large (14.91%). During the analysis period, 1,947 contracts experienced cost overruns and 1,166 contracts had cost underruns. Only 435 contract final costs were the same as the original bid amount. Since 1997, the total amount of cost overruns has decreased. In 2001, the total cost of overruns was $17,028,137. Figures 6.10 and 6.11 show the extensiveness and severity of cost overruns in Indiana between 1996 and 2001.

In a situation similar to that of liquidated damages, cost overruns were both extensive and severe in 1997. Moreover, it can be noticed that after 1997, the average cost overruns per cost overrun contract per year decreased to a level close to that of 1996.

A detailed statistical description of the average cost overrun amount was carried out for each project type and bid amount category, and is presented in the following section. Bid amounts were categorized into four groups as shown in Table 6.5.

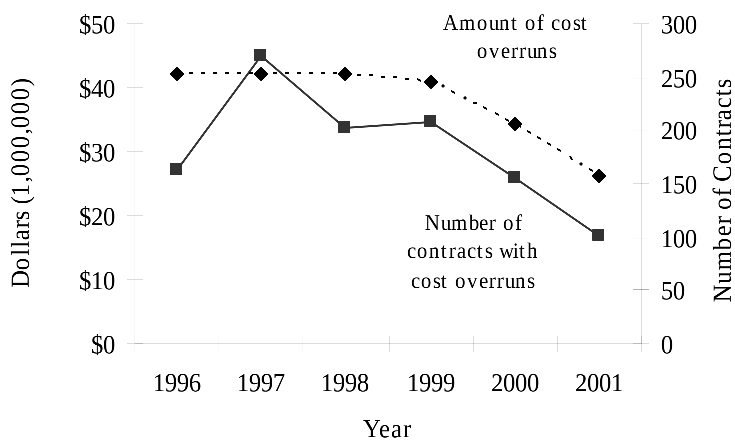

Figure 6.9: Annual Frequency and Amounts of Cost Overruns, 1996 – 2001

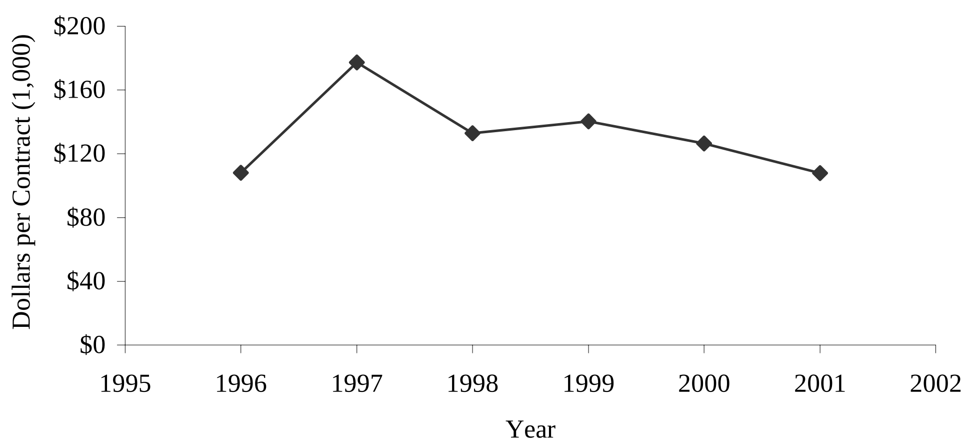

Figure 6.10: Average Cost Overrun per Contract, per Year

Table 6.5: Bid Amount Categories

Bid Amount Category	More than	and less than	Number of Contracts
Low Bid Amount	$0	$100,000	551
Medium Bid Amount	$100,000	$500,000	1,054
High Bid Amount	$500,000	$1,000,000	436
Very High Bid Amount	$1,000,000		627

Table 6.6 presents the average cost overrun amounts for a given project characterized by district, project type, and bid amount category. It is seen that the average amount of cost overrun for a contract was $43,661. Also, Fort Wayne had the highest average amount among all districts, and the resurfacing project experienced the highest average cost overrun amount among all project types.

Table 6.6: Average Cost Overrun Amounts

Project	Category of Bid Amount in Thousand	District						
		Crawford-sville	Fort Wayne	Greenfield	LaPorte	Seymour	Vincennes	Average for any District
Bridge	$0-100	15,956	163	2,364	-2,096	7,616	-920	5,046
	$100-500	5,544	9,637	-7,518	81,658	15,570	11,050	18,000
	$500-1,000	21,559	48,270	12,799	24,643	-22,278	10,282	15,531
	>$1,000	146,334	180,450	182,902	59,450	130,664	266,952	146,926
	Total	47,510	51,708	35,296	48,172	34,407	39,850	41,778
Maintenance	$0-100	38,923	8,426	5,037	14,190	17,795	5,394	13,577
	$100-500	-994	13,841	9,410	-10,806	9,917	14,964	6,221
	$500-1,000	8,003	18,871	-2,857	67,817	9,073	-19,525	12,971
	>$1,000	310,710	373,885	129,171	75,046	186,532	-16,813	162,746
	Total	80,476	90,409	45,861	30,859	58,661	1,113	49,851
Road Construction	$0-100	9,412	10,521	9,882	8,591	5,621	3,543	8,416
	$100-500	12,204	8,455	7,885	12,989	6,297	3,125	8,356
	$500-1,000	-12,419	-6,087	73,198	-20,026	-43,239	16,452	5,861
	>$1,000	-178,643	326,902	-21,063	135,216	-27,959	145,561	58,179
	Total	-38,976	54,655	13,736	27,177	-9,709	46,915	18,964
Resurfacing	$0-100	5,747	6,761	-75	20,621	7,213	-749	6,240
	$100-500	9,114	-3,392	5,304	-2,902	8,246	6,054	3,949
	$500-1,000	30,525	-8,691	6,913	70,938	126,080	60,511	40,233
	>$1,000	405,952	147,459	501,329	111,212	263,886	152,209	264,214
	Total	66,724	43,883	126,847	38,367	120,218	50,699	78,931
Traffic	$0-100	-1,664	4,787	9,194	2,506	13,192	-4,022	4,753
	$100-500	9,525	43,474	7,061	-2,373	6,457	-840	9,886
	$500-1,000	64,399	62,883	66,793	34,618	148,206	-12,992	59,836
	>$1,000	33,489	468,285	-195,361	53,727	78,621	-13,170	93,705
	Total	20,140	140,525	-26,399	16,367	43,492	-5,127	33,678
Traffic Maintenance	$0-100	-44	-6,836	116,668	-1,618	-303		27,456
	$100-500	-4,300	42,222	-25,410	-41,487	16,240		5,024
	$500-1,000	147,464			46,743	-93,638		36,828
	>$1,000	38,483	269,469		515,589	807,217		380,045
	Total	36,312	86,769	45,629	57,736	111,177		69,924
Total	$0-100	13,546	6,468	8,243	6,453	10,200	1,715	8,117
	$100-500	6,064	14,185	2,743	19,923	9,821	7,143	9,688
	$500-1,000	22,713	12,912	28,160	27,581	24,380	7,875	21,781
	>$1,000	143,626	297,685	125,660	88,716	146,400	94,023	147,922
	Total	39,584	75,666	37,365	34,057	50,808	25,560	43,661

If the distribution of cost overrun amounts is examined by project type and by bid amount category, it is seen that the average amount of cost overrun is the highest for an original bid amount greater than $1 million. It can be noticed that for bid amounts less than $1 million, the average cost overrun is of the same magnitude and is much lower than for those bid amounts greater than $1 million. For road construction, traffic, and resurfacing, the districts experienced very different types of cost under and overruns. If cost overrun amounts were examined by district and bid amount category, it is seen (Table 6.3) that for every district there are more cost overruns for expensive (over $1 million) projects. Graphical illustrations of these results are presented in Appendix E.

Figure 6.5 shows the variation of the average cost overrun amount by project and by district. For bridge projects, no district consistently had the highest average cost overrun amount over the analysis period: Fort Wayne was highest in 1996, LaPorte in 1997, Crawfordsville in 1998, Vincennes in 1999, Greenfield in 2000, and Seymour in 2001. In 2000, highest average cost overruns for road construction, resurfacing, and traffic projects occurred in Crawfordsville, Fort Wayne, and Greenfield Districts, respectively.

Figure 6.6 shows the distribution of cost overruns by project type. The shape was the same for each type. Moreover, the trend at the extremes was the same although the number of contracts with low cost under or overruns differed by project type. Bridge projects had the highest curve, then maintenance, road construction, resurfacing, and traffic. The traffic maintenance curve was very low because of the very small amount of contracts in this category.

Figure 6.11 presents cost overrun rates by dividing all of the data points Figure 6.6 by the total number of contracts in each project type category. It appears that the five major project types exhibited similar distributions.

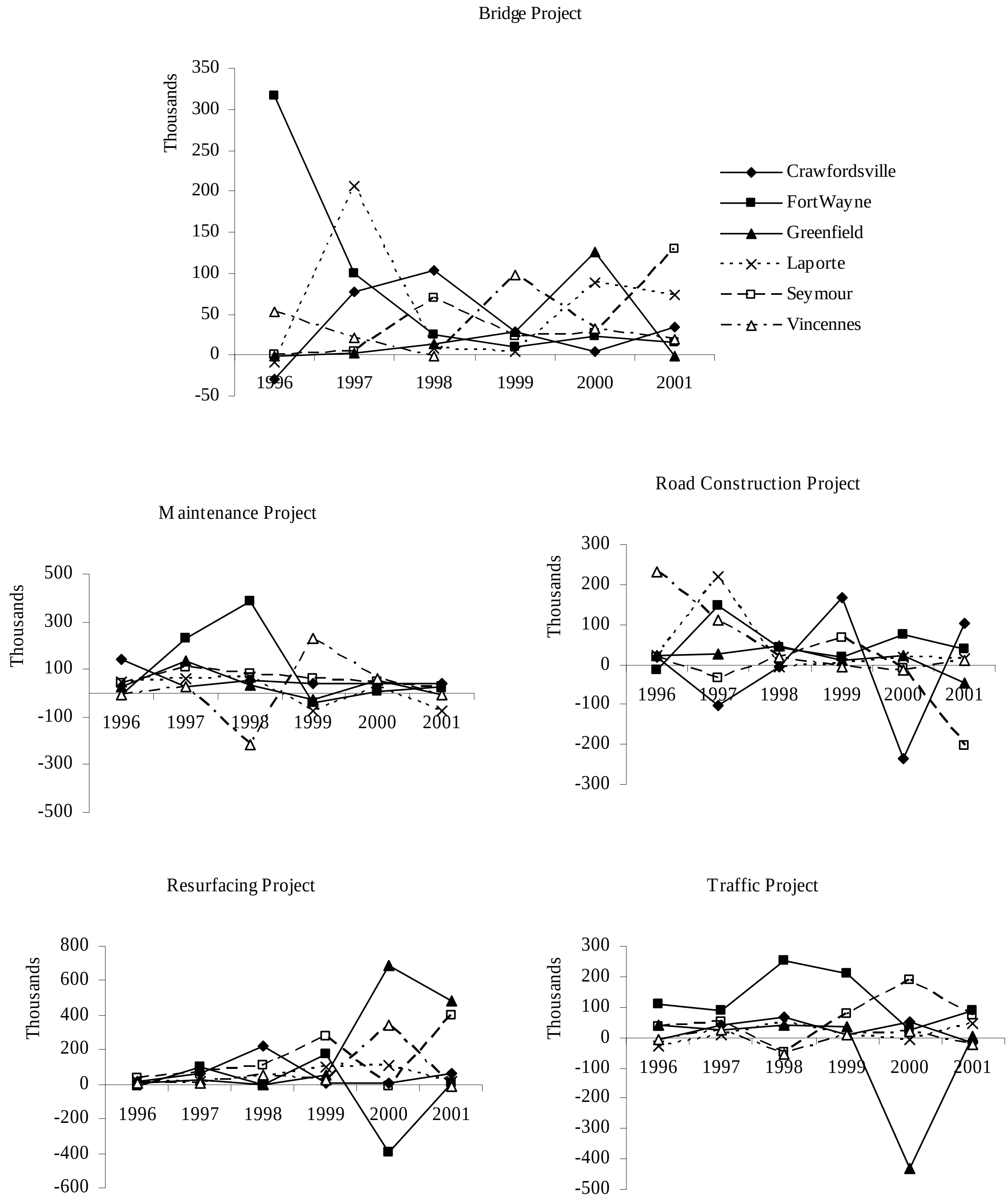

Figure 6.11: Variation of the Average Cost Overrun Amount by Project Type and by District

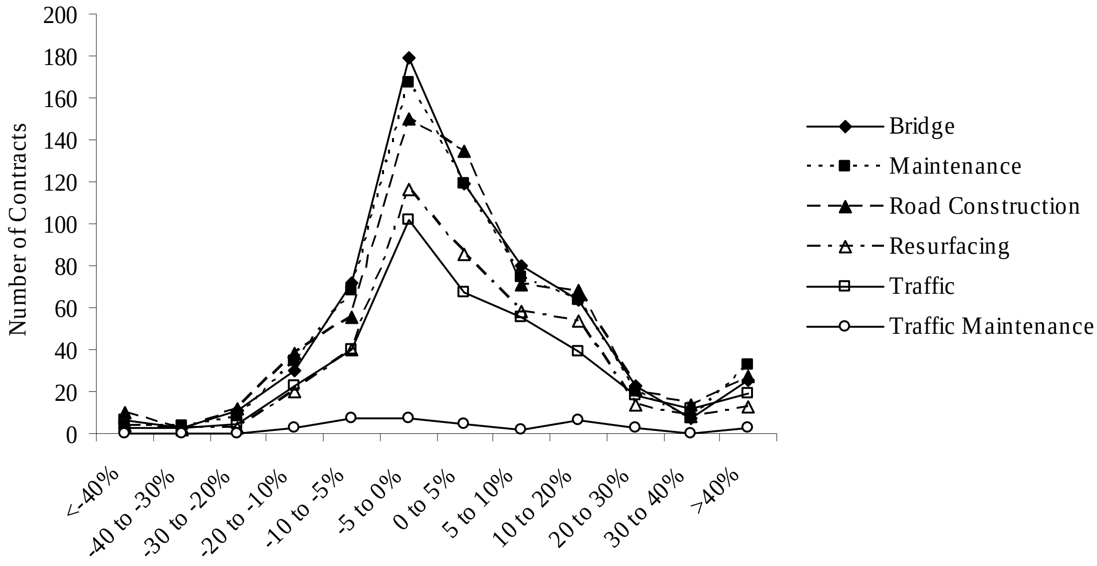

Figure 6.12: Frequency of Cost Overrun Rates by Project Type

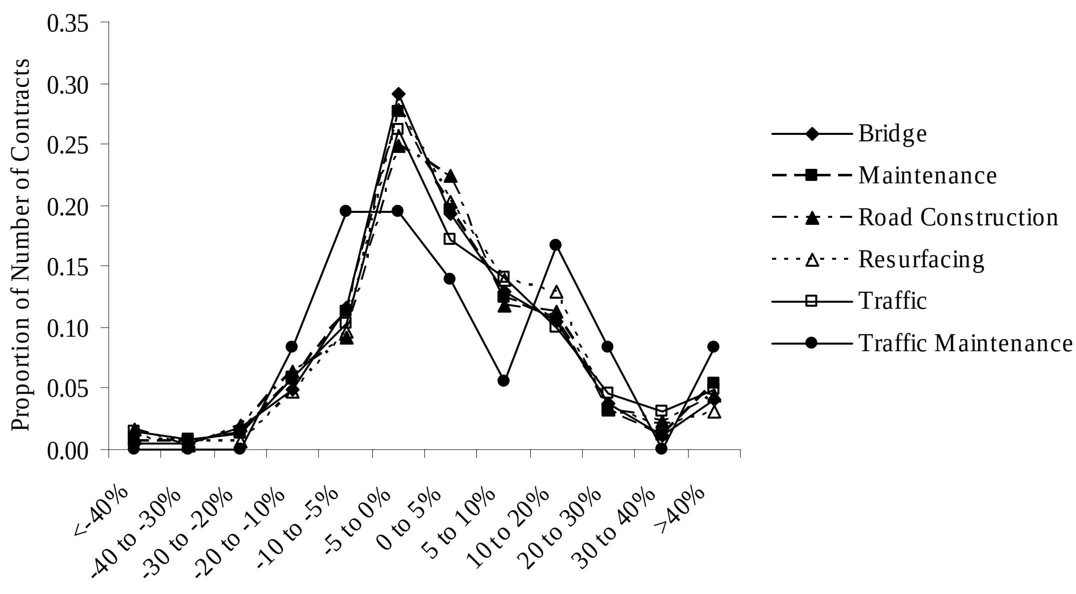

Figure 6.13: Relative Frequency of Cost Overrun Rates by Project Type

6.4.1 Cost Underruns

Figure 6.14 shows the number of cost underrun contracts in various percentage ranges. For example, the majority of the contracts (645 out of the 1,166 contracts) had cost underruns in the 5% range. However, Figure 6.9 shows that the cost underruns ranges of -10% to -5% and -20% to -10% were dominant in terms of dollars associated with each cost underrun rate category. These two figures show that the category of underrun “<-40%,” for instance, was not extensive but rather was severe. This concerned only ten contracts but represented over $6,300,000. These underrun amounts were taken into account in the bid amount although they were actually not spent.

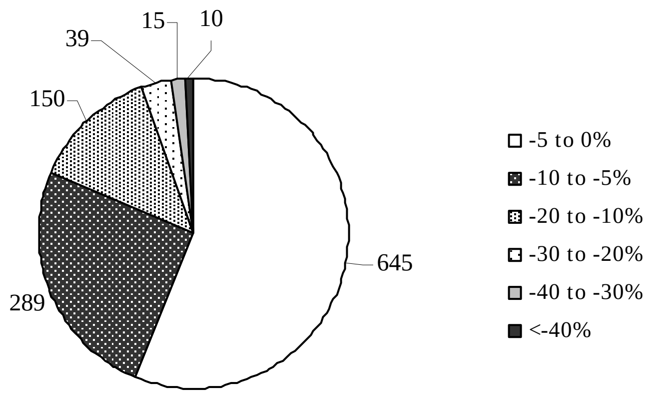

Figure 6.14: Number of Contracts by Cost Underrun Category

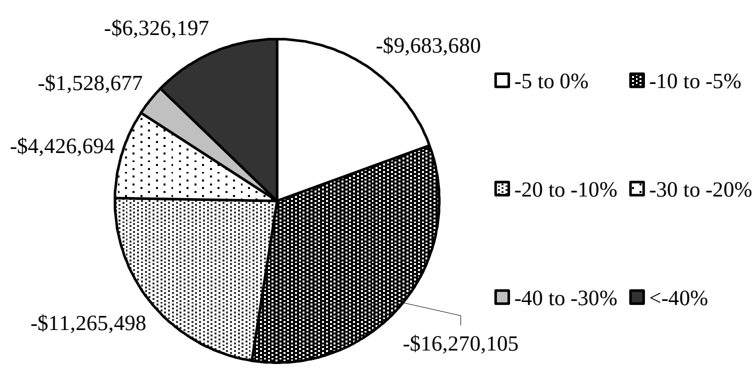

Figure 6.15: Value of Underrun Amounts by Underrun Category

6.4.2 Cost Overruns

Figure 6.16 shows the percentage of cost overrun contracts in various ranges. The highest number of overruns was in the 0-5% range. The next highest was the 5-10% range, and the third highest was the 10-20% range. Approximately one in every four contracts had cost overruns within the range of 5-20%. Figure 6.17 shows that approximately half of the expenditure incurred on cost overruns was in the 5-20% range.

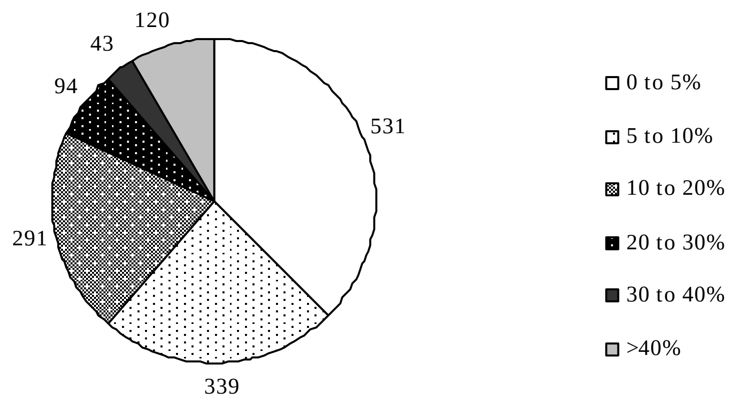

Figure 6.16: Number of Contracts by Cost Overrun Category

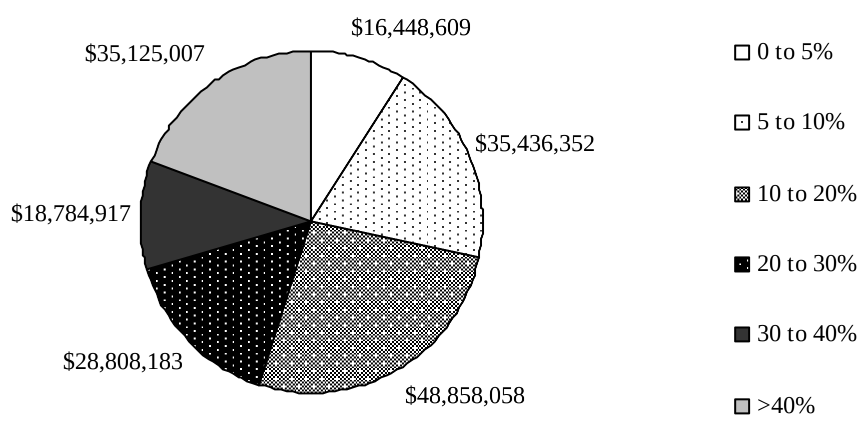

Figure 6.17: Cost Overrun Amounts by Overrun Category

In the case of cost overruns, it is important to consider the severity and the extensiveness of the trend, particularly in the categories “0 to 5%” and “30 to 40%.” The first category represented 531 projects with less than $16,500,000, and the second category had only 43 projects and represented more than $18,700,000 of cost overruns. Figure 6.18 provides an alternative representation of the categorization of cost over/under runs in Indiana within the analysis period. As the figure shows, the money saved due to cost underruns in that period did not compensate for that incurred due to cost overruns.

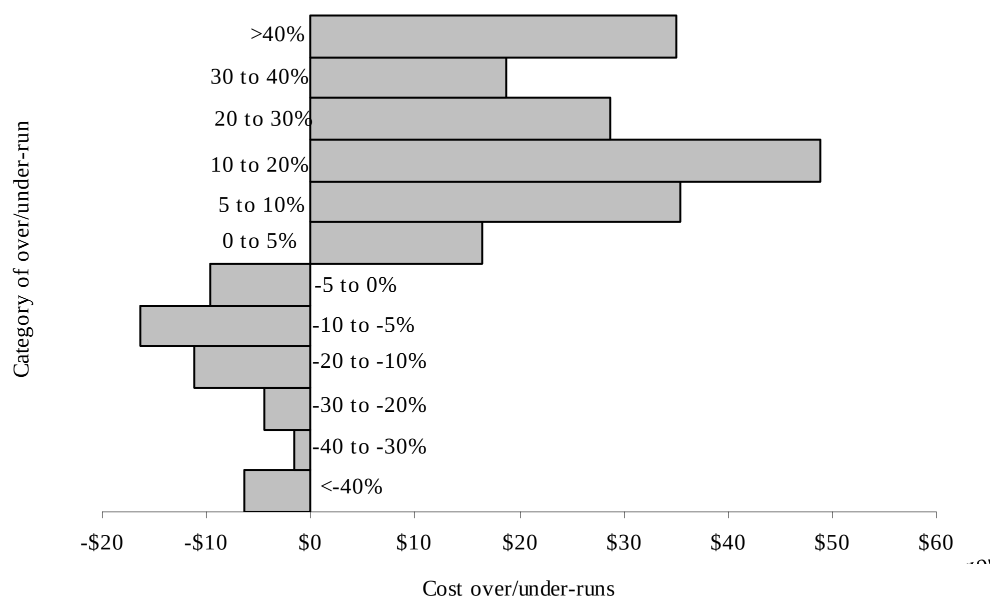

Figure 6.18: Cost Over/Underrun Amount by Over/Underrun Category

6.5 Change Orders

6.5.1 General Description of the Change Orders

A total of 2,668 contracts was available to study daily change orders. Table 6.7 shows that an average contract had between four and five daily change orders. Figure 6.19 shows the distribution of the number of change orders. Most contracts had fewer than nine change orders.

Table 6.7: Descriptive Statistics of Change Order Frequency.

Statistics	Number of contracts
Number of observations	2,668
Mean	5
Standard Deviation	6
Variance	34
Range	55
Minimum	0
Maximum	55

Figure 6.19: Distribution of the Number of Daily Change Orders per Contract

In a bid to investigate whether the distribution of the number of daily change orders per contract followed any standard distribution, three tests were carried out: normal, log normal, and Poisson distributions. Figure 6.20 shows plots of such distributions with their respective means and standard deviations. Good fits were obtained for the normal and lognormal distributions (0.72 and

2.45, respectively) compared to the maximum expected (74.47 with a 95% confidence). The Poisson distribution did not give good results although it seems to fairly fit the observed distribution.

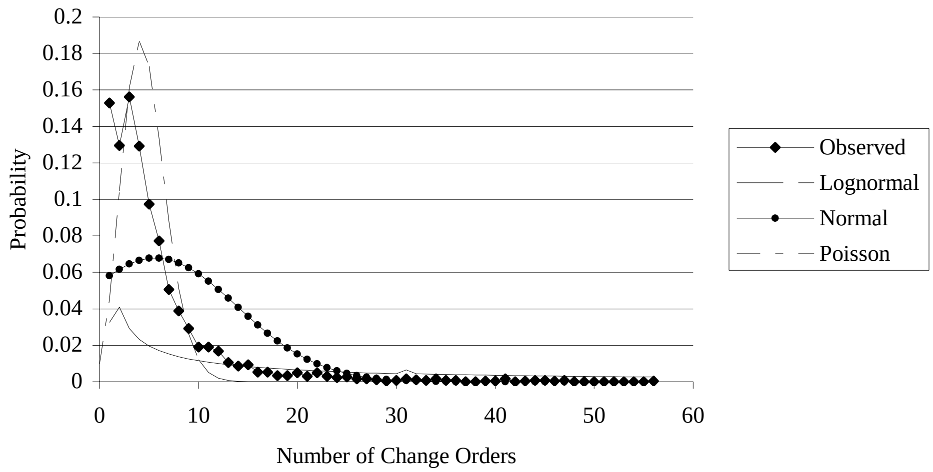

Figure 6.20: Plot of the Observed Values, Normal, and Log Normal Distributions for the Number of Daily Change Orders

Table 6.8 describes the total amount of change orders (in dollars) for each contract. It shows that out of 2,668 contracts, 413 contracts did not require change orders and for 340 projects, the final contract amount after the change orders was reduced. However, Table 6.2 also shows that the main part of the change orders increases the project cost.

Table 6.8: Distribution of Daily Change Order Frequency

Total Amount of Change Orders		Number of contracts
More than	Less than	
	0	340
0	0	413
0	10,000	466
10,000	20,000	205
20,000	30,000	149
30,000	40,000	118
40,000	50,000	63
50,000	100,000	276
100,000	500,000	470
500,000	1,000,000	94
1,000,000		84

6.5.2 Reasons for Change Orders

The change orders described in the previous section contained various small-amount change orders issued daily for various reasons. Detailed information relating to such change orders could not be obtained. As such available data pertain to change orders of only 822 contracts between 1996 and 1999. This involved a total of 17,992 change orders. Figure 6.21 provides the distribution of the average number of change orders per contract, for these contracts.

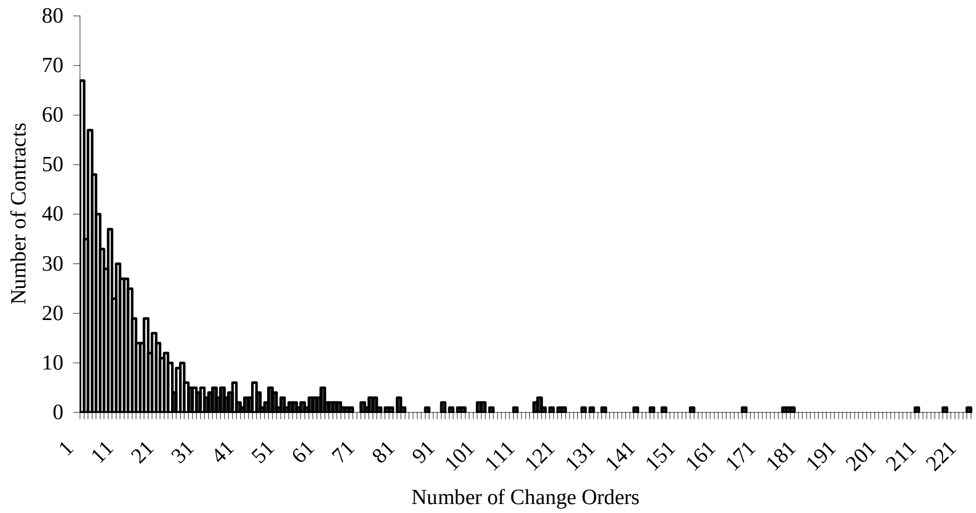

Figure 6.21: Distribution of the Number of Contract Change Orders

Table 6.9 provides a general overview of the change order reasons. The "amount" column shows the amount spent for the 822 contracts for a particular change order reason. The next column gives the number of change orders corresponding to the change order reason, and the "rate" column gives the importance in terms of dollars of each change order reason. The "no recorded reason" category represents approximately $29 million for 6,024 change orders and 224 contracts. The "errors and omissions" category (100) represents approximately $12 million for 3,937 change orders and 476 contracts. The "constructability" category (200) represents approximately $10 million for 3,227 change orders and 410 contracts. The "scope changes" category (300) represents approximately $7 million for 2,093 change orders and 278 contracts. The "changed field conditions" category (400) represents approximately $2 million for 1,813 change orders and 324 contracts. The "failed materials" category (500) represents approximately -$1 million for 392 change orders and 251 contracts. The "incentive/disincentive" category (600) represents $4 million for 116 change orders and 22 contracts. The "standard specifications update or changes" category (700) represents $700,000 for 390 change orders and 94 contracts. The total number of 2,079 contracts is much higher than the original 822 contracts because there are many different types of reason category in a same contract.

Table 6.9: Reasons for Change Orders

Reason Code	Reason for Change Order	Amount	Number	Rate
000	No Recorded Reason	$29,288,445.35	6,024	45.28%
101	ERRORS & OMISSIONS, Contract Related	$1,100,928.48	378	1.70%
102	ERRORS & OMISSIONS, Design Related	$9,416,964.21	1,743	14.56%
103	ERRORS & OMISSIONS, Environmental	$70,567.28	42	0.11%
104	ERRORS & OMISSIONS, Materials Related	$5,574.99	97	0.01%
105	ERRORS & OMISSIONS, Permits	$2,727.50	4	0.00%
106	ERRORS & OMISSIONS, Quantity Related	$1,142,288.56	1,358	1.77%
107	ERRORS & OMISSIONS, R/W Related	$15,450.89	14	0.02%
108	ERRORS & OMISSIONS, Soils Related	-$41,469.41	14	-0.06%
109	ERRORS & OMISSIONS, Staging Related	-$110,666.64	14	-0.17%
110	ERRORS & OMISSIONS, Traffic Control	$723,059.88	260	1.12%
111	ERRORS & OMISSIONS, Utilities Related	$50,060.88	13	0.08%
201	CONSTRUCTABILITY, Construction Related	$3,661,076.21	1,792	5.66%
202	CONSTRUCTABILITY, Design Related	$3,396,308.49	580	5.25%
203	CONSTRUCTABILITY, Environmental Related	$192,384.05	57	0.30%
204	CONSTRUCTABILITY, Materials Related	$707,927.02	258	1.09%
205	CONSTRUCTABILITY, R/W Related	$71,599.73	19	0.11%
206	CONSTRUCTABILITY, Soils Related	$950,976.50	104	1.47%
207	CONSTRUCTABILITY, Staging Related	-$42,970.52	43	-0.07%
208	CONSTRUCTABILITY, Traffic Control	$670,108.10	300	1.04%
209	CONSTRUCTABILITY, Utilities Related	$99,648.15	74	0.15%
301	SCOPE CHANGES, FHWA	$70,921.94	6	0.11%
302	SCOPE CHANGES, Central Office	$3,110,165.84	277	4.81%
303	SCOPE CHANGES, District/Subdistrict	$1,555,618.77	290	2.41%
304	SCOPE CHANGES, District Construction Eng	$519,015.68	125	0.80%
305	SCOPE CHANGES, Area Engineer	$305,965.65	288	0.47%
306	SCOPE CHANGES, Project Engr/Supervisor	-$118,425.72	340	-0.18%
307	SCOPE CHANGES, Traffic Engineer	$396,932.79	253	0.61%
308	SCOPE CHANGES, Local Agency Request	$856,812.54	462	1.32%
309	SCOPE CHANGES, Public/Political Request	$167,123.14	52	0.26%
401	CHANGED COND, Construction Related	$1,317,316.52	1,473	2.04%
402	CHANGED COND, Environmental Related	$248,912.51	48	0.38%
403	CHANGED COND, Materials Related	$124,549.99	107	0.19%
404	CHANGED COND, R/W Related	-$26,324.45	20	-0.04%
405	CHANGED COND, Soils Related	$808,472.88	94	1.25%
406	CHANGED COND, Staging Related	-$149,318.87	35	-0.23%
407	CHANGED COND, Utilities Related	$148,829.06	36	0.23%
500	FAILED MATERIAL	-$1,062,604.73	392	-1.64%
601	INCENTIVE/DISINCENT, Contract Compl	$1,780,056.84	10	2.75%
602	INCENTIVE/DISINCENT, Contract Payments	$138,260.17	8	0.21%
603	INCENTIVE/DISINCENT, Cost Reduction	-$34,452.97	95	-0.05%
604	INCENTIVE/DISINCENT, A+B Contract	$1,700,000.00	2	2.63%
605	INCENTIVE/DISINCENT, A+B+C Contract	$700,000.00	1	1.08%
701	STANDARDS/SPECS CHANGE, Completion Time	$298,176.36	124	0.46%
702	STANDARDS/SPECS CHANGE, Contract Payment	-$32,128.47	15	-0.05%
703	STANDARDS/SPECS CHANGE, Other	$481,777.95	251	0.74%
Total	TOTAL	$64,676,643.12	17,992	

Figure 6.22 presents the annual number of change orders for which reasons are provided, between 1996 and 2001. Most change order reason information came from contracts in year 2000, which experienced almost 5,700 change orders with given reasons. Figure 6.23 shows that most of the change orders concerned road construction contracts, with 9,402 change order reasons. Only 96 change orders were recorded for traffic maintenance projects between 1996 and 1999.

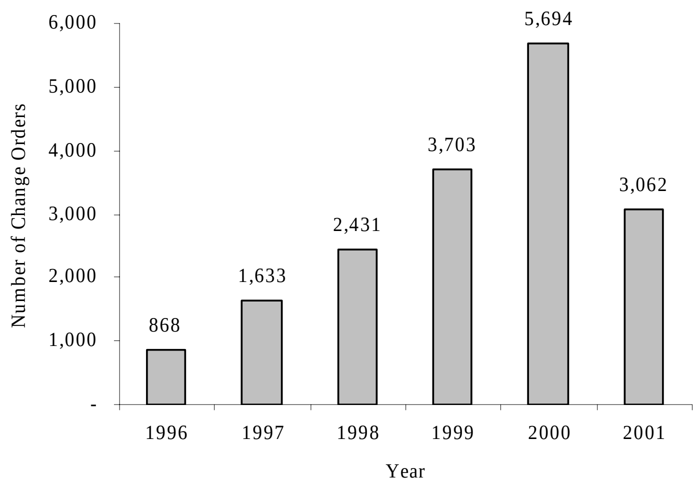

Figure 6.22: Annual Number of Change Orders for which Reasons were Provided

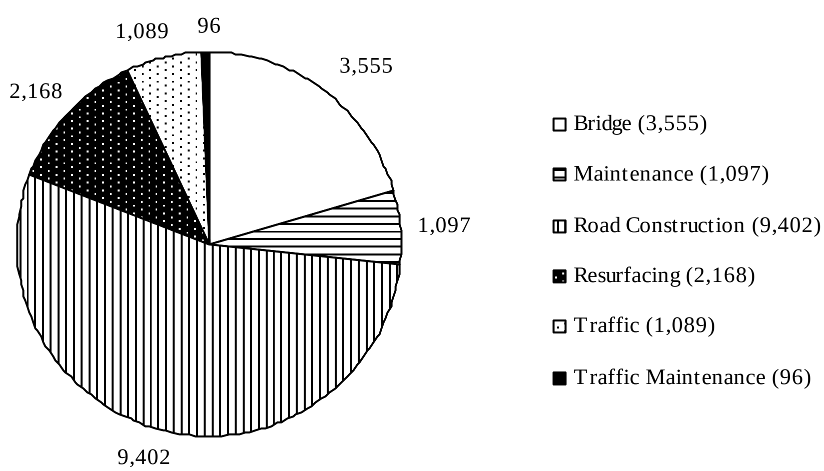

Figure 6.23: Available Change Order Reason Data per Project Type

Figure 6.24 presents the number of available change orders per district. The Greenfield District experienced more change orders than the other districts, with 4,599 change orders. Also, Vincennes District experienced the least number of change orders.

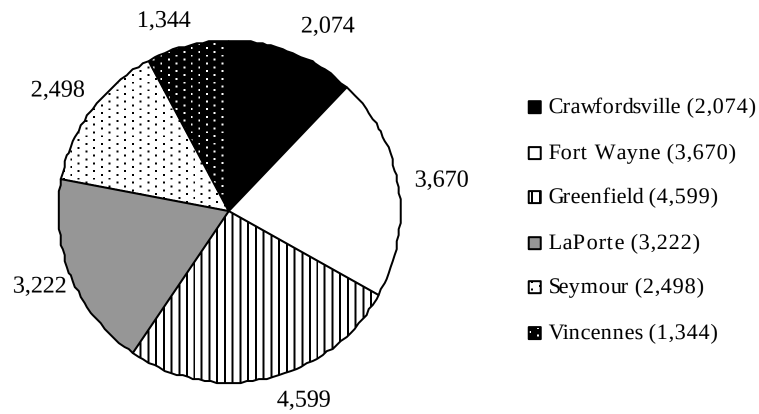

Figure 6.24: Availability of Change Order Reason Data per District

Figure 6.25 shows that the most frequent reasons for change order were “construction-related constructability”, “design-related error and omissions”, “construction-related changed conditions”, and quantity-related error and omissions”. Figure 6.26 presents the total amount involved in each type of change orders. Figure 6.27 provides an indication of the average dollar amount involved per change order. “No recorded reason” as used in this section of the report actually means no reason was indicated for the change order as seen in the records, even though it is likely that there actually was a reason. There were 6,024 change orders in the “no reason,” while 8,612 change orders were assigned a reason. The bar charts shown on Figure 6.25 does not include reason types for change orders associated with very high amounts. These are: “A+B”, “A+B+C”, and contract completion incentive/disincentive” change orders which represented approximately $850,000, $700,000, and $178,000, respectively. The overall average change order amount was $1,245.

The responsibility for these change orders was defined in the available dataset and is presented as Table 6.10. It is seen that most change orders are the responsibility of INDOT and its consultants. One category is the responsibility of FHWA, and seven others are the responsibility of the contractors.

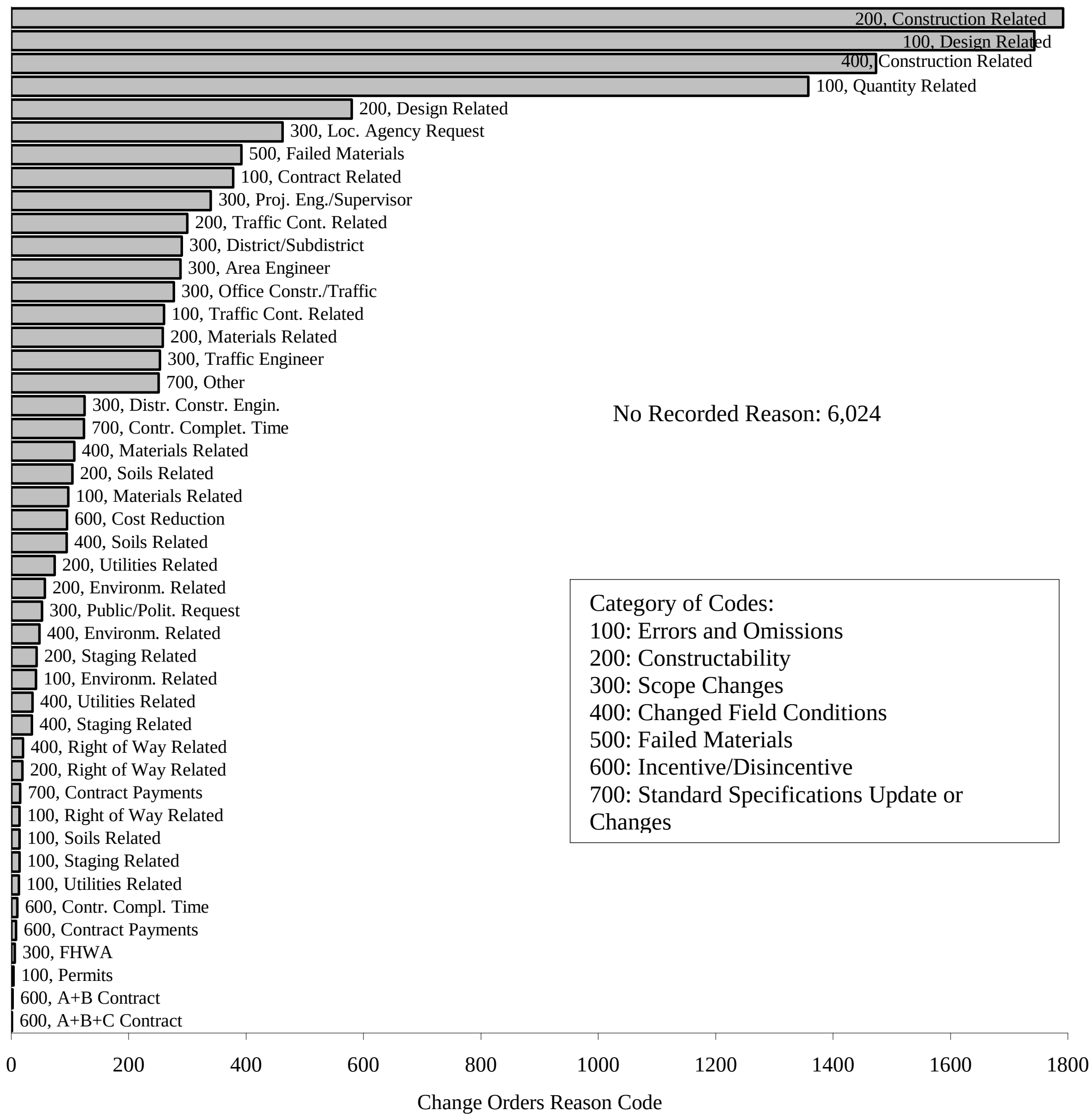

Figure 6.25: Distribution of the Number of Change Orders by Reason Type for all Types of Projects

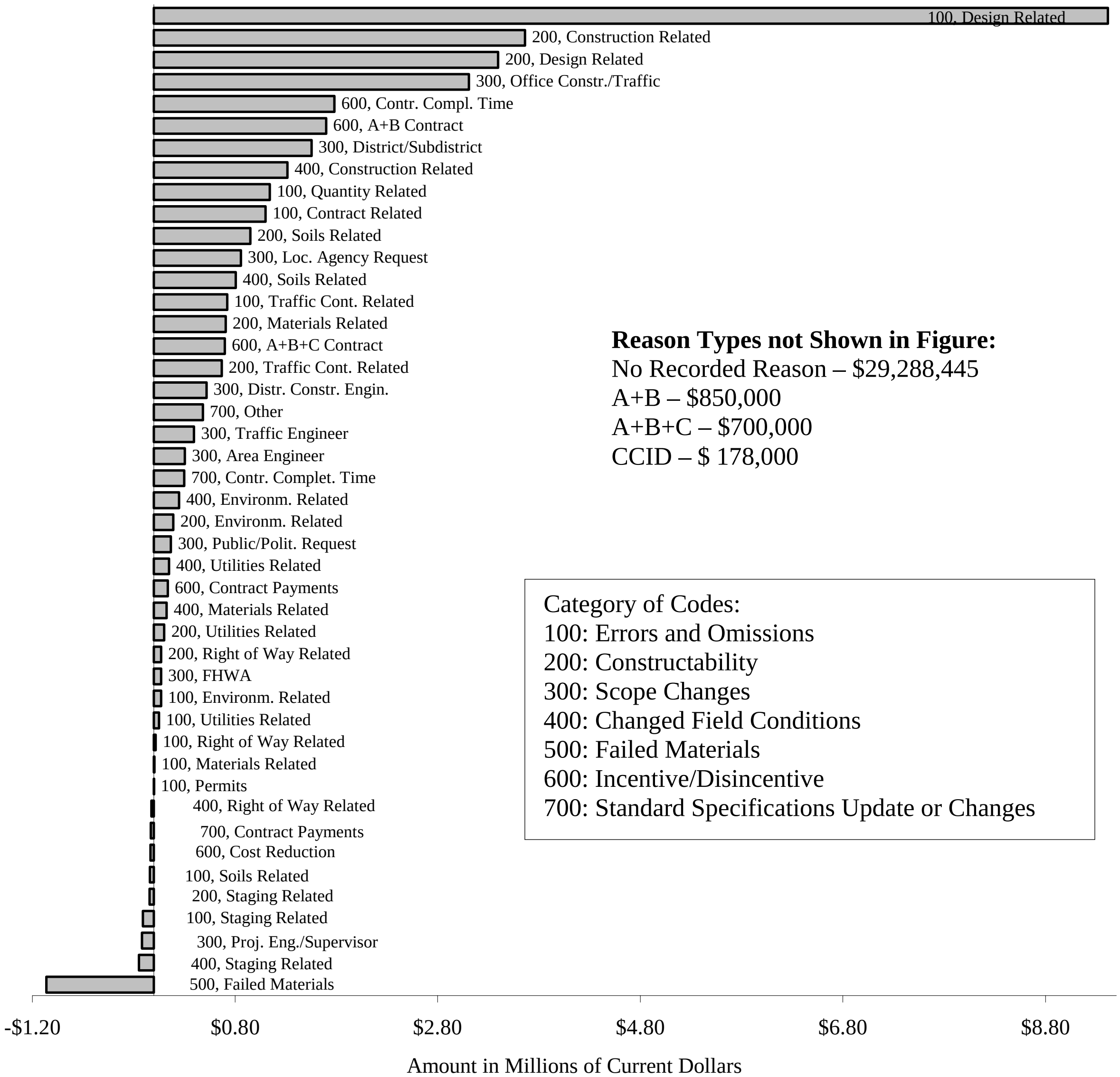

Figure 6.26: Distribution of Total Change Order Amounts by Change Order Type

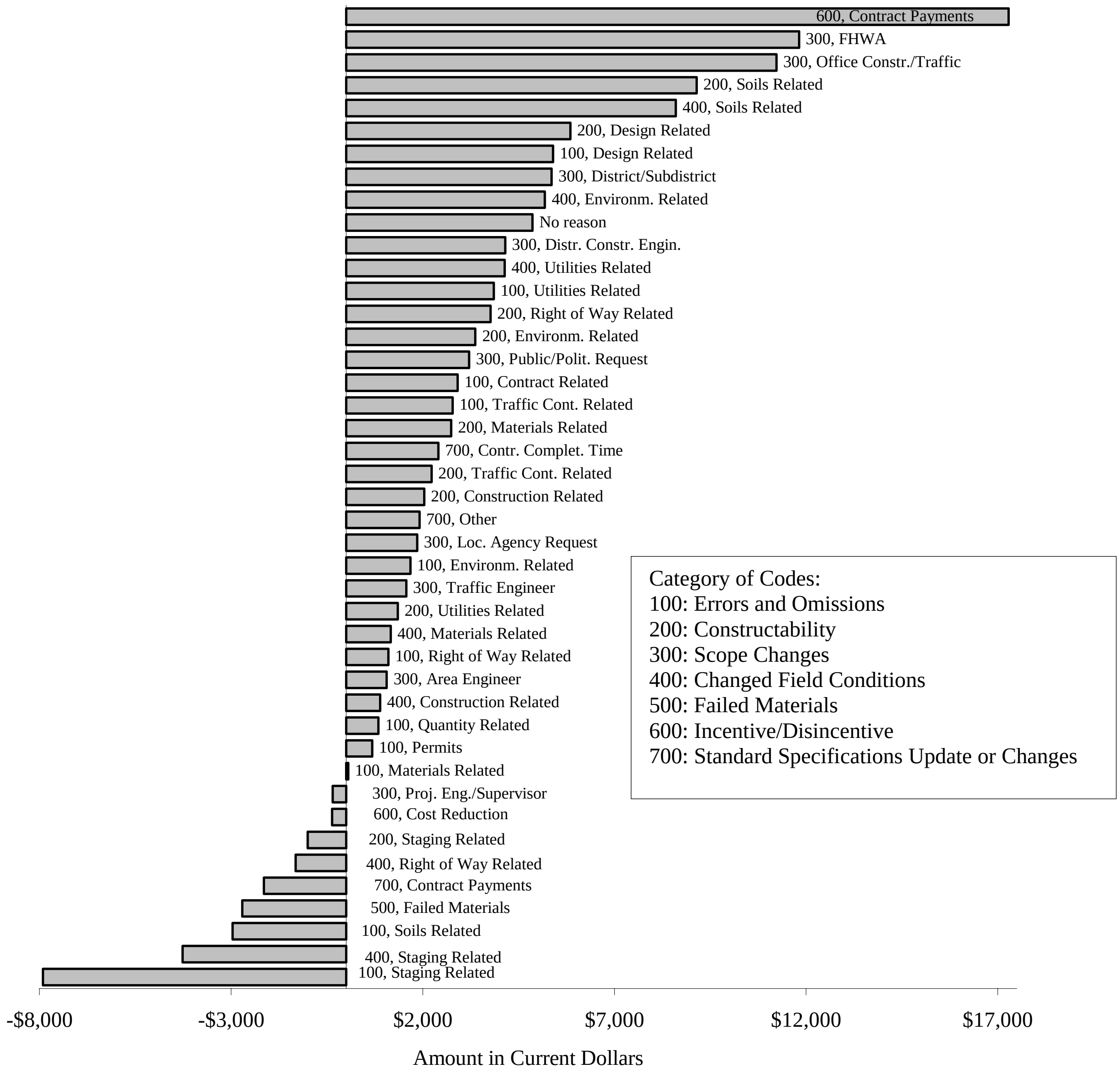

Figure 6.27: Distribution of the Average Amount per Change Order by Reason Type for all Types of Projects

Table 6.10: Responsibility of Change Orders

Code	Reason	Responsibility
101	Errors & Omissions, Contract Related	INDOT
102	Errors & Omissions, Design Related	INDOT
103	Errors & Omissions, Environmental Related	INDOT
104	Errors & Omissions, Materials Related	INDOT
105	Errors & Omissions, Permits	INDOT
106	Errors & Omissions, Quantity Related	INDOT
107	Errors & Omissions, Right of Way Related	INDOT
108	Errors & Omissions, Soils Related	INDOT
109	Errors & Omissions, Staging Related	INDOT
110	Errors & Omissions, Traffic Control Related	INDOT
111	Errors & Omissions, Utilities Related	INDOT
201	Constructability, Construction Related	Contractors
202	Constructability, Design Related	INDOT
203	Constructability, Environmental Related	INDOT
204	Constructability, Materials Related	Contractors
205	Constructability, Right of Way Related	INDOT
206	Constructability, Soils Related	INDOT
207	Constructability, Staging Related	Contractors
208	Constructability, Traffic Control Related	INDOT
209	Constructability, Utilities Related	INDOT
301	Scope Changes, FHWA	FHWA
302	Scope Changes, Central Office Construction/Traffic	INDOT
303	Scope Changes, District/Subdistrict	INDOT
304	Scope Changes, District Construction Engineer	INDOT
305	Scope Changes, Area Engineer	INDOT
306	Scope Changes, Project Engineer/Supervisor	INDOT
307	Scope Changes, Traffic Engineer	INDOT
308	Scope Changes, Local Agency Request	INDOT
309	Scope Changes, Public/Political Request	INDOT
401	Changed Field conditions, Construction Related	Contractors
402	Changed Field conditions, Environmental Related	INDOT
403	Changed Field conditions, Materials Related	Contractors
404	Changed Field conditions, Right of Way Related	INDOT
405	Changed Field conditions, Soils Related	INDOT
406	Changed Field conditions, Staging Related	Contractors
407	Changed Field conditions, Utilities Related	INDOT
500	Failed Materials,	Contractors
601	Incentive/Disincentive, Contract Completion Time	INDOT
602	Incentive/Disincentive, Contract Payments	INDOT
603	Incentive/Disincentive, Cost Reduction	INDOT
604	Incentive/Disincentive, A+B Contract	INDOT
605	Incentive/Disincentive, A+B+C Contract	INDOT
701	Stand/Spec Update or Changes, Contract Completion Time	INDOT
702	Stand/Spec Update or Changes, Contract Payments	INDOT
703	Stand/Spec Update or Changes, Other	INDOT

The data shows that over $30 million of change orders were the responsibility of INDOT or their consultants; approximately $70,000 was due to FHWA, and over $4.5 million was due to the contractors. Change orders are classified as preventable or non preventable. In Indiana, there is clear definition of what constitutes a preventable or non preventable change order [INDOT, 2002]. Preventable change orders include those due to errors and omissions in contract documents, constructability problems, and changes in scope of the project. On the other hand, non preventable change orders are those associated with changed field conditions, failed materials, incentive/disincentive provisions, and changes or updates to standards/specifications. Further explanation of each category of preventable and non preventable change orders are provided in Appendices A and C of this report. Using these definitions, the present study determined that of the $30 million due to INDOT or its consultants for change orders incurred on contract between 1996 and 2001, about $25 million was preventable.

For bridge projects, the reasons associated with the highest change order amount were "design related errors and omissions", and construction related changes field conditions. Again, the "no reason" change orders represented more than $6.5 million, which is large compared to the approximately$10million spent overall in change orders in this category (bridge projects). More than $2.5 million was related to change orders due to INDOT, with more than $2.3 million that could have been prevented. FHWA was responsible for no change orders in bridge projects, less than $1 million was due to the contractors, and more than half of it could have been prevented.

Road construction projects also experienced the highest amount of change orders in the type “design related errors and omission." The "no reason" was approximately $19.8 million, while the total amount of change orders for bridge projects was approximately $40 million. More than $19 million was the responsibility of INDOT, and more than $14 million could have been prevented. More than $700,000 spent on change orders were due to the contractors and actually about $1 million were preventable (some not preventable change orders were negative amounts).

The most important reasons for change orders in terms of amount spent in maintenance projects were the following: "design related errors and omissions,” "construction completion time in constructability," and "construction and environmental related changed filed conditions." In maintenance projects, the "no reason" change orders represented more than $532,000. The percentage of the dollar amount of "no reason" change order out of the total change order amount for maintenance projects (22.4%) was not as high as for other project categories. For maintenance projects, about $1.5 million of the change orders out of $2.37 million was the responsibility, of INDOT, with less than $900,000 preventable. Moreover, the contractors were responsible for more than $380,000, with half of it preventable. The data on this project category did not indicate any FHW A responsibility for change orders.

For traffic projects, the amount of money spent in change orders involved mostly traffic related reasons ("traffic engineer" and "scope changes"). It is also interesting to notice that in this category of projects, "construction related changes field conditions" and district construction engineering scope changes," the change orders resulted in a smaller final amount (were negative amounts). Approximately $680,000 was the responsibility of INDOT and most of it was preventable. About $118,000 out of $380,000 in change orders that were the responsibility of the contractors could have been prevented.

For resurfacing, "design related errors and omissions" and "construction related in constructability" Were the main reasons for change order amounts. For such projects, approximately all of $5.3 million spent on INDOT responsible change orders could have been prevented. Approximately $1.3million was the responsibility of the contractors, but most of this amount came from "construction related constructability: and was preventable. In this category of projects, over $70,000 was attributed to FHWA change orders.

Among the 96 change orders recorded in the traffic maintenance projects, only 2 had a reason for such change orders, "construction related changed filed conditions" and "district/sub district scope changes".

Concerning the distribution of change order reasons per district location, the "errors and omission, design related" was always at the first or second position for the most expensive reasons for change orders, except in the Crawfordsville District where it was at the fourth position. The "error and omission" reason category was in every district the most expensive one in terms of change order attributable to INDOT.

Figure 6.26 shows that the most influential change order reason was “design related errors and omissions,” with almost $10 million. It must be added that for approximately $29,300,000 (which represents 45% of the total change orders available for the study) no explicit reason was given for the change order. Figure 6.26 does not take into account such “no-reason” change orders. A second category of reasons for change orders was “construction-related and design-related constructability” and “Central Office scope changes,” with approximately $3.1 to $3.6 million. Some change order reasons do not represent a large amount, such as, the following “errors and omissions reasons”: “environmental-related,” “utilities-related,” “right-of-way related,” “materials-related,” and “permits related.” On the contrary, the failed material reason for change orders generally resulted in a diminution of the contract amount. Indeed, it is obvious that INDOT would not pay for a failed work.

Tables 1 to 5 present the average number of change orders (per contract) by district, bid amount category and reason category (bridge, maintenance, road construction, resurfacing, traffic and traffic maintenance projects) The change order reason categories corresponded to the following categories: 0: no reason given, 1: errors and omissions, 2: constructability, 3: scope changes, 4: changed field conditions, 5: failed materials, 6: incentive/disincentive, 7: standard specifications update or changes.

Table 6.11: Average Number of Bridge Contract Change Orders

Category of Bid Amount	District	Change Order Reason Category								
		0	1	2	3	4	5	6	7	Any Reason
$0-100,000	Crawfordsville	3.50	21.25	5.60	1.00	3.50	1.00		1.00	6.64
	FortWayne		3.67	8.33	2.50	10.00	1.25		1.00	4.25
	Greenfield	56.00	16.57	13.71	8.83	6.40	2.25	1.33	2.00	10.26
	Laporte	3.00	4.80	3.00	13.00	2.00	2.00			4.07
	Seymour	9.00	5.00	7.33		7.00	1.00			6.08
	Vincennes		8.00	5.00	4.67	1.67	1.50			4.36
	Average of all Districts	9.89	10.77	8.13	6.62	5.35	1.53	1.33	1.25	6.88
$100,000-500,000	Crawfordsville	16.67	2.44	6.33	2.00	2.00	1.25		5.00	4.48
	FortWayne	3.00	12.29	3.57	3.75	3.67	1.00			4.97
	Greenfield	14.80	6.93	13.22	5.88	1.86	1.25			7.75
	Laporte	9.75	6.27	5.70	5.00	8.00	1.17	3.00	1.00	6.02
	Seymour	13.83	4.50	4.33	4.00	3.33	1.00	1.00	1.00	4.97
	Vincennes	2.00	4.25	3.25		3.00	1.00			3.17
	Average of all Districts	11.90	6.24	6.62	4.16	4.00	1.14	1.67	3.00	5.74
$500,000-1,000,000	Crawfordsville	8.00	3.00			1.00	1.00			4.00
	FortWayne	28.33	6.75	6.00	7.50	5.00	1.00			8.45
	Greenfield		5.50	4.50	5.50	3.67	1.00			4.29
	Laporte	11.75	5.00	4.00	3.33	4.00	1.83		1.00	5.52
	Seymour	29.67	4.67	2.60	4.00	3.00	1.00		5.00	7.94
	Vincennes	1.00			7.00	16.00				10.00
	Average of all Districts	16.76	5.21	4.13	5.22	5.05	1.36		3.00	6.42
>$1,000,000	Crawfordsville	20.00	5.00	3.00	4.50	5.20	1.00		1.00	6.42
	FortWayne		3.00	4.33	1.00		1.00			3.00
	Greenfield	14.75	2.33	12.67	2.80	4.00	1.00	30.00		7.41
	Laporte	19.20	5.88	5.00	3.00	7.50	1.25		3.00	6.97
	Seymour	13.00	8.67	15.60	3.00	4.00	1.25	36.00	6.00	8.68
	Vincennes		13.00	4.00	6.00	2.00	1.00			5.20
	Average of all Districts	17.87	5.46	8.31	3.47	5.20	1.11	33.00	3.80	6.90
Average of all Bid Amount Category	Crawfordsville	11.69	6.65	5.06	3.08	4.00	1.09		3.00	5.66
	FortWayne	18.20	7.82	5.06	3.92	5.17	1.07		1.00	5.51
	Greenfield	17.53	8.64	11.36	5.95	4.36	1.35	8.50	2.00	7.96
	Laporte	12.32	5.67	4.95	4.73	5.60	1.47	3.00	2.00	5.91
	Seymour	17.64	5.44	7.32	3.67	4.13	1.09	12.67	4.50	6.63
	Vincennes	1.67	6.75	4.00	5.40	6.00	1.25			4.71
	Average of all Districts	14.04	6.88	6.99	4.56	4.82	1.25	9.38	2.80	6.36

Table 6.12: Average Number of Maintenance Contract Change Orders

Category of Bid Amount	District	Reason for change order								
		0	1	2	3	4	5	6	7	Any Reason
$0-100,000	Crawfordsville									
	FortWayne		8.00		59.00		1.00		2.00	17.50
	Greenfield	8.00	4.00	1.00	1.00	6.00	1.00		2.00	3.10
	Laporte						1.00			1.00
	Seymour	3.00	1.00			2.00				2.00
	Vincennes	1.00	3.67	3.00		4.00				3.17
	Average for all Districts	**4.00**	**4.00**	**1.67**	**30.00**	**4.50**	**1.00**		**2.00**	**5.29**
$100,000-500,000	Crawfordsville	42.50	5.83	4.17	5.00	5.00	1.00		4.50	7.18
	FortWayne	7.00	3.00	3.83	2.67		1.00			2.90
	Greenfield	7.00	2.20	3.00	2.33	1.00	1.00		61.00	6.57
	Laporte	5.50	3.30	2.13	4.00	1.71	1.00			2.71
	Seymour		3.60	2.00	6.00	1.50	1.00		1.00	2.62
	Vincennes	1.00	4.33			1.00	4.00	1.00	2.00	2.75
	Average for all Districts	**15.86**	**3.68**	**3.13**	**3.50**	**2.67**	**1.21**	**1.00**	**10.38**	**4.26**
$500,000-1,000,000	Crawfordsville		3.00	1.00		4.00	1.00			2.25
	FortWayne		3.00	4.00		6.00	1.00			3.11
	Greenfield	4.00	2.33	6.00		2.50	1.00			3.22
	Laporte		2.50	1.67	4.00	3.50				2.63
	Seymour	3.00	6.33		1.00	1.00				4.00
	Vincennes									
	Average for all Districts	**3.50**	**3.70**	**3.40**	**2.50**	**3.29**	**1.00**			**3.08**
>$1,000,000	Crawfordsville		3.00	6.75		1.00	1.00			5.38
	FortWayne		2.00	5.00	5.00	1.00	1.00			2.89
	Greenfield		1.00	3.25	10.00	2.00	1.00			2.15
	Laporte	61.00	2.50		1.00		1.00			9.25
	Seymour	11.00	4.40	8.00	5.00	3.00	1.00			5.53
	Vincennes		3.00	8.00		1.00		1.00		3.25
	Average for all Districts	**23.50**	**2.60**	**5.64**	**5.17**	**1.75**	**1.00**	**1.00**		**4.08**
Average of all Bid Amount Category	Crawfordsville	42.50	4.70	4.82	5.00	4.00	1.00		3.00	5.56
	FortWayne	7.00	3.50	4.15	14.40	2.67	1.00		2.00	4.33
	Greenfield	6.33	1.87	3.33	3.60	2.64	1.00		31.50	3.68
	Laporte	24.00	3.00	2.00	3.50	2.11	1.00			3.69
	Seymour	7.80	4.29	5.00	4.40	2.00	1.00		1.00	4.05
	Vincennes	1.00	3.86	5.50		2.00	4.00	1.00	2.00	3.00
	Average for all Districts	**14.00**	**3.40**	**3.80**	**6.27**	**2.68**	**1.09**	**1.00**	**7.25**	**4.14**

Table 6.13: Average Number of Road Construction Contract Change Orders

Category of Bid Amount	District	Reason for change order								
		0	1	2	3	4	5	6	7	Any Reason
$0-100,000	Crawfordsville	33.00	1.00		2.50	1.00			4.00	11.00
	FortWayne	50.00	5.67	3.25	45.50	10.75	4.00		2.50	12.61
	Greenfield	6.50	12.60	7.80	23.33	6.75	1.50		1.00	9.13
	Laporte	11.83	13.00	9.00	14.50	17.50	1.00	2.00		11.47
	Seymour	29.00	3.00	2.00	9.00	2.00	1.00			6.56
	Vincennes		8.50	6.00	11.00	5.33				7.00
	Average for all Districts	**19.08**	**10.25**	**6.12**	**18.07**	**8.94**	**1.80**	**2.00**	**2.50**	**10.23**
$100,000-500,000	Crawfordsville	49.33	3.00	3.25	5.00	2.67	1.00			16.43
	FortWayne	56.50	12.50	11.75	9.00	11.25	1.57	1.00	4.33	16.13
	Greenfield	33.25	17.36	13.29	12.42	11.08	2.29	4.00	2.67	13.01
	Laporte	31.71	10.90	12.78	9.20	6.67	2.00	1.00	2.50	14.58
	Seymour	66.13	10.10	14.80	16.13	5.50	3.60	1.00	1.00	18.36
	Vincennes	67.80	5.25	8.00	5.00	13.17	1.50		1.00	18.25
	Average for all Districts	**47.67**	**11.78**	**11.84**	**10.71**	**9.00**	**2.18**	**1.60**	**2.64**	**15.70**
$500,000-1,000,000	Crawfordsville	31.00	13.50	4.50	20.00	1.50				11.25
	FortWayne	52.25	6.40	10.88	11.33	11.57	1.67		2.00	15.29
	Greenfield	27.33	36.00	33.40	18.40	4.60	1.33	1.50	2.00	20.66
	Laporte	32.80	8.33	3.00	14.00	5.00	1.00		1.00	13.76
	Seymour	54.00	47.00	19.00	8.00	4.00	3.00		3.00	19.25
	Vincennes	20.00	7.50	12.00	2.00	5.00				8.00
	Average for all Districts	**41.15**	**17.92**	**15.33**	**12.42**	**6.94**	**1.58**	**1.50**	**2.00**	**16.18**
>$1,000,000	Crawfordsville	31.67	6.25	6.00	6.00	2.67	1.50		1.00	8.33
	FortWayne	64.67	22.67	19.67	12.67	7.67	2.00		1.00	22.65
	Greenfield	83.75	27.50	15.67	13.25	8.83	1.50	11.50	5.50	21.76
	Laporte	30.00	48.75	5.00	19.33	8.00	2.33			18.00
	Seymour	15.00	19.50	10.67	5.50	4.50	1.33	1.00	1.00	7.47
	Vincennes	19.50	4.40	13.67	1.00	5.00	1.00			7.50
	Average for all Districts	**50.57**	**21.42**	**11.74**	**11.19**	**6.67**	**1.60**	**8.00**	**2.50**	**15.36**
Average of all Bid Amount Category	Crawfordsville	40.67	5.91	4.60	6.44	2.22	1.33		2.00	12.05
	FortWayne	55.70	10.68	11.11	15.13	10.77	1.94	1.00	2.78	16.18
	Greenfield	43.31	23.00	16.20	15.17	8.74	1.78	6.00	3.14	15.87
	Laporte	27.72	17.32	9.00	12.42	9.28	1.71	1.50	2.00	14.25
	Seymour	56.75	13.57	13.06	12.13	4.64	2.60	1.00	1.50	15.45
	Vincennes	49.75	5.77	9.42	4.50	8.85	1.25		1.00	12.59
	Average for all Districts	**43.06**	**14.69**	**11.61**	**12.29**	**8.16**	**1.88**	**3.36**	2.44	14.90

Table 6.14: Average Number of Resurfacing Contract Change Orders

Category of Bid Amount	District	Reason for change order							
		0	1	2	3	4	5	7	Any Reason
$0-100,000	Crawfordsville	12.00	5.00	2.00	1.50	8.00	1.00	1.00	3.67
	FortWayne	11.00	4.67	3.00	5.00		1.25	1.50	3.47
	Greenfield	31.00	5.00	6.33	4.33	4.50	1.67		6.13
	Laporte	6.00	7.00	4.50	2.00	2.00	1.00		4.56
	Seymour		5.33	1.67	5.00	2.00	1.00	5.00	3.54
	Vincennes	7.00	8.00	5.50		25.00	2.50	1.00	7.22
	Average for all Districts	**13.40**	**5.80**	**3.93**	**3.91**	**6.86**	**1.46**	**2.00**	**4.70**
$100,000-500,000	Crawfordsville	5.00	6.89	4.38	4.00	6.60	1.00	5.75	5.06
	FortWayne	20.00	3.71	4.78	2.50	4.67	2.00	1.40	3.79
	Greenfield	21.00	10.10	7.00	6.38	3.80	1.86	6.00	7.00
	Laporte	14.25	2.33	3.80	1.50	3.25	1.50	1.00	4.58
	Seymour	8.00	3.75	3.14	2.00	3.00	1.00	3.67	3.44
	Vincennes		4.00	13.33	4.00	4.00	3.00	1.00	6.67
	Average for all Districts	**14.00**	**5.95**	**5.38**	**4.11**	**4.31**	**1.70**	**3.44**	**5.03**
$500,000-1,000,000	Crawfordsville	12.00	7.00	3.67		4.00	1.00	4.00	5.18
	FortWayne		3.00	6.00		2.00	1.00	2.00	3.71
	Greenfield		6.00	5.67	4.67	11.50	2.50		5.47
	Laporte	2.50	3.00	3.00		16.00	2.00	1.00	4.00
	Seymour		3.50	6.00	2.67	4.00	1.50	2.00	3.69
	Average for all Districts	5.67	4.77	5.07	3.67	7.13	1.89	2.25	4.48
>$1,000,000	Crawfordsville		2.00	9.67	1.00	3.33			4.89
	FortWayne	5.00	5.00	16.17	7.60	3.83	2.00	1.00	6.18
	Greenfield	44.00	14.00	4.60	5.75	4.67	1.75	2.00	7.43
	Laporte	7.00	9.50	6.00	4.50	2.33	1.00		5.00
	Seymour	11.00	4.73	4.50	4.29	1.75	1.33	3.33	4.03
	Vincennes	6.00	9.33	7.25	5.00	3.00	1.00	1.00	5.50
	Average for all Districts	**14.60**	**6.93**	**8.44**	**5.30**	**3.19**	**1.61**	**1.90**	**5.53**
Average of all Bid Amount Category	Crawfordsville	9.67	6.13	5.13	2.00	5.36	1.00	4.67	4.85
	FortWayne	12.00	4.29	7.95	5.27	4.08	1.79	1.36	4.59
	Greenfield	29.25	9.50	6.05	5.61	5.42	1.94	4.00	6.73
	Laporte	9.38	5.27	4.00	2.80	4.22	1.29	1.00	4.59
	Seymour	9.00	4.41	3.90	3.69	2.62	1.29	3.50	3.73
	Vincennes	6.50	7.43	8.89	4.50	8.75	2.25	1.00	6.31
	Average for all Districts	**12.91**	**6.07**	**5.93**	**4.45**	**4.58**	**1.65**	**2.66**	**5.05**

Table 6.15: Average Number of Traffic Contract Change Orders

Category of Bid Amount	District	Reason for change order								
		0	1	2	3	4	5	6	7	Any Reason
$0-100,000	Crawfordsville			1.00	2.00					1.50
	FortWayne	16.50	5.67	6.00	8.20	1.00	1.67		2.00	5.73
	Greenfield		3.33	3.00	5.00					3.60
	Laporte	11.00	5.00	2.00	4.00		1.00			6.25
	Seymour		2.00	1.00						1.50
	Vincennes		8.00		2.00	6.00				5.33
	Average of all Districts	13.20	5.06	3.17	6.00	2.25	1.50		2.00	5.20
$100,000-500,000	Crawfordsville	4.00	4.80	5.33	2.00	6.00				4.71
	FortWayne		4.43	5.25	3.67	8.50	1.50		2.00	4.47
	Greenfield	6.00	2.60	2.25	1.00	3.50				2.87
	Laporte	10.00	2.00	10.50	5.00	2.50				5.00
	Seymour	5.00	1.33	3.00	1.00					2.57
	Vincennes	8.00	12.29	4.17	5.25	1.25				6.59
	Average of all Districts	6.33	5.59	4.75	3.69	3.76	1.50		2.00	4.68
$500,000-1,000,000	Crawfordsville	4.00	4.67	2.00	3.00	1.00	2.00			2.69
	Greenfield		16.50	4.50	29.00	7.00	1.00	1.00	1.00	9.00
	Laporte		2.00	22.00	3.00	3.00	2.00			5.83
	Average of all Districts	4.00	8.17	6.17	8.20	2.60	1.67	1.00	1.00	5.39
>$1,000,000	Crawfordsville	11.00	25.00			8.00				14.67
	FortWayne	8.00	7.83	7.33	5.60	4.33	1.00		14.00	6.38
	Greenfield		2.50	4.00	3.00	1.00				3.00
	Laporte	15.50	7.00							12.67
	Seymour	3.00	1.00	4.67	2.50	6.00				3.63
	Vincennes	1.00	6.50	2.00		2.00				3.60
	Average of all Districts	9.00	7.54	5.00	4.33	4.29	1.00		14.00	5.98
Average of all Bid Amount Category	Crawfordsville	6.33	7.00	3.29	2.40	4.14	2.00			4.63
	FortWayne	13.67	5.86	6.11	6.15	4.13	1.43		5.00	5.58
	Greenfield	6.00	5.08	3.30	8.20	3.67	1.00	1.00	1.00	4.49
	Laporte	12.33	3.83	11.25	4.00	2.60	1.50			6.36
	Seymour	4.33	1.40	3.60	2.00	6.00				2.94
	Vincennes	4.50	10.70	3.86	4.60	2.17				5.97
	Average of all Districts	9.00	6.09	4.79	5.06	3.52	1.45	1.00	4.20	5.19

Examination of Tables 1 to 5, particularly the bottom right cells, shows that on the average, all the project types experienced approximately the same number of change orders (approximately 5). The only exception was road construction projects where the average is approximately 15 change orders per contract.

Figure 6.29 shows that the average number of change orders per contract does not vary greatly among districts. Greenfield experienced the highest average number of change orders, with ten change orders per contract, while Crawfordsville experienced the lowest average number of change orders, with five change orders per contract. Figure 6.30 shows that road construction projects experiences a greater average number of change orders by contract, with 15 change orders, and maintenance projects experienced fewer change orders, with an average of only four change orders per contract.

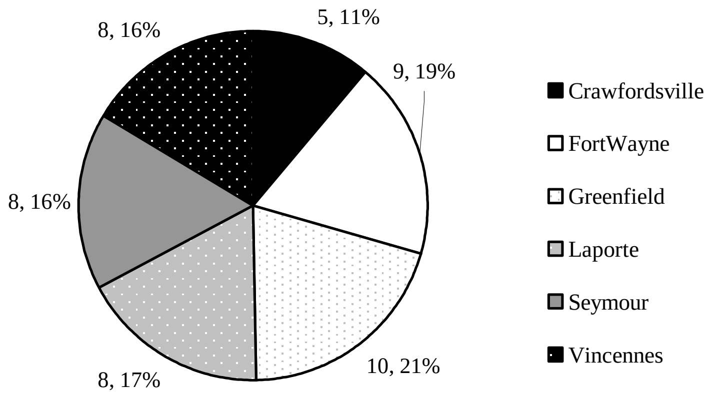

Figure 6.29: Average Number of Change Orders per Contract and Percentage of Contracts with Change Order, by District

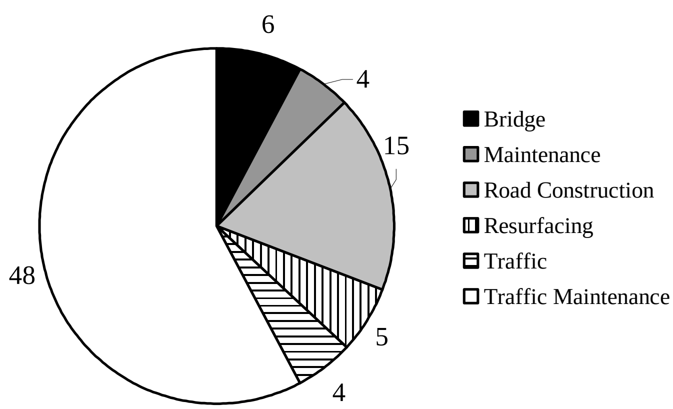

Figure 6.30: Average Number of Change Orders per Contract by Project Type

Figure 6.31 provides the average number of change orders per contract by bid amount category. Projects in the bid category less than $100,000 or more than $1 million had less average number of change orders per contract than the projects with bid amounts in the medium range of $100,000 - $1 million. Figure 6.32 shows that the yearly variation of the average number of change orders per contract varied from 4 in 1996 to 13 in 1999.

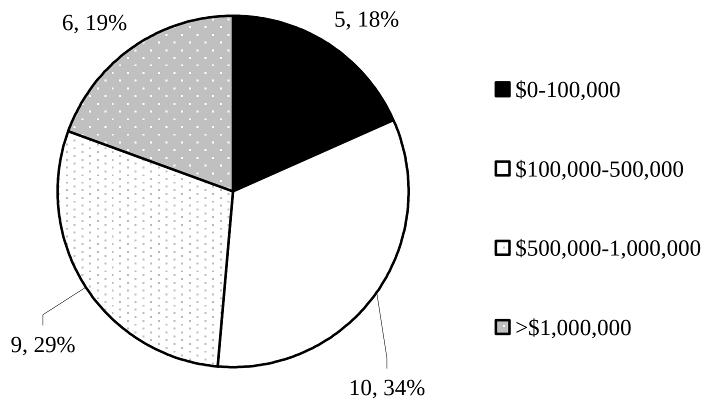

Figure 6.31: Average Number of Change Orders per Contract and Percentage of Contracts with Change Orders, by Bid Amount Category

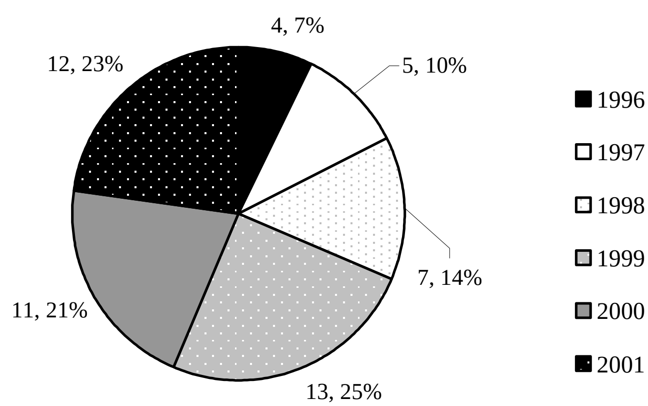

Figure 6.32: Average Number of Change Orders per Contract and Percentage of Contracts with Change Orders, by Year

Appendix E provides further detailed information on change orders. A comparison of the average frequency of change orders per contract by project type and by district shows that Greenfield bridge projects had the highest average number of change orders. For maintenance projects, Crawfordsville had the highest average. In the six districts, road construction projects experienced more change orders, with a much higher average (approximately 15 change orders), with no particularly dominant district. For resurfacing projects, the Greenfield and Vincennes Districts had more change orders per contract than the other district, and for traffic projects, the Seymour District is had fewer change orders per contract. The “no reason” change order category was dominant in every district, with only exception of Crawfordsville, where the proportion of “no reason” change orders was much less than for the other districts. Concerning the other change order reason categories, the Greenfield District had more “errors and omissions” and “constructability” change orders per contract. Otherwise, there was little disparity among districts for change order reasons. Traffic projects seem to experience less “no reason” change orders in proportion to other project types. Road construction projects had the highest average number of change orders in the “errors and omissions,” “constructability,” and “scope changes” categories.

6.6 Chapter Summary

The present chapter provided a discussion on the incidence of cost overruns, time delays, and change orders in terms of their distribution by district, project type and bid amount category. Almost half of the amount spent on change orders was associated with “no recorded reason.” If the “no recorded reason” category is excluded, the “error and omission” category was the overwhelming reason for change orders. Resurfacing projects experienced the most cost overruns, and maintenance projects had the most time delay. The following chapter carries out detailed statistical analysis of cost overruns, time delays, and change orders.

CHAPTER 7: STATISTICAL ANALYSIS I

7.1 Introduction

In discussing the distribution of cost overruns, time delays, and change order frequency by project type, location, and bid amount category, the previous chapter laid the groundwork upon which further statistical analysis could be carried out. The present chapter carries out preliminary statistical investigations aimed at confirming identified trends between the dependent variables (cost overruns, time delay and change order frequency) on one hand, and the potentially influential factors (independent variables) on the other hand, and also to further establish a-priori expectations of the strength and direction of such relationships. Four statistical tools were used to conduct the preliminary statistical analysis. The **correlation matrix** was carried out to ascertain the existence of any linear correlation between each pair of independent variables. The **analysis of variance** was carried out to investigate any differences in the means of each dependent variables for various combinations of levels of the potential influential factors. Then a *pair-wise t-test* was carried out to study any such differences in a more precise manner. Finally, an analysis of the influence of each potentially influential factor on the dependent variables was carried out.

7.2 Correlation Matrix

The correlation matrix between the independent variables provided in Table 7.1 showed the Pearson correlation coefficient for each pair of variables. This statistic helped to identify any correlations so that possible modeling biases from using correlated variables in the same model could be avoided. Table 7.1 (where correlations are at 10% significance) shows that most of the Pearson correlation coefficients were between -0.3 and 0.3. A notable exception is that for the variables representing the *proportion of the difference between the first and second bids* and the *proportion of the difference between the lowest bid and the engineer's estimate,* which had a correlation coefficient of 0.83 and is indicative of a strong positive association. As such, it was necessary to avoid using these two variables in the same model or to exercise due caution where they had to be used in the same model. For the other variables, there seemed to be no problem with correlation as their correlation coefficients were sufficiently low.

Table 7.1: Correlation Matrix of the Independent Variables

Variables	Bid Amount	Proportion of Inclement Days	Level of Competition	Second and First Bid	Bid and Engineer's Estimate	Duration
Bid Amount	**1.00**	**-0.05**	**-0.13**	**-0.10**	**-0.03**	**0.09**
	.	0.01	0.00	0.01	0.50	0.00
	2668	2575	730	674	714	2668
Proportion of Inclement Days	**-0.05**	**1.00**	**-0.02***	**0.04***	**-0.02***	**-0.03***
	0.01	.	0.50	0.31	0.67	0.12
	2575	2575	726	671	710	2575
Level of Competition	**-0.13**	**-0.02***	**1.00**	**0.14**	**0.14**	**-0.10**
	0.00	0.50	.	0.00	0.00	0.01
	730	726	730	674	714	730
Second and First Bid	**-0.10**	**0.04***	**0.14**	**1.00**	**0.83**	**-0.04***
	0.01	0.31	0.00	.	0.00	0.27
	674	671	674	674	662	674
Bid and Engineer's Estimate	**-0.03**	**-0.02***	**0.14**	**0.83**	**1.00**	**-0.02***
	0.50	0.67	0.00	0.00	.	0.65
	714	710	714	662	714	714
Duration	**0.09**	**-0.03***	**-0.10**	**-0.04***	**-0.02***	**1.00**
	0.00	0.12	0.01	0.27	0.65	.
	2668	2575	730	674	714	2668

*: these correlations are significant at the 0.05 level (two tailed).

Legend for each cell:

a
b
c

a is the Pearson correlation coefficient,
b is the level of significance (two tailed),
c is the number of observations

7.3 Analysis of Variance (ANOVA)

The analysis provides the mean responses for each combination of levels of the following variables: *proportion of inclement days*, *bid amount*, *level of competition*, *proportion of the difference between the first and second bids*, and *proportion of the difference between the winning bid and engineer's estimate*. Details are provided in Appendix F. The mean for time delays could not be provided in the preliminary analysis because there were inadequate data points for estimating some of the means. Moreover, the *duration* variable that was used for time delay, was not included in this analysis.

The analysis of variance enables simultaneous comparison at all the means, and consequently addresses the following questions:

(i) Are all time delays statistically the same regardless of the combinations of extents of the explanatory factors?

(ii) Are all cost overrun amounts statistically the same regardless of the combinations of extents of the explanatory factors?

(iii) Are all changer order frequencies the same regardless of the combinations of extents of the explanatory factors?

The hypothesis tests are:

H_0: $\exists(i, j) \in (1;32)^2, i \neq j, \mu_i = \mu_j$

H_1: $\mu_1 \neq \mu_2 \neq \ldots \neq \mu_{32}$

An affirmative answer to the above questions is evidenced by a high F-value. If the answer to the above questions is not affirmative, then that at least two means do not have a significant differences variable (but the others could be significant). Table 7.2 presents the ANOVA results.

Table 7.2: Analysis of Variance Using Selected Variables

		Sum of Squares	df	Mean Square	F	P-Value
Cost Overrun	Between Groups	2.29E+12	31	7.39E+10	1.34	0.10
	Within Groups	3.44E+13	627	5.49E+10		
	Total	3.67E+13	658			
Amount of Change Order	Between Groups	4.21E+12	31	1.36E+11	0.92	0.59
	Within Groups	9.22E+13	627	1.47E+11		
	Total	9.64E+13	658			
Number of Change Order	Between Groups	2.55E+04	31	8.24E+02	1.10	0.34
	Within Groups	1.57E+05	209	7.52E+02		
	Total	1.83E+05	240			

Table 7.2 shows that there are significant differences in the means of cost overruns between the combinations of variables at the 10% significance level. However, for average change order amounts or frequencies, such a difference was not found significant.

The analysis provides the means of each combination of various levels of each independent variable as shown in Appendix F. In this case, the intention was to investigate time delays, and the *duration* variable is included. When the bid comparison variables are added in the analysis, the means for time delays cannot be computed because there were missing observations in the groups defined for the ANOVA. The analysis makes it possible to examine the differences between the means for amount or frequency of change orders and cost overrun without the bid comparison variables.

For the four dependent variables, Table 7.3 shows the effect of the three selected independent variables on any of the dependent variables. This is reflected in the high F-value, indicating the strong statistical significance of such effects. Comparison of the two sets of ANOVA tests shows that bid amount and proportion of inclement days had a strong influence on cost overrun, time delay, amount and frequency of change orders. However, this is not true for bid comparison variables such as *level of* *competition* and *proportion of the difference between first and second bid* and *proportion of the difference between the winning bid and engineer's estimate.*

Table 7.3: Analysis of Variance Using Selected Independent Variables

		Sum of Squares	df	Mean Square	F	P-Value
Cost Overrun	Between Groups	7.88E+12	7	1.13E+12	9.82	0.00
	Within Groups	2.22E+14	1940	1.15E+11		
	Total	2.30E+14	1947			
Time Delay	Between Groups	1.13E+07	7	1.61E+06	90.16	0.00
	Within Groups	3.47E+07	1940	1.79E+04		
	Total	4.60E+07	1947			
Change Order Amount	Between Groups	1.52E+13	7	2.17E+12	3.29	0.00
	Within Groups	1.28E+15	1940	6.61E+11		
	Total	1.30E+15	1947			
Number of Change Order	Between Groups	1.92E+05	7	2.75E+04	21.42	0.00
	Within Groups	6.44E+05	502	1.28E+03		
	Total	8.36E+05	509			

7.4 Pairwise t-Tests

The pairwise t-test was constructed on the basis of the difference score for each matched pairs. The matched pairs were a pair of observation that differed from each other for only one variable, and the difference between the other variables could not exceed +/- 10 %. x was defined as the difference between $\mu_A - \mu_B$. x_A and x_B that were matched pairs of the two populations, and was assumed to be normally distributed. The null hypothesis was H_0: $\mu_A - \mu_B = 0$ which was equivalent to H_0: $\mu_x = 0$

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2}$$

The test statistic for matched pairs was: $t_{(n-1)} = \dfrac{\bar{x}-\mu_0}{s/\sqrt{n}}$ with $\mu_0 = 0$.

This t-test compared with $\left[-t_{(\alpha/2,n-1)};+t_{(\alpha/2,n-1)}\right]$. If $t_{(n-1)}$ was in this range, H_0 could not be rejected and the variable was not significant.

7.4.1 *Bid Amount* Pairs

For the purpose of carrying out the pairwise t-tests, two levels of bid amount were defined: bid amounts greater than $340,192, and bid amounts less than $340,192, each with 1,374 contracts.

A preliminary assessment was made for contracts with the following characteristics: bridge project types, Crawfordsville district locations, proportion of inclement weather days less than 0.5, and level of competition less than five. Table F5 and F7 show cost overruns and time delays of the selected contracts that were compared. For contracts in this category, the average time delay of low bid contracts was compared to that of high bid contracts, and any such difference was tested for statistical significance. This procedure was repeated for cost overrun, change order, and time delay. The results indicated that the bid amount was a significant variable for cost overrun and change orders at 95% level of confidence, but not for time delay.

7.4.2 *Duration* Pairs

Two levels of contract duration were defined: 975 contracts with *duration* greater than 110 days, and 1,007 contracts with *duration* less than 111 days. An assessment was made for contracts with the following characteristics: bridge project types, Crawfordsville district locations, *proportion of inclement weather days* less than 0.5, and *level of competition* less than five. Table F8 shows cost overruns and time delays of the selected contracts that were compared. The results suggested that the *duration* variable was not a significant variable for time delay at 95% level of confidence.

7.4.3 *Proportion of Inclement Weather Days* Pairs

Two levels of the *proportion of inclement weather days* variable were defined: 1,275 contracts with a proportion greater than 0.27, and 1,293 contract with a proportion less than 0.26. A preliminary assessment was made for contracts with the following characteristics: bridge project types, Crawfordsville district locations, and *level of competition* less than two. Table F9 and F10 show cost overruns and time delays of the selected contracts that were compared. The results suggested that the *proportion of inclement weather days* does not significantly affect cost overruns but could be a significant variable for time delay. For the frequency of change orders, pairs matched on the basis of available levels of the variables were inadequate for such analysis to be carried out.

7.4.4 *Level of Competition* Pairs

Two levels of the *level of competition* variable were defined: 377 contracts with a *level of competition* greater than four contractors, and 353 contracts with a *level of competition* less than three contractors. An assessment was made for contracts with the following characteristics: bridge project type and proportion of inclement weather days less than 0.5. Table F11 and F12 show cost overruns and time delays of the selected contracts that were compared. The results suggested that the *level of competition* was not a significant variable for cost overrun and for the frequency of change orders at

95% level of confidence. For time delay, pairs matched on the basis of available levels of the variables were inadequate for such analysis to be carried out.

7.4.5 *Proportion of the Difference between the First and Second Bid* Pairs

Two levels of the *proportion of the difference between the first and second bid* variable were defined: 337 contracts with a proportion greater than 0.064, and 337 contracts with a proportion less than 0.064. A preliminary assessment was made for contracts with the following characteristics: bridge project type, and a level of competition less than four. Table F13 and F14 show cost overruns and time delays of the selected contracts that were compared. From the results, it is seen that the *proportion of the difference between the first and second bid* was not a significant variable for cost overruns, but was significant for time delay. For frequency of change orders, pairs matched on the basis of available levels of the variables were inadequate for such analysis to be carried out.

7.4.6 *Proportion of the Difference between the Bid and the Engineer's Estimate* Pairs

Two levels of the *proportion of the difference between the winning bid and engineer's estimate* variable were defined: 357 contracts with a proportion greater than 0.2131, and 356 contracts with a proportion less than 0.2131. A preliminary assessment was made for contracts with the following characteristics: road construction project type and a *level of competition* less than three. Table F15 shows cost overruns and time delays of the selected contracts that were compared. The results indicated that the *proportion of the difference between the winning bid and engineer's estimate* was not a significant variable for cost overruns. For frequency of change orders and time delay, pairs matched on the basis of available levels of the variables were inadequate for such analysis to be carried out.

7.4.7 Conclusions of the Pair-wise t-Tests

The results of the pair-wise t-test analysis are summarized in Table 7.4. The results suggest that *bid amount* is the variable that most significantly influences cost overrun, while the *proportion of inclement days* variable is most significant for time delay. Both of these variables were significant for the frequency of change orders at 95% level of confidence.

Table 7.4: Results of the Pairwise t-Tests

Independent Variable	Cost Overrun	Time Delay	Frequency of Change Orders
Bid Amount	Significant	Not significant	Significant
Project Duration	-	Not Significant	-
Proportion of Inclement Days	Not Significant	Significant	-
Level of Competition	Not Significant	-	Significant
Proportion of the Difference between the First and Second Bids	Not Significant	Significant	-
Proportion of the Difference between the Winning Bid and Engineer's Estimate	Not Significant	-	-

7.5 Preliminary Graphical Analysis of the Influence of Potential Explanatory Factors (Independent Variables) on the Dependent Variables

The preliminary statistical analysis concerned the potential trends of the data. In order to investigate such trends, each variable was classified in three categories: low, medium, and high. The variation of a dependent variable as a function of a particular independent variable was considered, keeping the other variables constant at their "medium" level.

7.5.1 Cost Overrun

Figure 7.1 was developed using the following considerations on the other variables: a medium level of *bid amount*, a medium level of *proportion of the difference between the winning bid and the engineer's estimate*, and a medium level of *proportion of the difference between the first and the second bid*. The results suggest that cost overrun increases when the proportion of inclement days increased, which is expected. The next figure (Figure 7.2) was developed using a medium level of *bid amount* and a medium level of *proportion of the difference between the first and second bid*, but failed to yield any discernible trends.

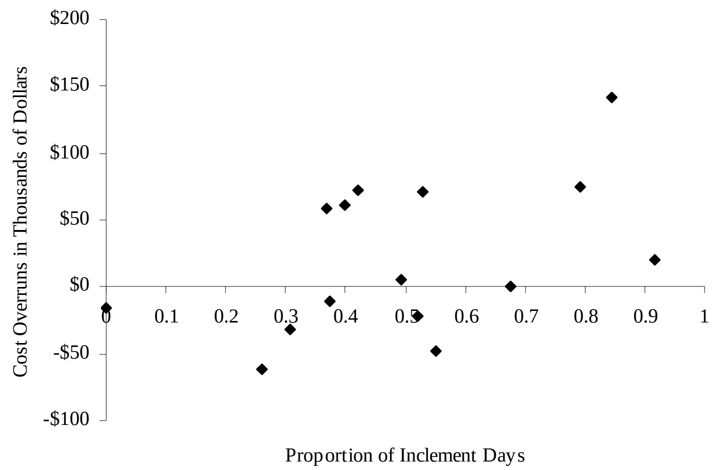

Figure 7.1: Cost Overrun Variation with *Proportion of Inclement Days*.

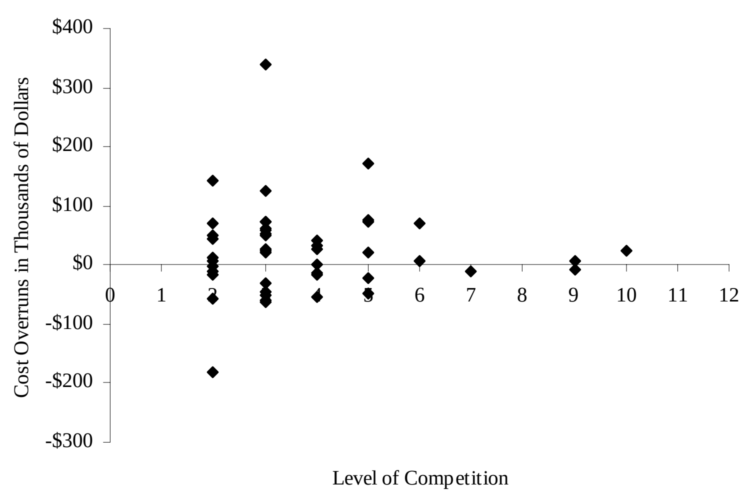

Figure 7.2: Cost Overruns Variation with the *Level of Competition*

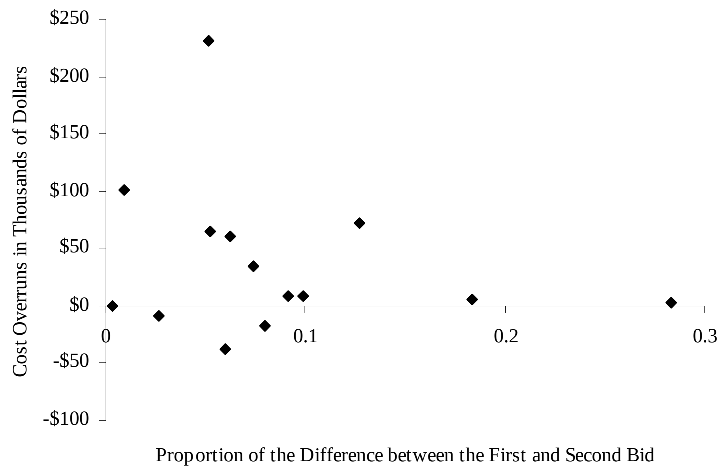

Figure 7.3: Cost Overruns Variation with the *Proportion between the First and the Second Bid*

Figure 7.3 is associated with medium levels of *bid amount, level of competition,* and *proportion of inclement days*. This figure seems to suggest that the larger the *difference between the first and second bid*, the generally lower the cost overrun amount, even though the trend is not so "clean". A similar trend is observed when the *Proportion between the Bid and the Engineer's Estimate* is used as a dependent variable (Figure 7.4)

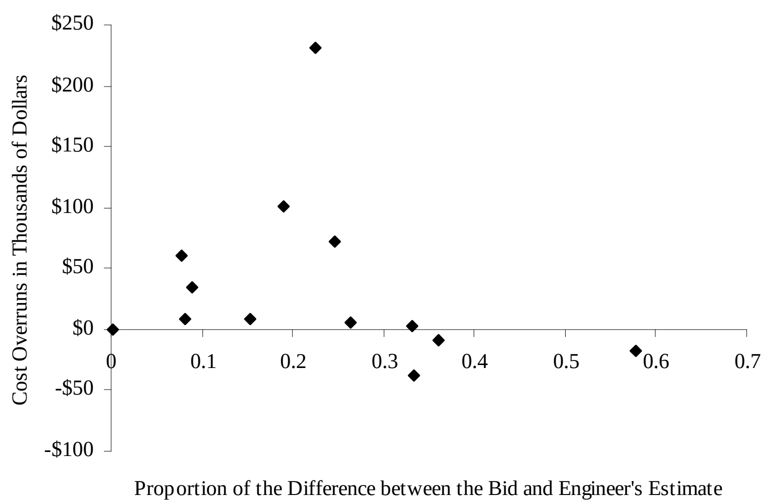

Figure 7.4: Cost Overrun Variation with the *Proportion between the Bid and the Engineer's Estimate*

Figure 7.5 was developed using the same levels of factors as was dome for the previous figure. It is seen that the larger the *bid amount,* the higher the cost overruns. Figure 7.5 was developed using a medium level of the *level of competition* variable and a medium level of the *proportion of inclement days* variable. The result is consistent with the finding of Rowland (1981).

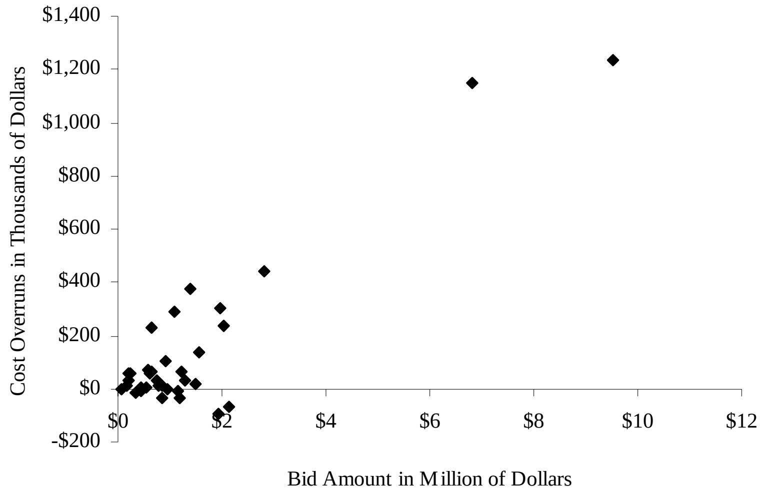

Figure 7.5: Cost Overrun Variation with the Bid Amount

7.5.2 Time Overrun

Figure 7.7 was developed using a medium level of the *bid amount* variable and a medium level of the *proportion of difference between the first and the second bid* variable. A higher proportion of inclement days in a project seemed to be associated with a fewer delayed days. Figure 7.7 utilized a medium level of *the proportion of inclement days* variable and a medium level of the *proportion of difference between the first and second bids* variable. A higher bid amount seemed to be associated with a lower number of delayed days.

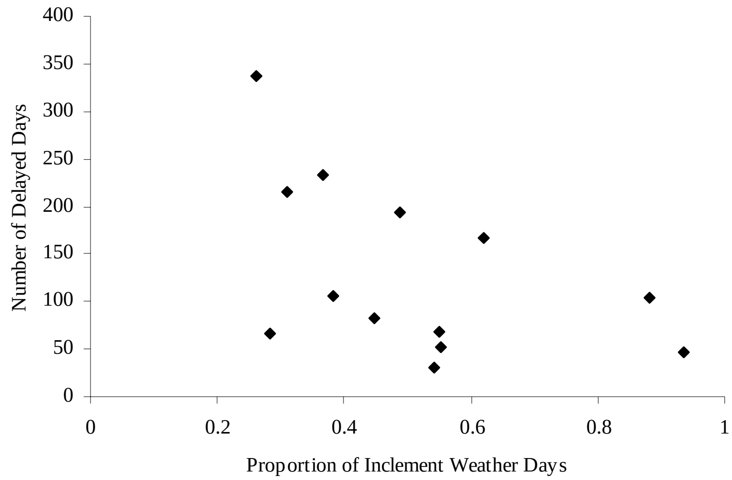

Figure 7.6: Time Delay Variation with the Proportion of Inclement Days

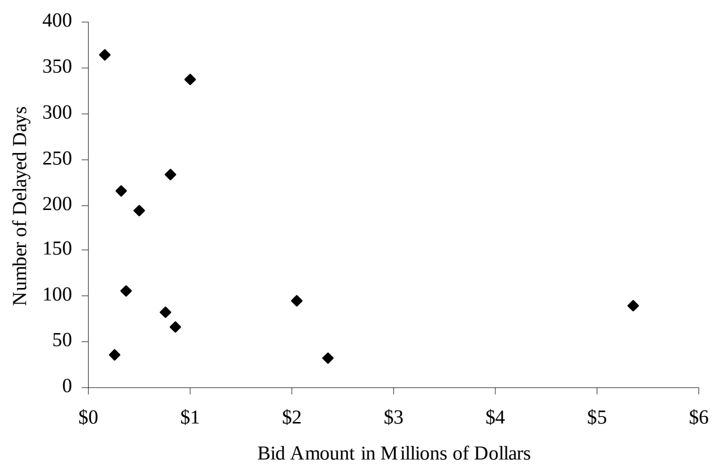

Figure 7.7: Time Delay Variation with the Bid Amount

Figure 7.9 was developed using a medium level of the *bid amount* variable, a medium level of the *proportion of inclement weather days* variable and a medium level of the *proportion of difference between the engineer's estimate and bid* variable. A higher original duration implied a lower number of delayed days. Figure 7.10 shows that the level of competition seemed to have a little influence on time delays. The conditions were a medium level of the (original) *duration* variable and a medium *proportion of difference between the first and second bid* variable.

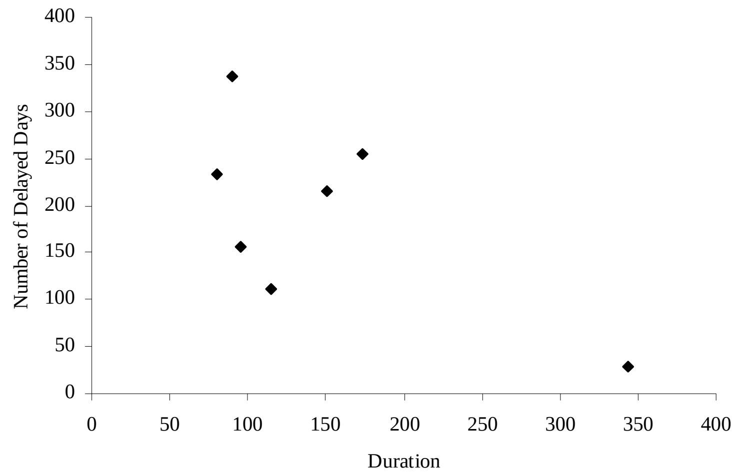

Figure 7.9: Time Delay Variation with *Contract Duration* in Days

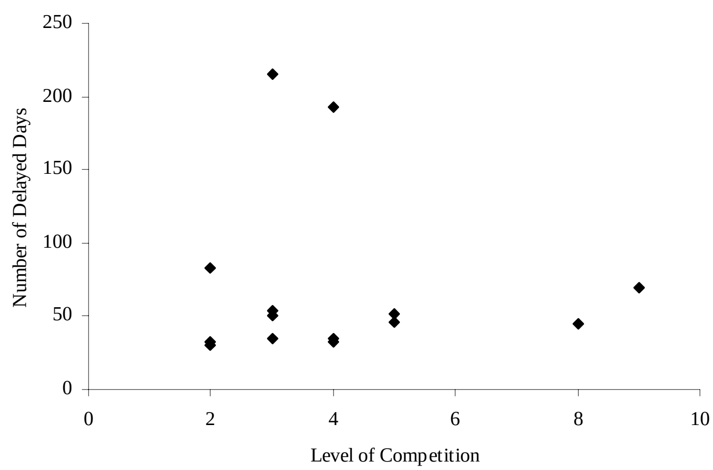

Figure 7.10: Time Delay Variation with the Level of Competition

Figure 7.11 suggests that if the *difference between the first and second bids* was large, the time delay was also large. The figure was developed using a medium level of the *level of competition* variable. Although there were only a few data points, Figure 7.12 shows that the number of delayed days decreased with the variation of the *difference between the winning bid and engineer's estimate*. This graph followed the same conditions as for the previous figure.

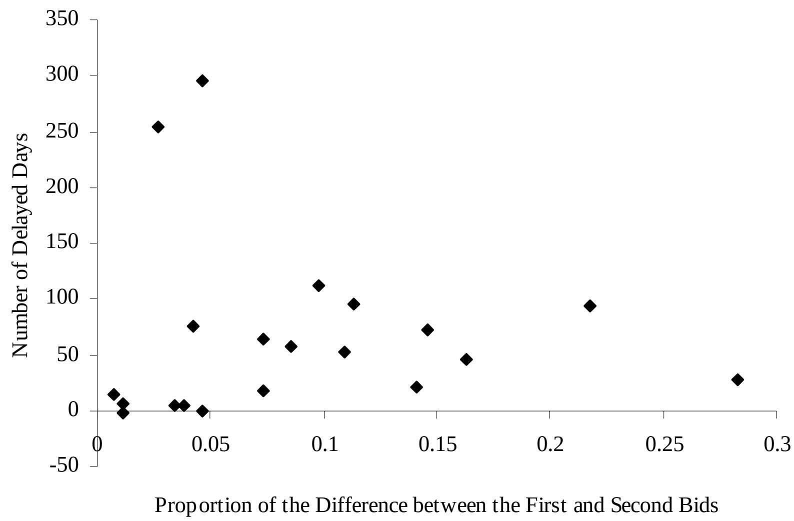

Figure 7.11: Time Delay Variation with the *Difference between the First and Second Bids*

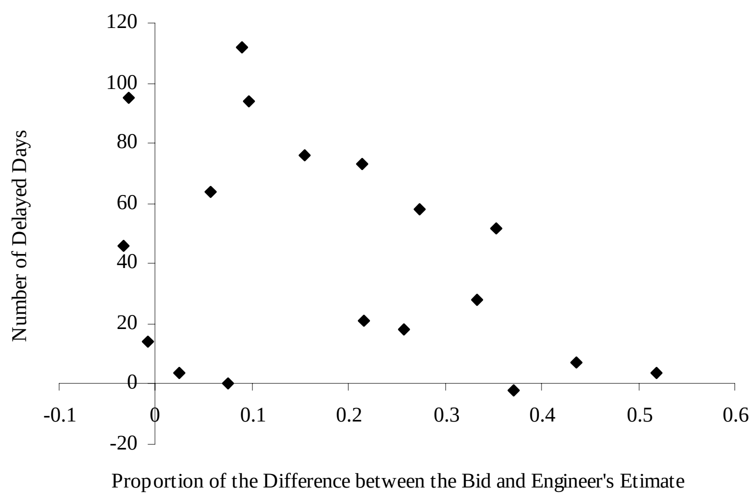

Figure 7.12: Time Delay Variation with the *Difference between the Engineers' Estimate and the Bid*

7.5.3 Frequency of Change Orders

Figure 7.13 shows that the frequency of change orders increased when the proportion of inclement days increased. This figure was developed using the following conditions: a medium level of the *level of competition* variable and a medium level of the *bid amount* variable. Figure 7.14 shows that the *level of competition* had a slight decreasing effect on the frequency of change orders. The condition was a medium level of the *proportion of difference between the first and second bids* variable.

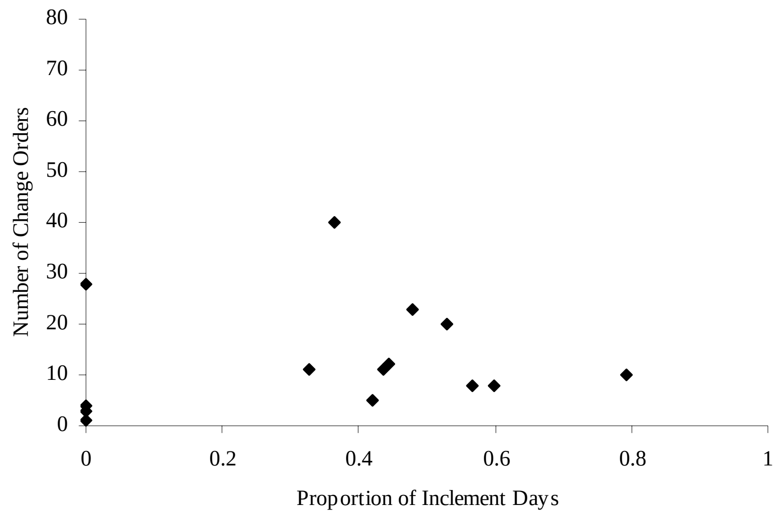

Figure 7.13: Variation of the Frequency of Change Orders with the Proportion of Inclement Days

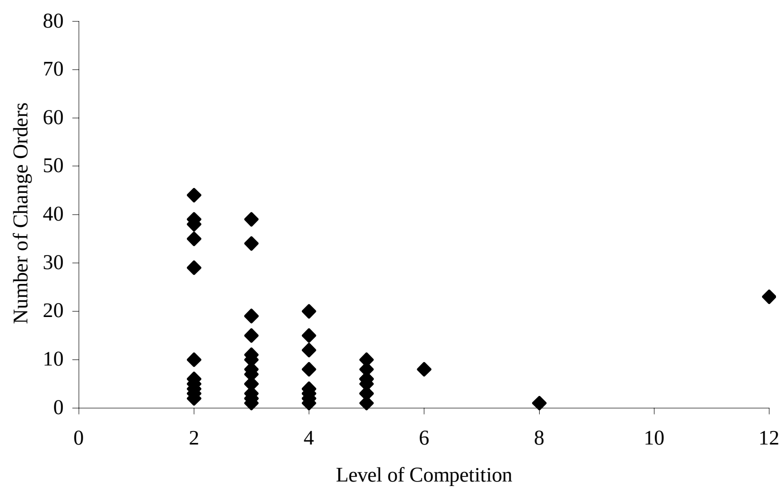

Figure 7.14: Variation of the Frequency of Change Orders with the *Level of Competition*

Figure 7.15 shows that increasing *proportion of difference between the first and second bid* is associated with decreased frequency of change orders. The condition was a medium level of the *level of competition* variable. The condition for Figure 7.16 is a medium level of the *level of competition* variable. It shows that if this proportion of difference was high, the frequency of change orders is lower than for small proportions.

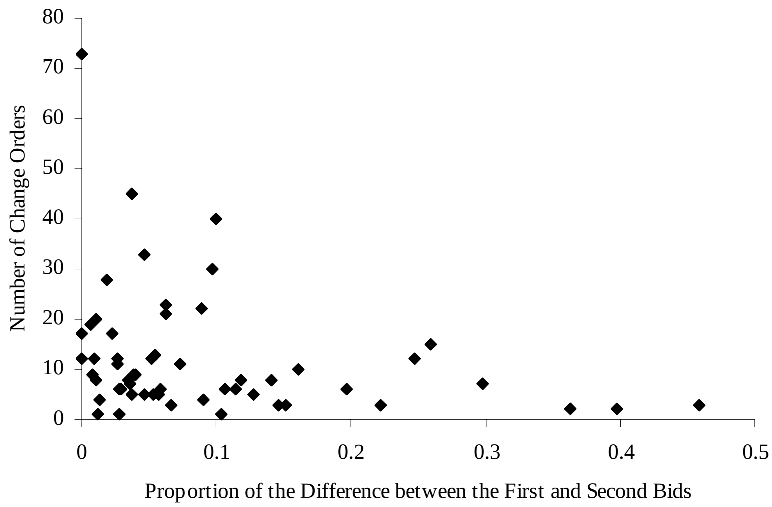

Figure 7.15: Variation of the Frequency of Change Orders with
the *Proportion of the Difference between the First and Second Bid*

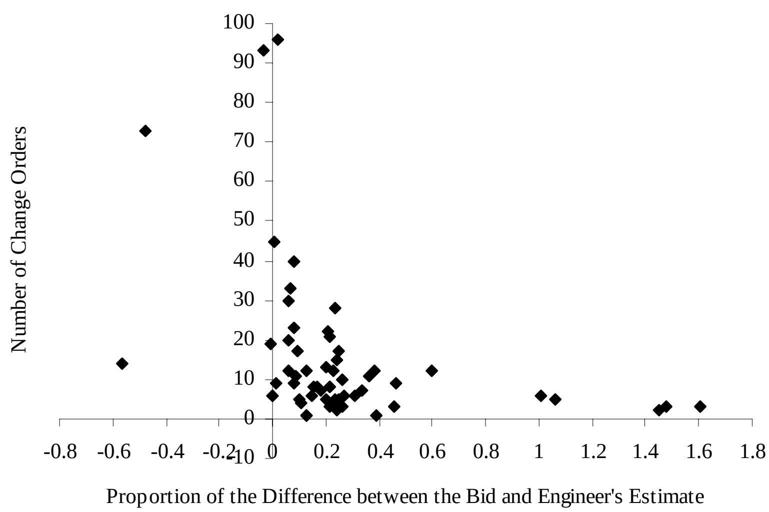

Figure 7.16: Variation of the Frequency of Change Orders with
the *Proportion of the Difference between the Winning Bid and Engineer's Estimate*

In Figure 7.17, the following conditions on the variables were used: a medium level of the proportion of inclement days variable and a medium level of the level of competition variable. The figure shows that as the bid amount increased, the frequency of change orders also increased.

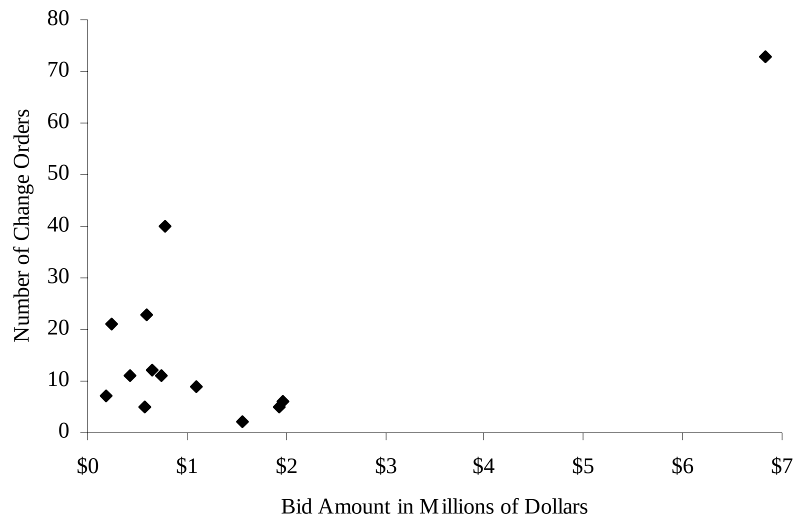

Figure 7.17: Variation of the Frequency of Change Orders with the Bid Amount

7.5.4 Conclusions for the Graphical Analysis

Table 7.14 summarizes the findings of the graphical analysis that sought to discern any clear trends in the relationships between the potentially influential factors (independent variables) on cost overruns, time delay, and change order frequency.

Table 7.5: Effects of each Independent Variable on the Dependent Variables

Independent Variable	Effect of Increasing Independent Variable on the following Dependent Variables while Keeping Other Independent Variables at a Fixed Level		
	Cost Overrun	Time Overrun	Frequency of Change Orders
Bid Amount	Increasing effect	Decreasing effect	Increasing effect
Length		Decreasing effect	
Proportion of Inclement Days	Increasing effect	Decreasing effect	Increasing effect
Level of Competition	No influence	Slightly decreasing effect	No influence
Proportion of the Difference between the First and Second Bid	Decreasing effect	Slightly decreasing effect	Decreasing effect
Proportion of the Difference between the Winning Bid and the Engineer's Estimate	Decreasing effect	Decreasing effect	Decreasing effect

This analysis provided somewhat contradicting results. The bid amount had a decreasing effect on time delays, although it was expected that the influence would be always increasing. The bid comparison variable had either no influence or a decreasing influence. The proportion of inclement weather days had an increasing effect, except on time delays.

7.6 Chapter Summary

The preliminary statistical investigations in the present chapter helped identify trends between cost overruns, time delay and change order frequency on one hand and the potentially influential factors on the other hand, and also to establish a-priori expectations of the strength and direction of such relationships. The correlation matrix analysis indicated no significant linear correlation between the independent variables, except for the two variables: *proportion of the difference between the first and second bids* and *proportion of difference between the winning bid and engineer's estimate*. The analysis of variance showed that the variables, *bid amount*, *proportion of inclement weather days* and *duration* had significant differences among cost overruns, time delays, and frequency of change orders.

The results of the pair-wise test and the graphical analysis did not yield results that were always consistent with the analysis of variance. For example, the *proportion of inclement day*s seemed to have a significant impact on cost overruns using graphical analysis, but the ANOVA test indicated otherwise. However, it is not unexpected to obtain such seemingly contradictory results from such analyses. The pair-wise t-test analysis or the influence analysis was conducted with very precise data characteristics and may have occluded some general trends that were revealed in the ANOVA tests. The results in this chapter provide only general hints for a-priori expectations for further investigations and results that are discussed in Chapter 8.

CHAPTER 8: STATISTICAL MODELS

8.1 Introduction

The present chapter investigates the influence of variables found significant from analyses presented in the previous chapter. This is done for cost overrun, time delay, and change orders. It is worth mentioning that the primary goal of the modeling process was to identify or confirm the magnitude and direction of the impacts of the variables, while the use of the developed models for prediction was considered only a secondary goal.

For each of the three response variables, two models were developed: one that included "bid comparison" variables, and one that excluded such variables. Models that included the "bid comparison" variables were developed using only those observations for which such data was available, and therefore the dataset for such models was only a subset of the full dataset. Such models are applicable in cases where bid have been received for a contract, and INDOT seeks to estimate the expected cost overruns, time delay or change orders for the contract. Models that excluded the "bid comparison" variables were developed using the entire dataset. Such models are applicable in cases where no bids are yet available for a contract, and are therefore useful for long term planning and estimation of expected cost overruns, time delay or change orders for contracts. The " bid comparison" variables are the *proportion of the difference between the amounts for the winning bid and the second bid*, the *proportion of the difference between the winning bid and the engineer's estimate,* and the *level of competition*. Each model was validated using 25% of data points set aside for that purpose.
Figure 8.1 presents a schematic framework of the modeling process.

The strength and magnitude of factors affecting change order frequency and amounts, time delay, and cost overrun amounts and rates, models were investigated using regression modeling. Recognizing that efforts by INDOT to predict these parameters for future projects may be constrained by lack of bidding information, separate models were attempted for cases where bid comparison variables are available and where such variables are not available. The regression modeling was carried out for each project type.

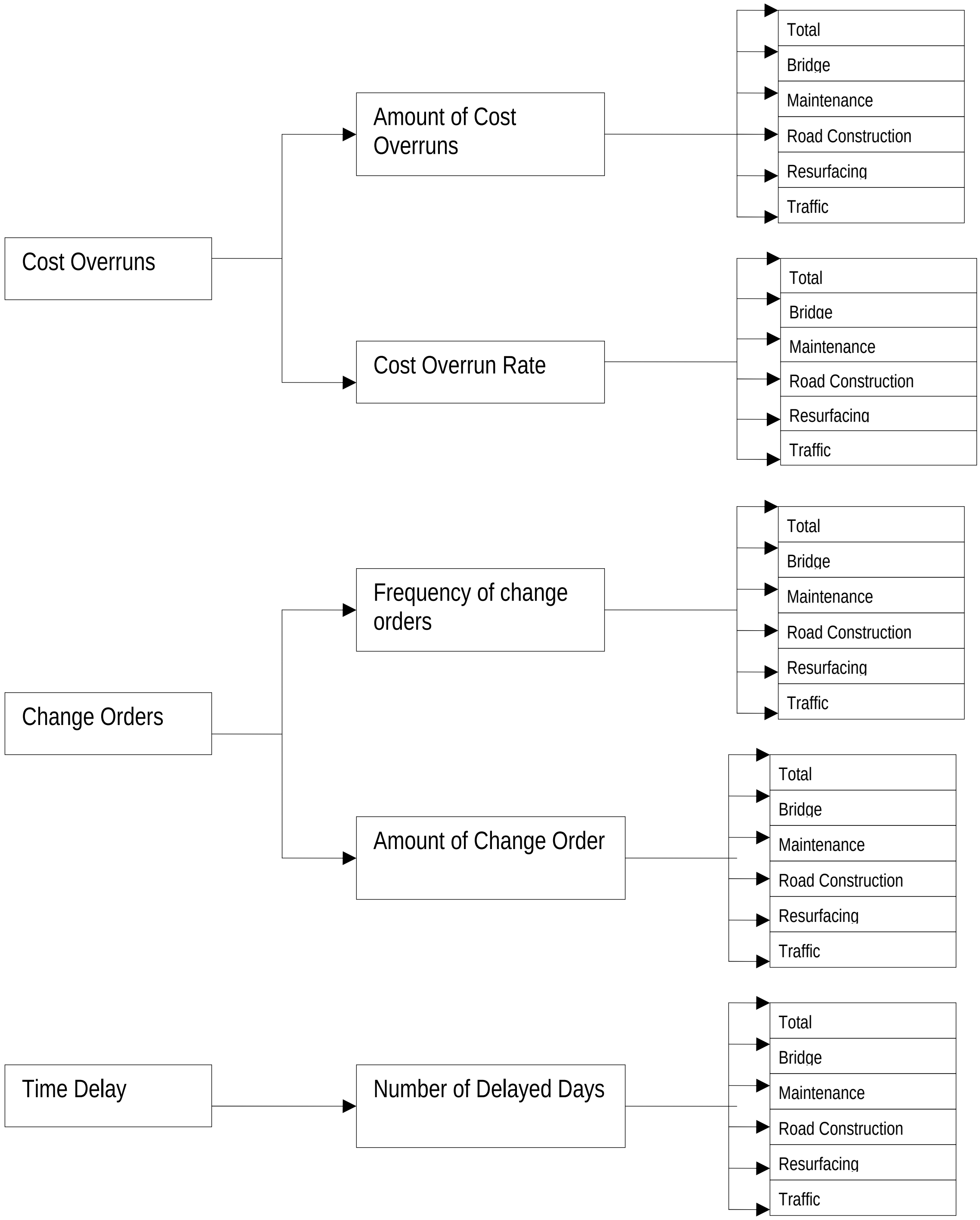

Figure 8.1: Organization of the Modeling Process

8.2 Models for Change Orders

Models were developed was attempted to identify the strength and magnitude of factors affecting change order frequency and also to estimate the amount involved in change orders. The first phase of the modeling exercise involved exclusion of the “bid comparison” variables, and the second phase involved inclusion of such variables. Models were developed first for all project types combined, and then separately for each project type.

8.2.1 Models for Change Order Frequency

8.2.1.1 Estimating the Frequency of Change Orders for All Project Types Combined

Several functional forms were investigated for developing the model for frequency of change orders. It was found that the linear model provided the best results. Table 8.1 below presents the model results for the estimated frequency of change orders given independent variables such as the *project type*, *location by district*, *bid amount* and *proportion of inclement days*.

Table 8.1: Linear Change Order Model Excluding the “Bid Comparison” Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Bridge Project	*B*	21.94	2.78	7.89	0.00
Maintenance Project	*M*	19.63	2.61	7.51	0.00
Road Construction Project	*R*	19.44	2.82	6.89	0.00
Traffic Project	*T*	20.19	3.50	5.77	0.00
Resurfacing Project	*RS*	19.56	3.20	6.12	0.00
Fort Wayne District	*FortW*	7.75	3.34	2.32	0.02
Proportion of Inclement Days	*PNINCL*	-3.13	1.69	-1.85	0.07
Bid Amount/1,000,000	*bidamount*	1.43	0.58	2.46	0.01

Adjusted R^2 = 0.368
Number of Observations = 555
Response Variable (*NCO*) is the Number of Change Orders Associated with a Contract

$$NCO = 21.94 * B + 19.63 * M + 19.44 * R + 20.19 * T + 19.56 * RS + 7.75 * Fortw - 3.13 * Pnincl + 1.43 * \frac{bidamount}{1{,}000{,}000}$$

The influence of each of the five project types on the frequency of change orders was found significant. Bridge projects were found to be associated with the highest frequency of change orders compared to the other project types. This is probably due to uncertainties regarding the quantities of bridge related work. Such uncertainties, which may include bridge structure and foundation defects that were probably not seen at time of inspection, but were subsequently uncovered during the construction work. On the other hand, traffic maintenance (which was assigned a value of zero for each of the above project type variables) was associated with the least frequency of change orders. This finding suggests that parties responsible for estimating the quantities required for traffic maintenance are providing better estimates which are in turn due to the fact that traffic maintenance work is less vulnerable to uncertainties at the site. The modeling results also showed that there are differences in the frequency of change orders across districts. It was seen that compared to projects at all other districts, projects in the Fort Wayne District were associated with a larger frequency of change orders, all other factors being equal. This finding can be attributed to the highly variable nature of ground conditions in the Fort Wayne district (Labi, 2001). Glacial depositional features in the region include moraines, outwash plains, kames, and lake plains, and surface geology in this area consist of a diverse mix of sediments with highly variable hydrogeologic properties and lithographic discontinuities [Fenelon et al., 1994]. Postglacial landforms in this region include a multiplicity of lakes found in northeastern Indiana, and the frequent pockets of muck and peat bogs that arise from the damming of drainage areas. The highly variable nature of the soils in the Fort Wayne District may therefore be responsible for the relatively high frequency of change orders in that district compared to the other districts.

The model results also showed that all else being the same, the higher the bid amount, the higher the frequency of change orders, a finding that is consistent with expectation. Finally, the model showed a decreasing effect of the proportion of inclement days on the frequency of change orders. This finding is counter intuitive, but it can be noted that the significant is only marginal, as seen from the t-statistic. The final model may be used by INDOT to estimate the expected number of change orders for a future project of any type where the “bid comparison” variables are not known.

Another model was developed that included the “bid comparison” variables, i.e., the level of competition, the proportion of the difference between the winning and second bids and the proportion of the difference between the winning bid and the engineer’s estimate. Again, several functional forms were tried for that model, but even the best model had an adjusted R^2 of only 0.135.

8.2.1.2 Frequency of Change Orders for Bridge Projects

In a similar manner done for all project types combined, a model was developed for estimating the frequency of change orders associated with bridge projects. Again, several functional forms were tried, and the form that gave the best results was the linear form as shown below:

Table 8.2: Model for Frequency of change orders
for Bridge Projects, Excluding "Bid Comparison" Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Proportion of Inclement Days	*PNINCL*	-7.18	4.54	-1.58	0.12
Natural Logarithm of Bid Amount	*Ln(bidamount)*	2.11	0.29	7.15	0.00

Adjusted R^2 = 0.369
Number of Observations =126
Response Variable (*NCO*) is the Number of Change Orders Associated with a Contract

The proportion of inclement weather days was found to be only marginally significant in the model. Also, the model results showed that a higher bid amount is associated with a greater frequency of change orders, all else being equal. Validation of the model yielded a root mean square error of 25 units. INDOT may use this model to estimate the expected number of change orders for future contracts where the "bid comparison" variables are not known.

For estimating the expected frequency of change orders for bridge projects, another model was developed to include the "bid comparison" variables. Again, several functional forms were tried for that model, and the best model had an adjusted R^2 of 0.407. The significant variables were the *proportion of inclement weather days* (decreasing effect), the *bid amount* (increasing effect), and the *proportion of the difference between the bid and engineer's estimate* (decreasing effect). This model is appropriate for use by INDOT to predict the expected number of change orders for future contracts where the "bid comparison" variables are known.

8.2.1.3 Frequency of Change Orders for Maintenance Projects

For maintenance projects, the linear functional form yielded the most encouraging results, even though the adjusted R^2 of 0.232 may be considered relatively low. Three variables representing the project *location* were found significant: Crawfordsville, Fort Wayne and Seymour Districts. The results showed that maintenance projects in these districts had more change orders than the other districts, all else being equal. This finding may be attributed to natural variations in the project environment or management culture and practices. The model results also showed that the higher the *proportion of inclement days*, the greater the frequency of change orders. Also, the results showed that all else being the same, a higher *bid amount* significantly and directly influences the frequency of change orders.

In order to estimate the expected frequency of change orders for maintenance projects where "bid comparison" variables are known, another model was developed. After investigating the linear, quadratic and logarithmic functional forms, the logarithmic form was selected because it had the highest R^2. For all the functional forms that were tried, the *bid amount* had a (counter-intuitive) inverse relationship with the frequency of change orders for maintenance projects, and this may be attributed to the small number of observations (34) for which data were available. The models also showed that the location of projects at Crawfordsville and Laporte Districts had diametrically opposite effects on the frequency of change orders, while the location at the other districts do not seem to influence the frequency of change orders. The models also showed that the higher the *proportion of inclement days*, the higher the frequency of change orders, all else being equal, which is quite intuitive. Finally, it was seen that a higher frequency of change orders are obtained for a lower proportion of the *difference between the winning bid amount and the engineer's estimate* (which is intuitive), and for a lower proportion of the *difference between the winning and second bid* (which is counter-intuitive). The R^2 was 0.414. The logarithmic and linear models used the same variables, yielded the same coefficient signs of the variables except for the bid amount, and had comparable R^2 values. The logarithmic model validation yielded a percentage deviation of 6.3 and a root mean square error of 26.8 units. This model may be used by INDOT to predict the expected frequency of change orders for maintenance projects where the "bid comparison" variables are known.

Table 8.3: Model for Frequency of Change Orders
for Maintenance Projects, Including the "Bid Comparison" Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	1.65	0.30	5.46	0.00
Crawfordsville District	*CRAWF*	0.15	0.06	2.53	0.02
La Porte District / 100	*LAPOR*	-8.36	0.05	-1.58	0.13
Proportion of Inclement Days / 100	*PNINCL2*	4.32	0.02	1.86	0.07
Proportion of the Difference between the First and Second Bid	*PDIFSEC*	-0.23	0.10	-2.29	0.03
Proportion of the Difference between the Bid Amount and the Engineer's Estimate	*PDIFENG*	-0.28	0.08	-3.63	0.00
Natural Logarithmic of the Bid Amount / 100	*Ln(bidamount)*	-3.39	0.02	-1.48	0.15

Response variable is the natural exponent of the Frequency of change orders
Adjusted R^2 = 0.43
Number of Observations = 35
Response Variable (*NCO*) is the Number of Change Orders Associated with a Contract

8.2.1.4 Frequency of Change Orders for Road Construction Projects

To investigate the factors affecting the frequency of change orders associated with road construction projects and to predict the expected number of change orders for a future road construction project, various regression models were investigated. The initial models excluded the "bid comparison" variables, and a linear model was adjudged the most appropriate form for such models. The results are shown in Table 8.4.

Table 8.4: Change Order Frequency Model
for Road Construction Projects Excluding the "Bid Comparison" Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	11.54	4.29	2.69	0.01
Fort Wayne District	*FORTW*	14.11	5.62	2.51	0.01
Square Root of Bid Amount, in 1,000's	*SQRT(bidamount)*	7.82	0.00	1.60	0.11

Adjusted R^2 = 0.45
Number of Observations = 142
Response Variable (*NCO*) is the Number of Change Orders Associated with a Contract

$$NCO = 11.54 + 14.11 * Fortw + 7.82 * \frac{\sqrt{bidamount}}{1{,}000}$$

The model shown above had a R^2 of 0.45 and contained two variables: the *Fort Wayne District*, and a transformed variable representing the *bid amount*. The model results showed that all else being the same, road construction projects in Fort Wayne District had a greater frequency of change orders compared to similar projects in other districts. This finding is similar to that for the all projects combined, and may be attributed to the highly variable nature of the Fort Wayne subsoils. Also, the model showed that a higher bid amount translates directly to a higher frequency of change orders, all other factors remaining the same. This result is consistent with expectation. Validation of the model was carried out using the reserved dataset for that purpose, and it yielded a percentage deviation of 113% and a root mean square error of 21 units. INDOT may use this model to predict the expected frequency of change orders for road construction projects where the "bid comparison" variables are not known.

For estimating the frequency of change orders for road construction projects, another model was developed to include the "bid comparison" variables. Regardless of functional form, the models obtained had relatively poor validation statistics. The significant variables were the *proportion of the difference between the winning bid and engineer's estimate*, the *proportion of the difference between the winning and second bid, and the bid amount*.

8.2.1.5 Frequency of Change Orders for Traffic Projects

For the traffic projects and excluding the "bid comparison" variables, the modeling process indicated generally poor fits regardless of functional form used. Compared to the other functional forms, the linear form had the highest adjusted R^2 of 0.122 and only the *bid amount* variable was found to be significant.

When the "bid comparison" variables were included, the linear and logarithmic forms gave similar results, but the latter gave a better R^2. The model results showed that projects located at the Crawfordsville District seemed to experience more change orders for traffic projects. It may be noted that unlike road construction projects, traffic project scopes are relatively less influenced by variations in the project environment; therefore district such as Fort Wayne did not have a larger frequency of change orders for this project type. As such, the higher frequencies of change orders in Crawfordsville District may be attributed to its administrative/management practices or other peculiar environment. Finally, it was seen that a higher frequency of change orders are obtained for a lower *proportion of the difference between the winning bid amount and the engineer's estimate* (which is intuitive), and for a higher *proportion of the difference between the winning and second bid* (which is intuitive). It is worth noting that even though the number of observations was rather small (17), the adjusted R^2 was quite high (0.724). Validation of the model yielded a percentage deviation of 5.63 and a root mean square error of 11.2. Even though the quadratic form had similar results as the linear and logarithmic forms, and even had a better R^2 (0.788), it had relatively poor validation statistics. INDOT may use this model to predict the expected frequency of change orders for traffic projects where the "bid comparison" variables are known.

Table 8.5: Model for Estimating Frequency of Change Orders for Traffic Projects Including the "Bid Comparison" Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	1.38	0.10	13.35	0.00
Crawfordsville District	*CRAWF*	0.17	0.11	1.51	0.16
Proportion of the Difference between the First and Second Bid	*PDIFSEC*	2.40	0.49	4.85	0.00
Proportion of the Difference between the Bid Amount and the Engineer's Estimate	*PDIFENG*	-1.42	0.29	-4.84	0.00
Bid Amount / 1,000,000	*Amoun6*	-0.16	0.08	-2.08	0.06

Response Variable is the exponent of the Frequency of change orders
Adjusted R^2 = 0.724
Number of Observations = 17
Response Variable (*NCO*) is the Number of Change Orders Associated with a Contract

$$NCO = \ln\left(1.38 + 0.17 * Crawf + 2.4 * Pdifse - 1.42 * Pdifeng - 0.16 * \frac{bidamount}{1{,}000{,}000}\right)$$

8.2.1.6 Frequency of Change Orders for Resurfacing Projects

Model development for estimating the frequency of change orders for road resurfacing projects was attempted using various functional forms, but the results showed that only the bid amount seems to be significant: A higher bid amount translates to a higher frequency of change orders, all else being equal. The logarithmic form provided the best fit, compared to the other forms. The model was validated using a dataset reserved for such purpose, and a percentage deviation and root mean square error of 29 and 50.5, respectively, were obtained. This model may be used by INDOT to estimate the frequency of change orders for future resurfacing projects where the “bid comparison” variables are not known.

Table 8.6: Model for Frequency of Change Orders for Resurfacing Projects Excluding the “Bid Comparison” Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Seymour District / 10	SEYMO1	1.44	0.11	1.31	0.19
Natural Logarithmic of the Bid Amount, in 100’s	Lnamou2	9.79	0.00	24.72	0.00

Response Variable is the exponent of the Frequency of change orders
Adjusted R^2 = 0.895
Number of Observations = 95
Response Variable (*NCO*) is the Number of Change Orders Associated with a Contract

$$NCO = \ln\left(1.44 * \frac{Seymo}{10} + 9.79 * \frac{\ln(bidamount)}{100}\right)$$

8.2.2 Change Order Amount

Model development was attempted to estimate the amount spent on all change orders in a given contract. However, the resulting models were not encouraging and such modeling efforts were abandoned. As such, the present study provides only average values of change order amounts by project type and by district (Table 8.7). It is seen that bridge projects are associated with the highest amount spent on change orders per contract. On the other hand, traffic maintenance projects have the least amount spent on change orders per contract. The results seem to be similar to those obtained for the frequency of change orders. It is seen that bridge projects in Crawfordsville and Seymour have the highest amount of change orders. Also, the table shows that maintenance and road construction projects located at Fort Wayne District have higher amounts spent on change orders, compared to such projects at other districts. Resurfacing and traffic projects at Seymour, and traffic maintenance projects at Laporte have the highest amount spent on change orders, compared to similar projects at the other districts. It may be interesting to examine the variations of average amount spent per change order given other attributes such as project type, district location, bid amount, and other factors.

Table 8.7: Average Change Order Amounts by Project Type and by District

Project Type	District	Average Amount for Change Orders Per Contract	Average per Project Type, for all Districts
Bridge	Crawfordsville	$245,409	$179,997
	Fort Wayne	$138,819	
	Greenfield	$174,451	
	La Porte	$161,581	
	Seymour	$234,006	
	Vincennes	$102,010	
Maintenance	Crawfordsville	$129,056	$164,082
	Fort Wayne	$431,666	
	Greenfield	$97,115	
	La Porte	$154,079	
	Seymour	$136,803	
	Vincennes	$86,312	
Road Construction	Crawfordsville	$210,919	$164,569
	Fort Wayne	$308,341	
	Greenfield	$115,616	
	La Porte	$115,531	
	Seymour	$181,504	
	Vincennes	$72,595	
Resurfacing	Crawfordsville	$109,371	$117,365
	Fort Wayne	$143,620	
	Greenfield	$57,369	
	La Porte	$41,635	
	Seymour	$189,894	
	Vincennes	$128,550	
	Fort Wayne	$28,583	
Traffic	Crawfordsville	$218,514	$162,776
	Fort Wayne	$79,912	
	Greenfield	$151,436	
	La Porte	$100,274	
	Seymour	$273,810	
	Vincennes	$181,156	
Traffic Maintenance	Crawfordsville	$51,824	$55,669
	Fort Wayne	$28,583	
	Greenfield	$42,215	
	La Porte	$100,965	
	Seymour	$46,534	
	Vincennes	not available	

8.3 Models for Estimating Time Delay and to Identify Influential Variables

The dataset for developing time delay models consisted of 1,452 contracts. In the present section of this report, the response variable was denoted by "*TD*", an estimate of the number of delayed days. A variable representing contract duration, computed as the time difference between the expected and actual last days of work, was added to the time delay dataset. The contract duration variable was not used in the cost overrun and change order models in order to avoid statistical bias that could arise from correlation between the *bid amount* and contract *duration* variables.

Models were developed was attempted to identify the strength and magnitude of factors affecting the extent of time delay. The first phase of the modeling exercise involved exclusion of the "bid comparison" variables, and the second phase involved inclusion of such variables. Models were developed first for all project types combined, and then separately for each project type.

8.3.1 Time Delay for All Project Types Combined

The modeling process started with the development of time delay models using a dataset that excluded the "bid comparison" variables. After deleting approximately 10% of outliers from the dataset, various functional forms were tried, and the linear model yielded the best results as shown below.

Table 8.8: Model for Time Delay for All Project Types Combined, Excluding the "Bid Comparison" Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	*(Constant)*	284.91	7.77	36.67	0.00
Bridge Project	*B*	14.29	7.88	1.81	0.07
Road Construction Project	*R*	27.70	8.22	3.37	0.00
Proportion of Inclement Weather Days	*PNINCL*	-351.45	14.61	-24.05	0.00
Project Duration	*LENGTH*	-0.50	0.03	-16.23	0.00
Bid Amount / 1,000,000	*amoun6*	9.29	1.40	6.61	0.00

Response variable is time delay (*TD*) in days
Adjusted R^2 = 0.345
Number of Observations =1305

$$TD = 284.91 + 14.29 * B + 27.70 * R - 351.45 * Pnincl + 9.29 * \frac{bidamount}{1,000,000} - 0.50 * Length$$

The model results showed that all other factors being the same, bridge and road construction projects experienced more time delays than the other project types. This may be due to the higher levels of uncertainty of field conditions, and design errors and omissions that are associated with road and bridge projects. The results also showed that a higher bid amount, all else being the same, resulted in a greater time delay. An interesting result was that a longer contract duration is associated with a smaller time delay. This finding seems rather surprising as a longer contract duration would typically be expected to have a greater time delay. It is possible that such unexpected finding was caused by correlation between the project duration and bid amount. However, the correlation matrix for these two variables did not reveal existence of any linear correlation. It may be interesting to carry out further investigation of these trends such as examining any existence of non-linear correlation between these two variables. Validation of the model showed rather high percentage deviation and root mean square error.

The model development was repeated with the consideration of the "bid comparison" variables. The linear and logarithmic functional forms gave good results, R^2 of 0.241 and 0.225, respectively. In this case, maintenance and resurfacing projects were found to be associated with less time delay compared to other project types, which is not inconsistent with the findings of the model that excluded the "bid comparison" variables. The proportion of inclement weather days was found to have an inverse effect on time delays, a finding which is contrary to expectation. The bid amount and duration variables had the same influence as found for the models that excluded the "bid comparison" variables. The variable representing the proportion of the difference between the first and second bid had a direct influence on contract time delay, which is consistent with expectation. INDOT may use this model to predict the expected time delay any project type where the "bid comparison" variables are not known.

8.3.2 Time Delay for Bridge Projects

For bridge projects, the best model was the linear model, with an R^2 of 0.355. Using this functional form, the following variables were significant: the proportion of inclement days (which had a decreasing effect on the response variable), the contract duration (which had a decreasing effect), and the bid amount (which had an increasing effect).

For time delay on bridge projects, the modeling process was repeated using "bid comparison" variables among other variables, and yielded a linear model with R^2 of 0.566. The following variables were found significant: *Seymour District* location, where projects were found to experience more time delays than at the other districts, the *proportion of inclement weather days* (which was seen to have an inverse relationship with time delay), the "bid comparison" variables (which were seen to have inconsistent effects on time delay), the project duration variable (which was seen to have an inverse relationship with time delay), and the bid amount (which had an increasing effect on time delay).

The logarithmic model yielded very similar results as that using the linear form. The influence of each variable on time delay remained the same, but the obtained R^2 was much smaller than for the linear model. The linear model was validated using 36 observations, and yielded a percentage deviation and root mean square error of 34.5 and 96.5, respectively. INDOT may use the linear model to predict the expected time delay for bridge projects where the "bid comparison" variables are known.

Table 8.9: Logarithmic Time Delay Model Including the "Bid Comparison" Variables for Bridge Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	1.20	0.05	24.45	0.00
Seymour District / 100	*SEYMO2*	8.3	0.04	2.15	0.04
Proportion of Inclement Days / 100	*PNINCL2*	-9.5	0.02	-4.36	0.00
Project Duration / 10,000	*LENGTH4*	-8.34	0.00	-3.72	0.00
Bid Amount / 100,000,000	*Amoun8*	8.24	0.02	3.45	0.00
Proportion of the Difference between the First and Second Bid / 10	*PDIFSEC1*	5.28	0.23	2.31	0.03
Proportion of the Difference between the Bid Amount and the Engineer's Estimate / 10	*PDIFENG1*	-1.78	0.09	-2.01	0.06

Response Variable: Exponent of time delay, where time delay is in days
Adjusted R^2 = 0.548
Number of Observations = 28

$$TD = \ln\left(1.2 + 8.3 * \frac{Seymo}{100} - 9.5 * \frac{Pnincl}{100} - 8.34 * \frac{Length}{10{,}000} + 8.24 * \frac{bidamount}{100{,}000{,}000} + 5.28 * \frac{Pdifse}{10} - 1.78 * \frac{Pdifeng}{10}\right)$$

8.3.3 Time Delay for Maintenance Projects

For time delay on maintenance projects, excluding the "bid comparison" variables, the following linear model shown in the Table 8.10 below was adjudged the best. Like the model for bridge projects, it was again found that the proportion of inclement weather days had a negative effect on time delay. Also, the bid amount was found to have a positive and expected effect on tie delay. The validation statistics showed rather poor prediction of the observed values. The percentage deviation was 3303 and the root mean square error was 204. INDOT may use this model to predict the expected time delay for maintenance projects where the "bid comparison" variables are not known.

The modeling process for estimating time delay of maintenance projects was repeated, this time with the inclusion of the "bid comparison" variables. However, such models did not provide any significant results possibly due to the paucity of observations.

Table 8.10: Time Delay Model Excluding the "Bid Comparison" Variables for Maintenance Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	*(Constant)*	285.95	15.39	18.58	0.00
Proportion of Inclement Weather Days	*PNINCL*	-398.51	38.75	-10.28	0.00
Bid Amount / 1,000,000	*amoun6*	10.63	3.08	3.45	0.00
Project Duration	*LENGTH*	-0.48	0.07	-7.26	0.00

Response Variable is the Time Delay (*TD*) in days
Adjusted $R^2 = 0.273$
Number of Observations = 314

$$TD = 285.95 - 398.51 * Pnincl - 0.48 * Length + 10.63 * \frac{bidamount}{1,000,000}$$

8.3.4 Time Delay for Road Construction Projects

For the 257 road construction projects, a model was developed for the estimation of time delay. It was found that the linear form produced the best results, which are shown in the table below. The model calibration and validation results were similar to those for bridge and maintenance projects.

Table 8.11: Time Delay Model Excluding the "Bid Comparison" Variables for Road Construction Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	*(Constant)*	304.83	20.12	15.15	0.00
Proportion of Inclement Weather Days	*PNINCL*	-347.40	33.26	-10.45	0.00
Bid Amount in millions	*amoun6*	5.67	2.96	1.92	0.06
Project Duration	*LENGTH*	-0.43	0.08	-5.60	0.00

Response Variable is the Time Delay (*TD*) in days
Adjusted $R^2 = 0.319$
Number of Observations = 257

$$TD = 304.83 - 347.40 * Pnincl + 5.67 * \frac{bidamount}{1,000,000} - 0.43 * Length$$

INDOT may use the developed model to predict the expected time delay for road construction projects where the "bid comparison" variables are not known.

The modeling process for estimating time delay on road construction projects was repeated with the "bid comparison" variables included. The linear functional form produced the best results, with an adjusted R^2 of 0.309. The two variables representing the proportions for "bid comparison" had an increasing effect on the response variable and the proportion of inclement weather days still had a decreasing effect on the number of delayed days. The results obtained using the logarithmic form were comparable to those obtained using the linear form, with a similar R^2 value and the same significant variables of similar magnitude and direction.

8.3.5 Time Delay for Traffic Projects

The time delay experienced on traffic projects were modeled using 183 contracts for which such data were available. At the initial phase of the modeling process, "bid comparison" variables were excluded. Again, it was found that the linear model seemed to provide the best explanations for the trends in the data. The model calibration and validation results were similar to those for bridge and maintenance projects.

Table 8.12: Time Delay Model Excluding the "Bid Comparison" Variables for Traffic Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	*(Constant)*	320.84	20.79	15.43	0.00
Proportion of Inclement Weather Days	*PNINCL*	-377.75	37.39	-10.10	0.00
Bid Amount in millions	*amoun6*	21.83	5.01	4.36	0.00
Project Duration	*LENGTH*	-0.76	0.10	-7.82	0.00

Response Variable is the Time Delay (*TD*) in days
Adjusted R^2 = 0.430
Number of Observations = 183

$$TD = 320.84 - 377.75 * Pnincl - 0.76 * Length + 21.83 * \frac{Bidamount}{1{,}000{,}000}$$

INDOT may use this model to predict the expected time delay for bridge projects where the "bid comparison" variables are not known.

Model development was then attempted for estimating the time delay associated with traffic projects, this time with the inclusion of the "bid comparison" variables. However, such efforts did not produce any significant results because the observations were inadequate.

8.3.6 Time Delay for Resurfacing Projects

Data from 247 contracts were used to develop a model for estimating the time delay associated with resurfacing projects. After exhaustive investigation of various functional forms, the linear model was found to provide the best explanation, and had an R^2 of 0.394. Similar results were obtained as in the models for the time delay on other project types. However, in this case, the location of a project in Fort Wayne District seemed to be associated with less time delay than similar projects located at other districts all else being the same. This may be attributable to differences in management practices.

Table 8.13: Time Delay Model Excluding the "Bid Comparison" Variables for Resurfacing Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	306.98	17.00	18.05	0.00
Fort Wayne District location	*FORTW*	-38.97	16.22	-2.40	0.02
Proportion of Inclement Weather Days	*PNINCL*	-378.84	33.42	-11.33	0.00
Bid Amount / 1,000,000	*amoun6*	6.55	2.69	2.43	0.02
Project Duration	*LENGTH*	-0.53	0.06	-8.39	0.00

Response Variable is the Time Delay (*TD*) in days
Adjusted $R^2 = 0.394$
Number of Observations = 247

$$TD = 306.98 - 38.97 * Fortw - 378.84 * Pnincl - 0.53 * Length + 6.55 * \frac{Bidamount}{1{,}000{,}000}$$

INDOT may use this model to predict the expected time delay for resurfacing projects where the "bid comparison" variables are not known.

The modeling process for estimating time delay on resurfacing projects was repeated taking into the consideration the "bid comparison" variables, but various efforts in this regard did not yield any significant results largely because of lack of adequate observations.

8.3.7 Discussion for Time Delay Models

It can be noticed that for all the time delay models, the *proportion of inclement days* was not only consistently the most significant variable, but also had a negative sign, implying the higher the proportion of inclement weather, the lower the time delay. This seems to be contrary to expectation, and the reason for this finding requires further investigation. Also, the higher the project duration the lower the time delays. This also seems counter intuitive but probably suggests that contract periods are made more realistic for larger contracts. The bid amount variable was always significant and had an increasing effect on the dependent variable. The differences in the direction of the impacts of these two contract size variables shows that there could be some correlation between the two variables that could be investigated in a future study.

8.4 Models for Estimating Cost Overruns and Identifying Influential Factors

Models were developed was attempted to identify the strength and magnitude of factors affecting cost overrun amounts and cost overrun rates, and also to estimate the amount of cost overruns. The first phase of the modeling exercise involved exclusion of the “bid comparison” variables, and the second phase involved inclusion of such variables. Models were developed first for all project types combined, and then separately for each project type.

8.4.1 Estimation of Cost Overrun Amounts

8.4.1.1 Cost Overrun Amounts All Project Types Combined

In the present section, the dependent variable, *CO*, denotes the amount incurred in cost overruns for a contract. The first phase of the modeling process did not include the “bid comparison” variables. Various functional forms and transformations were attempted and the linear functional form yielded the most intuitive results (Table 8.14).

Table 8.14: Model for Cost Overrun Amount Excluding the “Bid Comparison” Variables

Variable		Coefficient	Std. Error	t-stat	P-value
Maintenance Project	*M*	-3.16	1.10	-2.86	0.00
Road Construction Project	*R*	-2.47	1.19	-2.07	0.04
Traffic Project	*T*	-3.08	1.43	-2.16	0.03
Fort Wayne District	*FORTW*	2.98	1.36	2.19	0.03
Laporte District	*LAPOR*	-2.34	1.37	-1.71	0.09
Bid Amount in millions	*amoun6*	6.45	0.25	26.17	0.00

Response Variable is the Cost Overrun (CO) in $10,000’s
Adjusted R^2 = 0.303
Number of Observations = 1664

$$\frac{CO}{10{,}000} = -3.16 * M - 2.47 * R - 3.08 * T + 2.98 * Fortw - 2.34 * Lapor + 6.45 * \frac{bidamount}{1{,}000{,}000}$$

The model results show that maintenance, road construction, and traffic projects generally had fewer cost overruns compared to other project types, all other factors being the same. For maintenance and traffic projects, this finding can be explained by the relatively low amounts involved in each contract of such project types. For road construction projects, quantities are estimated at design stage and final amount of work done depends more on established quantities rather than from inspection data. It may be argued that such projects may be vulnerable to unexpected or variable site conditions, thus making such projects have high overruns. The sign obtained therefore appears to be a net effect of these two contrasting justifications. Besides, the variable representing district which was found significant, may account partly for the relationship between high cost overruns and site variability. The model showed that a project located at Fort Wayne District is associated with more cost overruns compared to other districts, all else being equal. Also, the model showed that projects located at Laporte District is associated with lower cost overruns compared to other districts, all other factors being the same. It was found that the *bid amount* variable was the most significant, and that a higher bid amount translates to a higher amount of cost overruns, all else being equal. The proportion of inclement weather days was not found to be significant. Validation of the models yielded rather high values of percentage deviation (5814) and root mean square error ($309,000). INDOT may use the developed model to predict the expected cost overrun for any project type where the “bid comparison” variables are not known.

The model development was also carried out to include the “bid comparison” variables. Of the several forms investigated, only the logarithmic form produced encouraging results, with an R^2 of 0.23. The model showed that traffic maintenance projects generally had more cost overruns than other project types, all else being the same. Also, it was found that a higher level of competition was associated with a greater amount of cost overruns. This may be attributed to the fact that in a competitive environment, contractors try to reduce their prices as much as possible, but such reductions may result in unrealistic bid prices. Finally, the model with the “bid comparison” variables showed that a higher bid amount had an increasing effect on cost overruns. INDOT may use this model to predict the expected cost overrun amount for any project type where the “bid comparison” variables are known.

8.4.1.2 Cost Overrun Amounts for Bridge Projects

Using the 449 bridge contracts, models were developed to estimate the amount of cost overruns for bridge projects. The first step was to exclude the “bid comparison” variables. The linear model was found to be the most intuitive and gave the best results. From the model results, it is suggested that bridge projects located at Laporte District experienced fewer cost overruns than those located at other districts, all other factors being the same. Also, the bid amount had an increasing effect on cost overrun amount. This model may be used by INDOT to predict the expected cost overrun for bridge projects where the “bid comparison” variables are unknown.

Table 8.15: Cost Overrun Amount Model Excluding the "Bid Comparison" Variables for Bridge Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	-2.29	0.89	-2.58	0.01
Laporte District	LAPOR	-3.17	1.85	-1.72	0.09
Bid Amount in millions	amoun6	8.11	0.38	21.28	0.00

Response Variable is the Cost Overrun (CO) in $millions
Adjusted $R^2 = 0.505$
Number of Observations = 449

$$\frac{CO}{1{,}000{,}000} = -2.29 - 3.17 * Lapor + 8.11 * \frac{bidamount}{1{,}000{,}000}$$

The modeling process was repeated using the "bid comparison" variables, and again the linear model was found to be most explanatory of the observations, with an adjusted R^2 of 0.212. It was seen that bridge projects located at Greenfield and Seymour Districts experienced smaller cost overruns amounts than those at other districts, all else being the same. It was also seen that when there are more bidders for a contract, the cost overrun amount increases, which is intuitive. Also, for a higher proportion of the difference between the bid and the engineer's estimate, the model suggests that there is a smaller cost overrun amount. The final model may be used by INDOT to estimate the expected cost overrun amount for future bridge projects where the "bid comparison" variables are known.

8.4.1.3 Cost Overrun Amounts for Maintenance Projects

Attempts to develop models that explain the variability of cost overrun amounts of maintenance projects did not yield any encouraging results, regardless of functional form and inclusion (or otherwise) of "bid comparison" variables.

8.4.1.4 Cost Overrun Amounts for Road Construction Projects

Data on a total of 449 road construction projects served as the basis for developing a model to estimate the cost overrun amount for road construction projects. The first phase of model development involved exclusion of the "bid comparison" variables. The linear functional form provided the best results, as shown in the Table 8.16 below.

Table 8.16: Cost Overrun Amount Model Excluding "Bid Comparison" Variables, Road Construction Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Seymour District	SEYMO	-3.92	2.40	-1.63	0.10
Bid Amount / 1,000,000	amoun6	5.55	0.36	15.59	0.00

Response Variable is the Cost Overrun (CO) in $10,000's
Adjusted $R^2 = 0.351$
Number of Observations = 449

$$\frac{CO}{1{,}000{,}000} = -3.92 * seymo + 5.55 * \frac{bidamount}{1{,}000{,}000}$$

It was found that road construction projects located at Seymour District generally had smaller cost overruns amounts compared to projects at other districts. This may be attributed to differences in management practices. 137 observations were used to validate the model, and the validation statistics obtained were rather high. An attempt was made to find a significant model for the "amount of cost overrun model with the "bid comparison" variables for road construction projects," but the resulting models were consistently poor, with few relevant variables and very low R^2 values (about 1%). Further investigation using a logarithmic model did not provide a better result. The final model may be used by INDOT to estimate the expected cost overrun amount for future road construction projects where the "bid comparison" variables are not known.

8.4.1.5 Cost Overrun Amounts for Traffic Projects

Attempts to develop models that explain the variability of cost overrun amounts of traffic projects did not yield any encouraging results, regardless of functional form and inclusion (or otherwise) of "bid comparison" variables.

8.4.1.6 Cost Overrun Amounts for Resurfacing Projects

Models were developed was carried out to identify the strength and magnitude of factors affecting cost overruns, and also to estimate the amount of cost overruns for resurfacing projects. The first phase of the modeling exercise was to exclude the "bid comparison" variables, and both linear and logarithmic regressions provided good results. For the linear model (adjusted R^2 of 0.565), resurfacing projects located in Vincennes District seemed to experience a greater cost overrun amount compared to projects located in other districts, all other factors being equal. Also, the results suggest that the *bid amount* variable is significant and has an increasing effect on cost overrun amount. Logarithmic forms were also investigated but yielded an R^2 of 0.308 and suggested that the only significant variable was the bid amount. The final model may be used by INDOT to estimate the expected cost overrun amount for future resurfacing projects where the "bid comparison" variables are not known.

In the second phase of the modeling, the "bid comparison" variables were included. Again, both functional forms provided good results. The linear form produced a high R^2 of 0.804, and the three "bid comparison" variables were found significant. The *level of competition* had a decreasing effect, suggesting that higher competition is associated with lower cost overruns, but this finding may be considered counter intuitive. The results also suggest that for resurfacing projects, when the *difference between the winning bid and second bid* was high, greater cost overrun amounts are encountered, and when the *difference between the winning bid and the engineer's estimate* was high, there were lower cost overruns. Both results are consistent with expectation. Resurfacing projects located in Seymour District seemed to experience a smaller amount of cost overruns compared to similar projects at other districts, all else being the same, a finding that is similar to that found for road construction projects, and may be attributed to management practices at the highway administrative district of Seymour. The results also indicate that for resurfacing projects, the bid amount had an increasing effect on the dependent variable, which is quite intuitive. The logarithmic model produced similar results as those obtained using the linear model with a few differences in the variables that were found significant. Specifically, the variable representing the level of competition was not found significant. Also, the results suggest that projects located in both Laporte and Crawfordsville Districts generally experienced more cost overruns compared to those located in other districts. The other two "bid comparison" variables were found significant and had the same influence on the dependent variable as in the case of the linear model. Furthermore, the bid amount was found significant with an increasing effect on cost overruns, which is intuitive. With 12 observations, the validation yielded rather high values for the percentage deviation and the root mean square error (2,180 and $1,121,752, respectively). INDOT may use the final model to estimate the expected cost overrun amount for future resurfacing projects where the "bid comparison" variables are known.

Table 8.17: Logarithmic Cost Overrun Amount Model Including the "Bid Comparison" Variables for Resurfacing Projects

Variable		Coefficient	Std. Error	t-stat	P-value
Constant Term	(Constant)	0.86	0.07	11.93	0.00
Crawfordsville District / 10	CRAWF1	1.63	0.10	1.69	0.10
Bid Amount / 10,000,000	Amoun7	2.6	0.03	8.82	0.00
Proportion of the Difference between the First and Second Bid / 10	PDIFSEC1	7.89	0.38	2.07	0.05
Proportion of the Difference between the Bid Amount and the Engineer's Estimate / 10	PDIFENG1	-3.88	0.17	-2.32	0.03
Laporte District / 10	LAPOR1	1.79	0.13	1.36	0.19

Response Variable is the Exponent of Cost Overrun (CO) in $10,000's
Adjusted $R^2 = 0.804$
Number of Observations = 31

$$\frac{CO}{1{,}000{,}000} = \ln\left(0.86 + 1.63 * \frac{Crawf}{10} + 2.6 * \frac{bidamount}{10{,}000{,}000} + 7.89 * \frac{Pdifse}{10} - 3.88 * \frac{Pdifeng}{10} + 1.79 * \frac{Lapor}{10}\right)$$

8.4.2 Cost Overrun Rate

The modeling investigation for the dependent variable “cost overrun rate” did not produce any satisfactory results compared to those concerning cost overrun amounts as discussed in the preceding section. Attempts to develop cost overrun rate models yielded poor R^2 and no statistically significant variables.

8.5 Chapter Discussion

For models that estimate the time delay for a project, the R^2 varied between 0.27 and 0.55, depending on the project type, whether the model included “bid comparison” variables, and functional form. Also, for models that were developed to estimate the amount of cost overrun likely to be experienced on a project, the R^2 varied between 0.30 and 0.80, depending on the above attributes. Furthermore, for models that estimated the Frequency of change orders for a project, the R^2 varied between 0.37 and 0.89. Among the several models developed in each category, the best model was selected based on the R^2 and the results of the validation tests. Table 8.18 summarizes these categorizations, while Table 8.19 provides the significant variables in each model.

Table 8.18: Categories of Calibrated Models and Their Coefficients of Determination

Model Type	Change Order		Time Delay		Cost Overrun	
	Model Form	R^2	Model Form	R^2	Model Form	R^2
Any Project Type	Linear Excluding BCV	0.37	Linear Excluding BCV	0.34	Linear Excluding BCV	0.30
Bridge Project	Linear Excluding BCV	0.37	Logarithmic Including BCV	0.55	Linear Excluding BCV	0.51
Maintenance Project	Logarithmic Including BCV	0.43	Linear Excluding BCV	0.27	No Significant Model	-
Road Construction Project	Linear Excluding BCV	0.45	Linear Excluding BCV	0.32	Linear Excluding BCV	0.35
Resurfacing Project	Logarithmic Including BCV	0.89	Linear Excluding BCV	0.40	Logarithmic Including BCV	0.80
Traffic Project	Logarithmic Including BCV	0.72	Linear Excluding BCV	0.43	No Significant Model	-

BCV = “bid comparison” variables (level of competition, proportion of the difference between the first and second bid, or proportion of the difference between the bid and engineer’s estimate)

Table 8.19: Significant Variables of the Models

Dependent Variable / Model (Project) Type	Change Order	Time Delay	Cost Overrun
Any Project Type	PT (+), Fort Wayne location (+), Inclement days (-), Bid amount (+).	PT (+), Inclement days (-), Contract duration (-), Bid amount (+).	PT (-), Fort Wayne location (+), Laporte location (-), Bid amount (+).
Bridge Projects	Inclement days (-), Bid amount (+).	Seymour (+), Inclement days (-), Contract duration (-), Bid amount (+), PDSEC (+), PDENG (-),	Laporte location (-), Bid amount (+).
Maintenance Projects	Crawfordsville (+), Laporte location (-), Inclement days (+), PDSEC (-), PDENG (-) Bid amount (-).	Inclement days (-), Bid amount (+), Contract duration (-).	–
Road Construction Projects	Fort Wayne location (+), Bid amount (+).	Inclement days (-), Bid amount (+), Contract duration (-)	Seymour location (-), Bid amount (+).
Resurfacing Project	Seymour location (+), Bid amount (+).	Fort Wayne (-), Inclement days (-), Bid amount (+), Contract duration (-).	Crawfordsville location (+), Laporte location (+), Bid amount (+), PDSEC (+), PDENG (-).
Traffic Projects	Crawfordsville location (+), PDSEC (+), PDENG (-), Bid amount (-)	Inclement days (-), Bid amount (+), Contract duration (-)	–

PT- Project Type (in comparison to Traffic Maintenance Projects)
PDSEC: Proportion of the difference between the winning and second bids
PDENG: Proportion of the difference between the winning bid and engineer’s estimate

The modeling process showed that with respect to the response variables (frequency of change orders, time delay, or cost overrun amount), the most influential variables were as follows:

- *Bid amount*, with a dominant increasing effect on the response variables (in 14 out of 16 models, the bid amount had an increasing effect on the response variables),
- *Project duration*, with a decreasing effect,
- *Proportion of the difference between the winning bid and the second bid*, with a dominant increasing effect,
- *Proportion of the difference between the winning bid and engineer’s estimate*, with a decreasing effect,
- *Duration of inclement weather*, with a dominant decreasing (surprisingly) effect.

8.6 Chapter Summary

This chapter provided the results of the modeling process and attempted to explain the results found therein. A few models had satisfactory R^2 and validation statistics. The results obtained were generally consistent with expectation. However, there were a few cases where the variable signs were counter intuitive and may need further investigation. Using the model results it may be possible to obtain estimates of the Frequency of change orders, time delay or cost overruns associated with any future INDOT project, given basic characteristics such as bid amount, project type, location by district, nature of weather, and “bid comparison” variables if available.

CHAPTER 9 - CONCLUSIONS

This study analyzed the problem of cost overruns, time delays, and change orders associated with INDOT projects. This was carried out using a variety of methods including an agency survey, literature review, and statistical analyses.

The agency survey revealed that INDOT's contract management performance in terms of cost overruns and time delays is generally similar to that of other state DOTs. Nevertheless, cost overruns and time delays in Indiana represent a sizeable portion of agency costs, and even a marginal reduction can lead to substantial savings.

The study showed that between the years 1996 and 2001, 55% of all Indiana DOT contracts experienced cost overruns, and the overall cost overrun rate was 4.5% of the bid amount. With regard to cost overruns, it was determined that the average cost overrun amount and rate differ by project type. Also, the strength of influential factors differ by project type The average cost overrun rates were as follows: bridge projects -- 8.1%, road construction -- 5.6%, road resurfacing -- 2.6%, traffic projects -- 5.6%, maintenance projects -- 7.5%. It was also determined that influential factors of cost overrun of highway contracts include the contract bid amount, difference between the winning bid and second bid, difference between the winning bid and the engineer's estimate, project type and location by district. The developed models may be used to estimate the extent of future cost overruns on the basis of contract and project characteristics, and are therefore useful in long term budgeting and needs assessment studies. With regard to time delay, it was also found that 12% of all INDOT contracts experience time delays, and the average delay per contract was 115 days. The study also determined average time delay for each type of contract. From the various statistical analyses, it was determined that factors influential to time delays are contract bid amount, difference between the winning bid and second bid, difference between the winning bid and the engineer's estimate, project type and location by district. Based on the results of the analysis, recommendations can be made for improving the management of projects and the administration of contracts in order to reduce time delays.

Using an array of statistical methods, the present research project explored the problem statement further. The magnitude of cost overrun, time delay and change order problems associated INDOT's construction projects were explored by investigating the relationships between these parameters and key characteristics of the bidding process, project, and environment. The **descriptive**

statistics showed that the following change order types were the most critical in terms of frequency and cost: “errors and omissions, design related,” “errors and omissions, quantity related,” “constructability, construction related,” “constructability, design related,” and “changed field conditions, construction related.” It was found that most of such change order reason categories were the responsibility of INDOT or its consultants, and therefore is within INDOT’s capability to reduce the incidence of such change orders by improving its contract management system. The descriptive statistics also indicated that cost overruns and time delays have been on the decrease since 1997. It was indicated that more time delays were experienced for maintenance projects compared to other project types, and for projects in the Seymour District compared to those located at other districts. The results of such preliminary analyses also suggested that higher cost overrun amounts were experienced for resurfacing projects compared to other project types, and also for projects located in the Fort Wayne District compared to other districts. Furthermore, the descriptive statistics suggested that a higher number of change orders is associated with road construction projects compared to other project types, and also for projects in the Greenfield District compared to other districts. The **correlation matrix analysis** showed that the selected independent variables were not affected by the problem of linear correlation, with the exception of the variables representing the “proportion of the difference between the winning and second bids” and the “proportion of the difference between the winning bid and the engineer’s estimate.” From the **analysis of variance**, it was observed that there generally exists a statistical difference between the mean responses (cost overruns, time delays, and change orders) of any two categories of the independent variables. The pairwise t-tests provided confirmation of the ANOVA findings.

The last statistical method used was **regression modeling** to confirm the influence of the independent variables, and to estimate values of cost overruns, time delay and change orders for future projects. Given the inconsistent performance of a few of the developed models in terms of R^2 and validation statistics, it may be stated that some of models may be used for prediction only with caution. The developed models provided interesting information about the factors that affect cost overruns, time delays, and change orders. It was found that significant variables included bid amount, project type, location by district, weather, and bid comparison variables. The level of competition was generally found not influential. Specifically, the proportion of the difference between the winning and second bid had a dominant increasing effect. The proportion of the difference between the winning bid and the engineer’s estimates had a decreasing effect. These conclusions are similar to those found from the literature review. The advantage of the present study compared to the studies found in the literature is the greater dataset size so the resulting analysis is expected to yield results that are more consistent.

A major problem encountered during the course of the present study was existence of several change orders for which no reason was assigned to change orders. For approximately a third of all change orders (representing one-half of amounts incurred on change orders), no reason was assigned in the dataset. This suggests that there are a few lapses in the current management of change orders at INDOT. The constructability reviews report from the Constructability Process Review Committee shows that a key need was the development of a process to determine the causes of change orders. Therefore, the tracking for change orders and their causes may be expected to improve after implementation of such a mechanism. This recommendation was implemented on April 11, 1997. However, examination of the change order reason database even after that date showed that most of the "no-reason" change orders were for years subsequent to such implementation (i.e., 1999, 2000, and 2001). It is conceivable that because the year indicated in the dataset represented the final year of work, such contracts may have started several years earlier, at which time the Constructability Process Review Committee recommendations had not yet been implemented. Upon further investigation of archival data, it was determined that some change orders currently categorized as having "no recorded reason" in the dataset were actually categorized as "errors and omissions" change orders in the archives. However, it could not be ascertained why such reasons were not transferred from the archives to the dataset. It is obvious that further work needs to be done to identify the source and nature of this problem.

The implementation of *SiteManager* will provide a more effective way to classify and code change order information. This should reduce the occurrence of "no recorded reason" change orders and thereby improve the accessibility and evaluation of this type of data. Since the completion of data analysis, System Technology has deployed BAMS Decision Support System (DSS). DSS provides an easier way to retrieve project data.

The results of the present study provided a framework for subsequent recommendations made with a view to reducing the frequency and amounts involved in change orders, cost overruns, and time delays at INDOT.

CHAPTER 10 - RECOMENDATIONS

The present study revealed some areas where it is possible to improve, and the following recommendations are offered for consideration.

Improvements could be made to the current design review process of a project, particularly for large, high-value projects. The study found that "design errors and omissions" was the most frequent change order category that created the most cost. This was discussed at a November 20, 2003 meeting attended by INDOT personnel from Budget, Operations Support, and Design. Several options were floated such as: hiring additional design personnel to review contract documents; establishing a review of consultant's performance in regards to number and type of change orders occurring on projects; and, adding additional review requirements for consultants. After much discussion the following recommendations were made. First, a Change Order Management process needs to be developed and implemented. This will consist of:

1. Developing a Change Order mindset in the Department.
2. Developing procedures and instructions for recording change order information in *SiteManager*.
3. Developing a system of controls that routes change order information to the appropriate personnel in Operations Support and Design Divisions.

The change order mindset would raise the necessary awareness of the problem, help develop an agency-wide attitude geared towards the reduction of change orders, and help identify improvements needed at various stages of the project life-cycle for mitigating the problem.

In the past, change orders have not been recorded until the end of the contract. *SiteManager* allows for the recording of change order information as the project progresses. Also, with the current INDOT change order classification code, it is often not possible to determine the appropriate code that is applicable to all situations. The presence of so many "no indicated reason" change orders suggests that there may be some lapses in the recording of appropriate reasons for change orders. The code may therefore need review and modification. A system of instructions and more definitive definitions can improve documentation and eliminate the assignment of "no indicated reason" to change orders.

The problem of change orders needs to be addressed at source. Most bidding documents (with the exception of those for resurfacing projects) are prepared by consultants A standard report for each consultant and for each contract could be prepared and provided to such consultants to point out errors committed and how such errors may be avoided in future. Moreover, “real time” recording of change orders would probably accelerate the process of feedback to designers and field personnel. If data about change orders is collected on a daily basis, it is possible to create a “weekly change order report” and route it to the appropriate personnel.

It is recommended that INDOT should design an annual report that reviews the performance of consultants. Such a report would assign “grades” to each consultant, taking into account the number and dollar amount of preventable change orders that are attributable to the consultant. If grades are to be assigned in such manner, INDOT’s change order classification may be adapted to this new objective in order to better distinguish the responsibilities of each change order type.

INDOT personnel should be given ample opportunity to carry out a detailed review of change orders reports and their implications. Also, such personnel should be encouraged to continually improve their methods. Obviously, implementing additional requirements will be a challenge, given the current staffing levels and work loads at INDOT. However, an electronic routing system that collects and distributes change order information would reduce the resources needed to implement this recommendation.

Finally, it is recommended to develop a system that would facilitate communication of updated information concerning cost overruns, time delays, and change orders, to the general public. As has been done in some states (ADOT, 2003) and illustrated in Appendix G, this could be implemented using an electronic tool that could be made available on the internet.

CHAPTER 11 - IMPLEMENTATION

The project constitutes an evaluation of the problem of cost overruns, time delays, and change orders at INDOT. This research effort is consistent with INDOT's strategic objectives for resource management (INDOT, 2003) which include reduction in INDOT overhead costs and increase in the efficiency of the capital program expenditures. The present study provided some initial answers to address problems in the present system. Using the results herein as a starting point, it is possible to carry out future work such as the implementation of a methodology to enhance contract management at INDOT. Another activity is to develop an evaluation method or system to manage the collection, analysis, and presentation of change orders, cost overruns, and time delays information in an efficient manner. At the present time, there are indications that INDOT is considering establishing a new system to record change orders online directly from the construction site. The next step would be to develop or enhance the organization of a change order database to facilitate analysis of change order information and preparation of periodic consultant performance reports. Furthermore, with such enhanced information system, it will be possible to carry out future work geared towards improving the predictive ability of models relating to change orders, time delays, and cost overruns. Finally, conducting a meticulous review of construction management techniques used can help identify any weaknesses in the design and construction process, thus making it possible to make more precise recommendations for improvements in contract management at INDOT.

Appendix A:

Copy of E-Mail Message Soliciting Cost Overrun, Time Delay and Change Order Information form State Highway Agencies

The Indiana Department of Transportation (INDOT) is conducting an analysis about cost overruns and time delays of its projects for the last 5 years. The analysis will look at the causes by investigating final contract information. We would like to know the extent of this problem in other DOTs. We are looking for the following information: % of contracts with time and cost overruns, average cost overrun, annual amount spent on overruns, and causes of these overruns. If you posses this information and are willing to share it with us, please forward it to (Bob McCullouch, the study supervisor) at Purdue University at bgm@ecn.purdue.edu. T would be appreciated if you could please respond by December 1. Thank you in advance for your assistance.

Appendix B: Indiana Change Order Organization

B.1: Change Order Reasons

Table B.1: INDOT Classification of Reasons for Change Orders (INDOT, 2002)

Code	Type	Reason Type	Change Order
000	000		Uncoded
101	100	Errors & Omissions Contract Document	Contract Related
102	100	Errors & Omissions Contract Document	Design Related
103	100	Errors & Omissions Contract Document	Environmental Related
104	100	Errors & Omissions Contract Document	Materials Related
105	100	Errors & Omissions Contract Document	Permits
106	100	Errors & Omissions Contract Document	Quantity Related
107	100	Errors & Omissions Contract Document	Right of Way Related
108	100	Errors & Omissions Contract Document	Soils Related
109	100	Errors & Omissions Contract Document	Staging Related
110	100	Errors & Omissions Contract Document	Traffic Control Related
111	100	Errors & Omissions Contract Document	Utilities Related
201	200	Constructability	Construction Related
202	200	Constructability	Design Related
203	200	Constructability	Environmental Related
204	200	Constructability	Materials Related
205	200	Constructability	Right of Way Related
206	200	Constructability	Soils Related
207	200	Constructability	Staging Related
208	200	Constructability	Traffic Control Related
209	200	Constructability	Utilities Related
301	300	Scope Changes	FHWA
302	300	Scope Changes	Central Office Construction/Traffic
303	300	Scope Changes	District/Subdistrict
304	300	Scope Changes	District Construction Engineer
305	300	Scope Changes	Area Engineer
306	300	Scope Changes	Project Engineer/Supervisor
307	300	Scope Changes	Traffic Engineer
308	300	Scope Changes	Local Agency Request
309	300	Scope Changes	Public/Political Request
401	400	Changed Field conditions	Construction Related
402	400	Changed Field conditions	Environmental Related
403	400	Changed Field conditions	Materials Related
404	400	Changed Field conditions	Right of Way Related
405	400	Changed Field conditions	Soils Related
406	400	Changed Field conditions	Staging Related
407	400	Changed Field conditions	Utilities Related
500	500	Failed Material	
601	600	Incentive/Disincentive	Contract Completion Time
602	600	Incentive/Disincentive	Contract Payments
603	600	Incentive/Disincentive	Cost Reduction
604	600	Incentive/Disincentive	A+B Contract
605	600	Incentive/Disincentive	A+B+C Contract
701	700	Standards/Specifications Update or Changes	Contract Completion Time
702	700	Standards/Specifications Update or Changes	Contract Payments
703	700	Standards/Specifications Update or Changes	Other

B.2: DESCRIPTIONS OF PREVENTABLE CHANGE ORDERS

Errors and Omission – Contract Documents
"Contract documents" include the proposal book, schedule of pay items, specifications, supplemental specifications, special provisions, plans, and standards. Designers are responsible for the correctness in the development of the required pay items, appropriate special provisions, and corresponding plans, plus the correct designation of INDOT recurring special provisions and standard drawings.

Constructability
These codes should be used when it is not physically possible to perform the construction without a change in the contract quantities or the addition or new items. The proper code will depend on the association with environmental, materials, soils, etc., matters.

Scope Changes
These codes should be used for significant changes in the character of work, or a change in the termini of the construction. The proper code will depend on the person or agency that initiated the changes. (i.e., Construction Engineering, public official, political, etc.)

DESCRIPTIONS OF NON PREVENTABLE CHANGE ORDERS

Changes Field Conditions
These codes should be used when the current actual field conditions differ from those shown on the plans. The proper code should reflect which conditions are different.

Failed Materials
This code should be used for deductions assessed by either the district or Failed Materials Committee because of the contractor using materials that did not comply with the specifications.

Incentive/Disincentive
These codes should be used anytime a contract contains incentive or disincentive payments for early/late completion of a project. This can be for intermediate opening to traffic periods, completion dates or times, etc. Also incentives are paid to the contracts for cost reduction or value engineering changes; and incentives/disincentives are generated by contracts, which contain A+B or A+B+C bidding provisions. The code assigned to these different payment conditions should be chosen and used on the change order for documentation.

Standards/Specifications Update or Changes
These codes should be used if a specification is changed by the specification committee or by a memorandum from the central office, and the department wants all contracts currently active to change to the new specification requirements.

B.1: Change Order Classification Codes and Details

Table B.2: Change Order Classification Code used at INDOT (INDOT, 2002)

Code	Reason type	Name	Description
101	Errors & Omissions Contract Document	Contract related	Most usually, INDOT"s responsibility. For example, delay in the "Notice to proceed" can result in extending the contract
102		Design related	Designer's bust - something wrong or left out. For example, wrong elevation on bridge caps; or a mess in clear zone alignment, etc.
103		Environmental related	Example: Hazardous materials not designated on plans, or buried fuel tanks not identified
104		Materials related	Materials either designated incorrectly or left out. Example: Leaving out top mat of reinforcing steel in a bridge deck.
105		Permits	Example: Permits not current – or not obtained, causing delay of contract.
106		Quantity related	Probably the most criticized segment of contract documents errors. Quantities are critical for construction – both INDOT and contractors errors and omissions can lead to unbalanced bidding by contractors anticipating the necessary change orders. Can also necessitate time extensions to the contract.
107		R/W Related	When INDOT does not have all Right of Way cleared, this can cause a change in the contractors sequence of construction, leading to time extensions and additional costs.
108		Soils related	Example: Unsuitable material requires the substitution of suitable materials at increased negotiated cost.
109		Staging Related	Sequencing of construction operations must not interfere with the other public or private considerations.
110		Traffic control related	Second most criticized design error and can cause added delays, expense.
111		Utilities related	Utilities are not located, designated or are improperly identified.
201	Construc-tability	Construction related	Any condition other than those designed below, that prevents contractors to proceed unimpeded.
202		Design related	Example: Temporary runarounds too close to bridge construction.
203		Environmental related	Example: Hazardous materials omitted can cause redesign and delay.
204		Materials related	
205		R/W Related	Insufficient Right of Way can require special equipment or situations to require changes.
206		Soils related	Example: Improperly designated peat bog required excessive undercutting and replacement with special materials.
207		Staging Related	Sequencing cancels possibility of constructing properly.
208		Traffic control related	
209		Utilities related	Utilities causing delays and extra expense.
701	Standards/ Specifications Update or Changes	Contract completion time	It should only be used if a specification change would increase or decrease contract time requirements.
702		Contract payments	It should be used whenever the specifications that apply to the contract state different payment procedures than those stated in the Schedule of Pay Items.
703		Other	It should cover all other specifications changes such as material changes, construction procedure changes, etc.

Appendix C: How Departments of Transportation Classify Cost Overruns (Jacoby, 2001)

ALASKA
A change order procedure is specified but categories are not assigned.

ARIZONA
1. Value Engineering
2. Additional or extra work out of scope
3. Quantity omissions
4. Plans revisions and oversights
5. Changed condition
6. Penalty or bonus
7. Other

ARKANSAS
Engineers provide written explanations for items above a specified amount.
1. Value Engineering
2. Erosion Control quantity or new item increases
3. Item Deductions
4. Incentives or disincentives for early or late completion.
5. Incentives for pavement smoothness or mix production properties.

CALIFORNIA
A three character alphanumeric code is assigned. The code indicates the type and possible cause of the change. The first character identifies the group and the second identifies the change within the group. The last character identifies the originator or the source.

CONNECTICUT
A. Agreed Days
B. Bridge Design Revision
C. Consultant Design Error
D. DOT Design Error
E. Environmental Protection
I. Routine Item Review
N Drainage Revisions
P. Adjustment of Contract Unit Price
R. Roadway Design Revision
S. Specification Change
T. Traffic Design Revision

FLORIDA
Florida has the following groups and sub-groups
1. Changed Conditions
2. Utility Delays
3. Weather Related Damage
4. Plans Modifications
5. Specification Modification
6. Value Engineering
7. Partnering
8. Actions/Inactions
9. Minor Changes

Appendix C (Continued)

FLORIDA (continued)

10. Defective Materials
11. Contingency
12. Claim Settlement

INDIANA

Each group can have subgroups. The total subgroups defined are 44.

Preventable

1. Errors and Omissions - Contract Documents
2. Constructability
3. Scope Changes

Non Preventable

4. Changed Field Conditions
5. Failed Materials
6. Incentive/Disincentive Provisions
7. Standards/Specifications – Update Changes.

IOWA

Iowa separates incentive payments from other change order costs. No other classification is used.

KENTUCKY

1. Minor Miscellaneous
2. Roadway Excavation
3. Slide Excavation
4. Change in Quantities due to insufficient Original Estimate
5. Shoulder repairs for Traffic Control purposes
6. Change in quantities Additional work or a Change in Scope
7. Fuel and Asphalt Adjustment.
8. Incentive Pay

LOUISIANA

Louisiana overruns and underruns greater than 5% must be explained in Change Order.

MICHIGAN

Michigan separates extra work items from increases in regular bid work items to classify reasons for contract changes and cost overruns.

Appendix C (Continued)

MINNESOTA

They have developed a method to code the each change order item as to cause. The process has only been in place for a portion of the current fiscal year 2002. Each change order item is assigned one of the following codes. In future years, they will be able to assign overrun amounts to each category.

Acronym	Meaning
AD	Administrative Decisions
CD	Consultant Design Error
CS	Claim Settlement
DC	Design Change
DE	Design Error
DS	Differing Site Conditions
ES	Staking Error
IE	Inspection Error
ND	Natural Disaster
PP	Prompt Payment
RA	Routine Adjustment
SC	Consultant Staking Error
UD	Utility Delay
VE	Value Engineering

They do not have an effective method to identify time extensions. Contractors may granted additional time for excusable non-compensable delays (acts of God, acts of a public enemy, fires, floods, earthquakes, epidemics, quarantine restrictions, strikes, freight embargoes, unusually severe weather or other delays not caused by the contractor's fault or negligence).

In cases where the final value of all work performed exceeds the original contract amount, an extension in working days is granted to the contractor. The extension is made by increasing the contract time by the ratio of the total final cost of all work performed to the total amount of the original contract. Extensions are only computed if the contractor fails to complete the contract within the original time-frame.

NEW HAMPSHIRE

Written explanations

NEW JERSEY

A. Changes authorized by construction which are not in any other description of change.
D.Traffic impact modification of safety enhancement
E. Additional work for Corrective Action comment, including work after completion date.
F.Project Management change to add or delete work (scope change)
G.Change to address a Right of Way issue
H.Change to address a Utility issue
I.Change to address a Environmental issue
J.Change to address a error or omission in the contract.
K.Any other Project Management change based on field conditions.
L.Change in specification by the Department and/or Contractor.
M.Change in Material by the Department and/or Contractor
N.Implementation of a Value Engineering Proposal.
O.Implementation of a Contractor requested change

Appendix C (Continued)

P.Implementation of any Third Party initiated change
Q. Only a time adjustment and or mitigation of a delay
U. Unused or deleted item material purchase.
V. Partnering Agreements
W. Incentive/Disincentive Payments (including bonus and penalty)
X.Unique Situation, including Force Majeure, Enter Reason

NEW MEXICO
01Design Oversight
02Modification by Construction Personal
03Traffic Control Modifications
04Decreasing/Increasing Quantities
05Deleting/Adding Items
06Contract Time Adjustments
07Force Accounts
08Incentive/Disincentive
09Price Adjustment
10 Claim Settlement
11Liquidated Damages
12Cost Savings Proposals/Suggestions
13Quantity
14 Other
15Grass Receipt Taxes

NEW YORK
01Changes in Contract Quantity
02Design Errors
03Increasing Project Scope
04Structure Deterioration Increase
05Roadway Deterioration Increase
06 Soils
07Landscape
08Structural Changes
09Administrative Changes
10Specification Change
11Maintenance of Traffic
12Materials Change.
13Traffic Signal
14Administrative Settlement
15Emergency
16Accelerations.

NORTH DAKOTA
The project engineer is required to complete an explanation which identifies the reason for the change

Appendix C (Continued)

OHIO

01 Normal Difference Plan and Actual Quantities.
02 Significant Diff Plan and Actual Quantities.
03 Changes Preventable for Field Conditions
04 Change Non Preventable for Field Conditions.
05 Alter Specifications
06 Work in Plans but not General Summary/Prop
07 Unclear plan note
08 Improper Materials Specified
09 Plan omissions
10 Non performed Cont Item
11 Preventable Maintenance of Traffic Revision
12 Non-Preventable Maintenance of Traffic Revision
13 Incorrect Soil Subsurface Data
14 Utility Relocation Delay
15 Improperly located utility
16 Unknown utility
17 Delay caused for reasons other than utility
18 Cost to accelerate work
19 Asphalt lot adjustments
20 Non Specification Materials.
21 Bituminous price adjustments
22 Owner Requested Change
23 Accepted Value Engineering Change
24 Claims Resolution/Avoidance Agreement
25 Smoothness Price Adjustments
26 Partnering Workshop.

PENNSYLVANIA

1. Balancing of overruns/underruns
2. Design Omissions
3. Design Errors
4. Unforeseen Field Conditions
5. Field Changes Directed by the Engineer
6. Required change in Scope of Work
7. Differing Site Conditions
8. Suspension of work ordered by Engineer
9. Other

SOUTH DAKOTA

1. Normal Variations in Quantities.
2. Work for others no cost to us
3. Design Changes
4. Value Engineering
5. Incentive/Disincentive
6. Haul Roads/Detours
7. Change in Scope and/or Work Beyond Termini
8. PCCP Restoration (Major)
9. Excavation Major

Appendix C (Continued)

10. Changed Condition
11. Claims/Dispute Resolution
12. Asphalt Concrete Major
13. Railroad Projects
14. Utility Agreements
15. Differing Site Conditions
16. R.O.W Landowner issues
17. Asphalt Maintenance Repairs
18. Airport Projects
19. Plan Errors
20. Maintenance Contracts
21. Field Errors
22. Contractor Errors
23. Plan Change
24. Incentive/Disincentive
25. Lane Rental

TEXAS

Texas has six main groups and then each of these groups has as many as 13 subgroups. There are 39 total subgroups.

1. Design Error or Omission
2. Differing Site Conditions (Unforeseeable)
3. TxDOT Convenience
4. Third Party Accommodation
5. Contractor Convenience
6. Untimely Right of Way/Utilities

UTAH

There are six groups that are further categorized into 5 to 10 sub groups. The total amount of categories is 43. They also record the Division, Section or position that could have taken some action to prevent the need for the Change Order. There are 14 items here.

Group 1. Anticipated Supplemental Contract Work
Group 2. General Additions / Deletions / Adjustment
Group 3. Unforeseen Occurrences / Differing Site Conditions
Group 4. Differences/Conflicts in the Contract Documents
Group 5. Settlement of Claims and Disputes
Group 6. Cost Reduction Incentive Proposals / Alternative Design

WASHINGTON

What created the need for the change order?
AP Administrative Problem – Does not relate to the physical work
BC Budget Constraints – Deletion or modification was initiated because cost exceeded funding limits.
CC Changed Condition – Site conditions differed from design expectations.
CE Contractor Error
CS Claim Settlement
DR Disputes Board finding
EE Construction Engineering Error
EJ Engineer's Judgment

Appendix C (Continued)

HZ Hazardous Material encountered.
IP Contractor's cost revision incentive
MP Interim Maintenance Problem Temporary maintenance is required.
PI Plans Error Insufficient Information was available to the designer
PM Plans Error Mistake
SC Specification Conflict Ambiguity
TP Third Party Request
UC Unanticipated Condition

What does the Change order do?
AD Administrative Change
CA Condition of Award
CR Correction Repair
DC Design Change
DE Delay Compensation
EP Extra Pay Required
MO Quantity Variation
MR Material's Spec Revision
OR Other Spec Revision
RS Revised Scope
SA Schedule Adjustment
WC Work method Change

WISCONSIN
CR Cost Reduction
MI Miscellaneous
PC Plan Change
PI Plan Inadequacy
RO Request by Others
SE Safety Enhancement
SS Change/Credit Standards and Specifications

Appendix D: Weather Data Organization

Table D.1: Quality and Correction of the Weather Data

Number	Normal county	Problem	Replace by:	Final county	Final Number
1	Adams	NT in sep00, jul01 and 02	Wells	Adams	1
2	Allen	NT, no 01 to 02	Whitley	Allen	2
3	Bartholomew	OK		Bartholomew	3
4	Benton	OK		Benton	4
5	Blackford	OK		Blackford	5
6	Boone	OK		Boone	6
7	Brown	NT	Bartholomew	Brown	7
8	Carroll	nothing	Cass	Cass	9
9	Cass	OK		Cass	9
10	Clark	nothing	Jackson	Jackson	36
11	Clay	nothing	Owen	Owen	60
12	Clinton	no jan to jun 99	Tippecanoe	Clinton	12
13	Crawford	nothing	Dubois	Dubois	19
14	Daviess	no 98 to 00	Martin	Daviess	14
15	Dearborn	no 96 to 97 & end02	Decatur	Dearborn	15
16	Decatur	OK		Decatur	16
17	Dekalb	nothing	Whitley	Whitley	92
18	Delaware	OK		Delaware	18
19	Dubois	OK		Dubois	19
20	Elkhart	BT	Marshall	Elkhart	20
21	Fayette	nothing	Henry	Henry	33
22	Floyd	NT, no 00 to 02	Jackson	Floyd	22
23	Fountain	NT 98 to 02	Montgomery	Fountain	23
24	Franklin	no 96 to 97	Decatur	Franklin	24
25	Fulton	no 99	Cass	Fulton	25
26	Gibson	nothing	Knox	Knox	42
27	Grant	NT 02	Blackford	Grant	27
28	Greene	NT	Owen	Greene	28
29	Hamilton	no 96 to 99	Madison	Hamilton	29
30	Hancock	OK		Hancock	30
31	Harrison	NT	Madison	Harrison	31
32	Hendricks	no jan to feb96	Marion	Hendricks	32
33	Henry	OK		Henry	33
34	Howard	NT 97 to 02	Tipton	Howard	34
35	Huntington	nothing	Wells	Wells	90
36	Jackson	OK		Jackson	36
37	Jasper	OK		Jasper	37
38	Jay	OK		Jay	38
39	Jefferson	NT	Jackson	Jefferson	39
40	Jennings	nothing	Jackson	Jackson	36
41	Johnson	NT dec97 to jan00	Morgan	Johnson	41
42	Knox	OK		Knox	42
43	Kosciusko	NT	Marshall	Kosciusko	43
44	Lagrange	no 01 to 02	Whitley	Lagrange	44
45	Lake	OK		Lake	45

NT = no temperature data, NS = no snow data, BT = bad quality of the temperature data

Appendix D: Weather Data Organization (Continued)

Table D.1: Quality and Correction of the Weather Data

Number	Normal county	Problem	Replace by:	Final county	Final Number
46	Laporte	OK		Laporte	46
47	Lawrence	OK		Lawrence	47
48	Madison	OK		Madison	48
49	Marion	OK		Marion	49
50	Marshall	OK		Marshall	50
51	Martin	OK		Martin	51
52	Miami	NT	Cass	Miami	52
53	Monroe	OK		Monroe	53
54	Montgomery	OK		Montgomery	54
55	Morgan	OK		Morgan	55
56	Newton	NT, no 02	Jasper	Newton	56
57	Noble	BT	Whitley	Noble	57
58	Ohio	nothing	Decatur	Decatur	16
59	Orange	nothing	Lawrence	Lawrence	47
60	Owen	OK		Owen	60
61	Parke	nothing	Vermillion	Vermillion	83
62	Perry	no 01	Dubois	Perry	62
63	Pike	nothing	Dubois	Dubois	19
64	Porter	OK		Porter	64
65	Posey	NT sept00 to 02, no 97	Knox	Posey	65
66	Pulaski	no 01	Jasper	Pulaski	66
67	Putnam	OK		Putnam	67
68	Randolph	OK		Randolph	68
69	Ripley	NT NS 96 to 97	Decatur	Ripley	69
70	Rush	OK		Rush	70
71	SaintJoseph	NT 01	La Porte	SaintJoseph	71
72	Scott	no 01 to 02	Jackson	Scott	72
73	Shelby	NT	Rush	Shelby	73
74	Spencer	no 97 to 01	Dubois	Spencer	74
75	Starke	NT	La Porte	Starke	75
76	Steuben	no dec00 to 01	Whitley	Steuben	76
77	Sullivan	NT	Vigo	Sullivan	77
78	Switzerland	nothing	Jackson	Jackson	36
79	Tippecanoe	OK		Tippecanoe	79
80	Tipton	OK		Tipton	80
81	Union	BT, no 96 to 97	Rush	Union	81
82	Vandenburgh	NT, no 97	Knox	Vandenburgh	82
83	Vermillion	OK		Vermillion	83
84	Vigo	OK		Vigo	84
85	Wabash	NT jan to jun00 & oct to nov01	Whitley	Wabash	85
86	Warren	NT	Benton	Warren	86
87	Warrick	no 97 to 98	Dubois	Warrick	87
88	Washington	no 98 to 02	Jackson	Washington	88
89	Wayne	no 96 to 97	Randolph	Wayne	89
90	Wells	OK		Wells	90
91	White	BT	Jasper	White	91
92	Whitley	OK		Whitley	92
99	Divers				

NT = no temperature data, NS = no snow data, BT = bad quality of the temperature data

Appendix E: Additional Descriptive Statistics

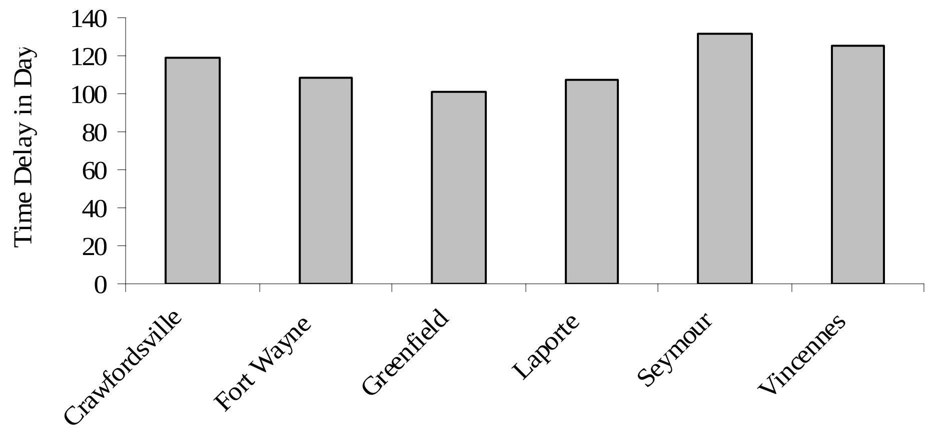

Figure E.1: Distribution of the Average Time Delay per Contract by District

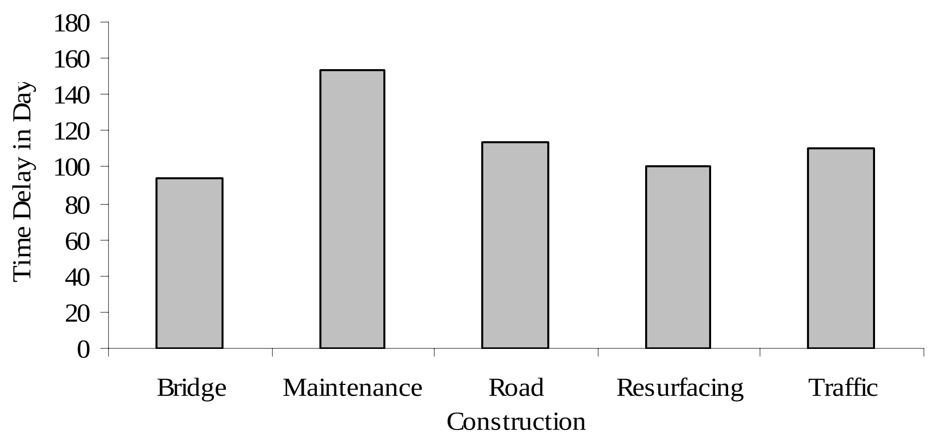

Figure E.2: Distribution of the Average Time Delay per Contract by Project Type

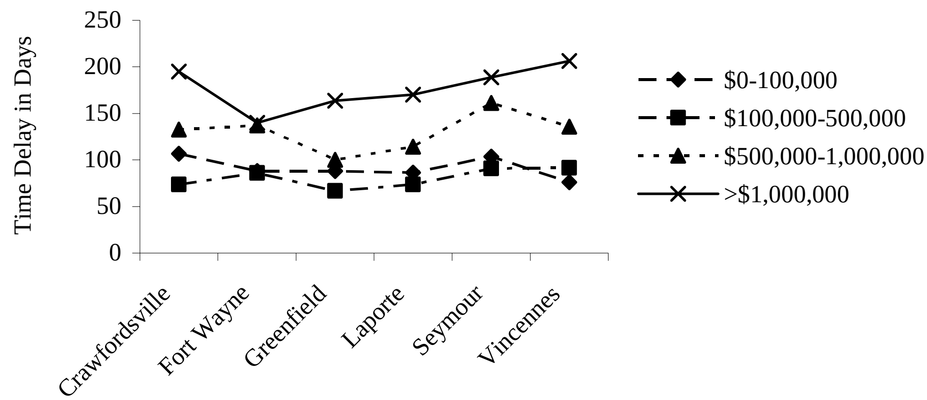

Figure E.3: Distribution of Average Time Delay per Contract by Bid Amount Category and by District

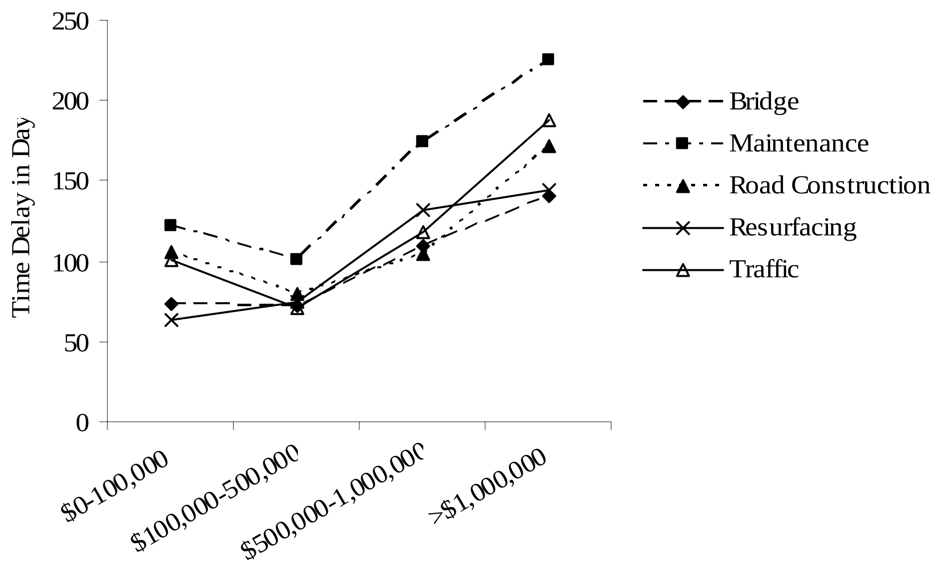

Figure E.4: Distribution of Average Time Delay per Contract by Project Type and Bid Amount Category

Appendix E: Additional Descriptive Statistics (Continued)

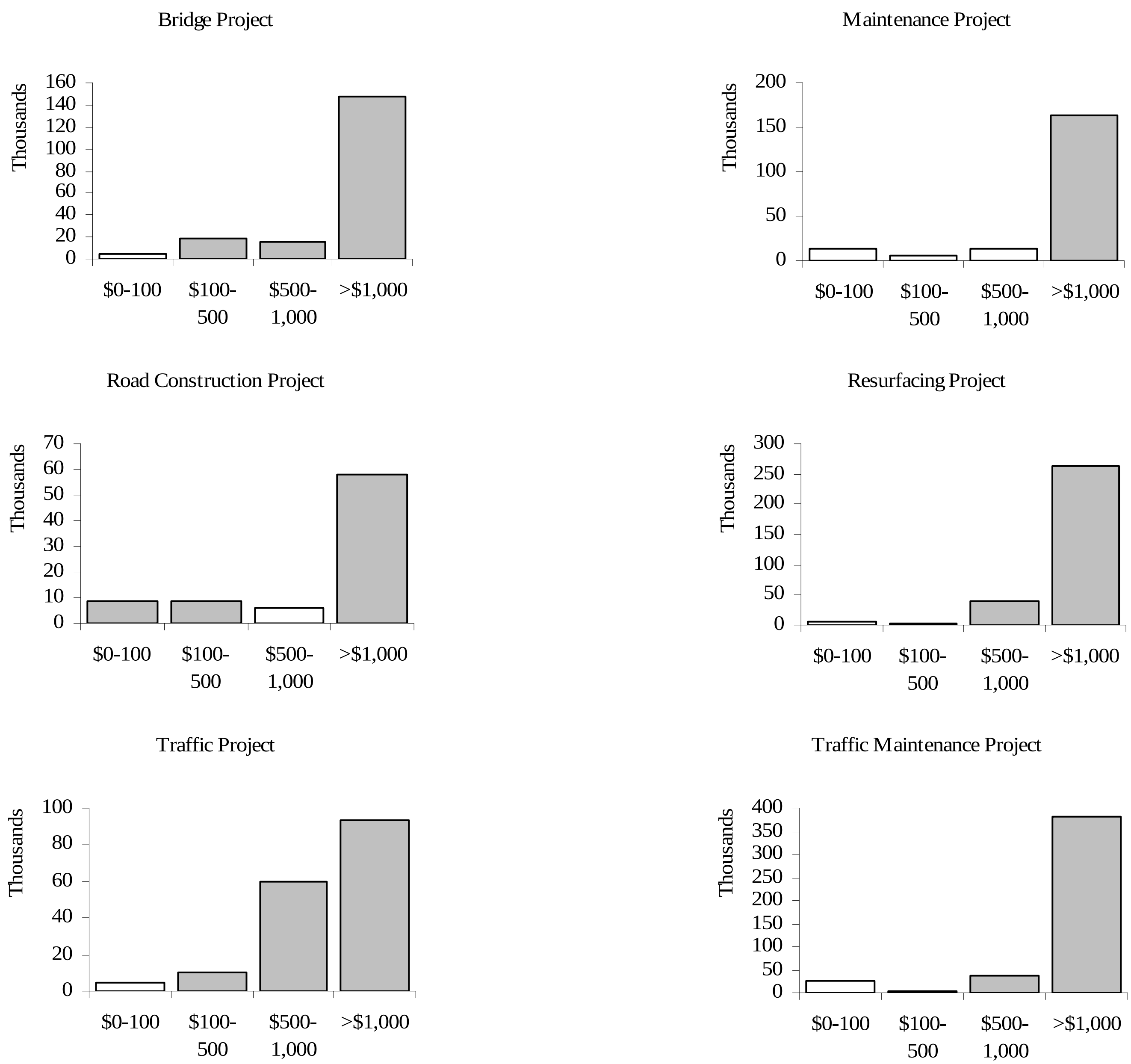

Figure E.5: Distribution of Cost Overrun Amounts ($1,000's) by Project Type and by Bid Amount Category

Appendix E: Additional Descriptive Statistics (Continued)

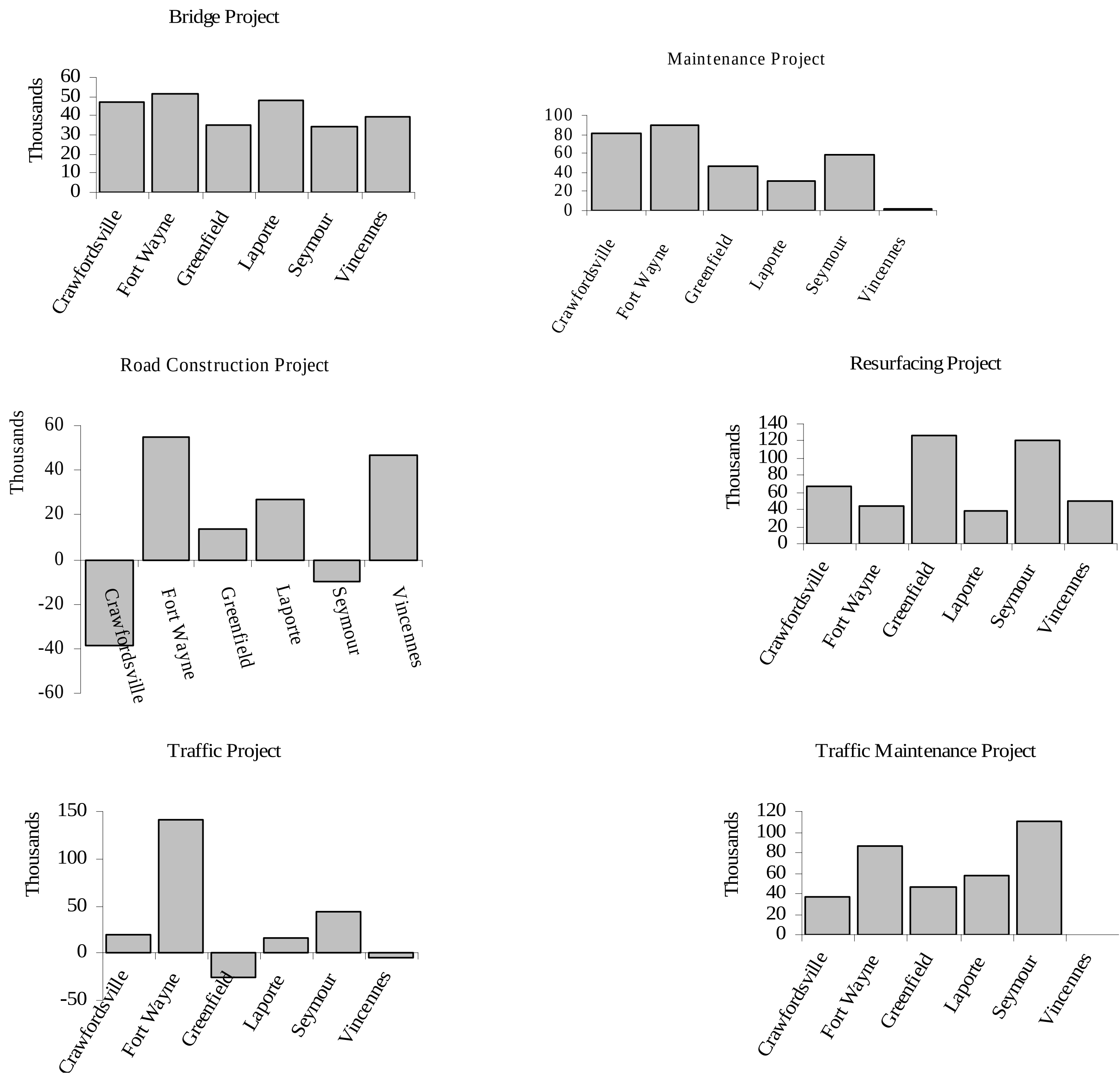

Figure E.6: Distribution of Cost Overrun Amounts ($1,000's) by Project Type and by District

Appendix E: Additional Descriptive Statistics (Continued)

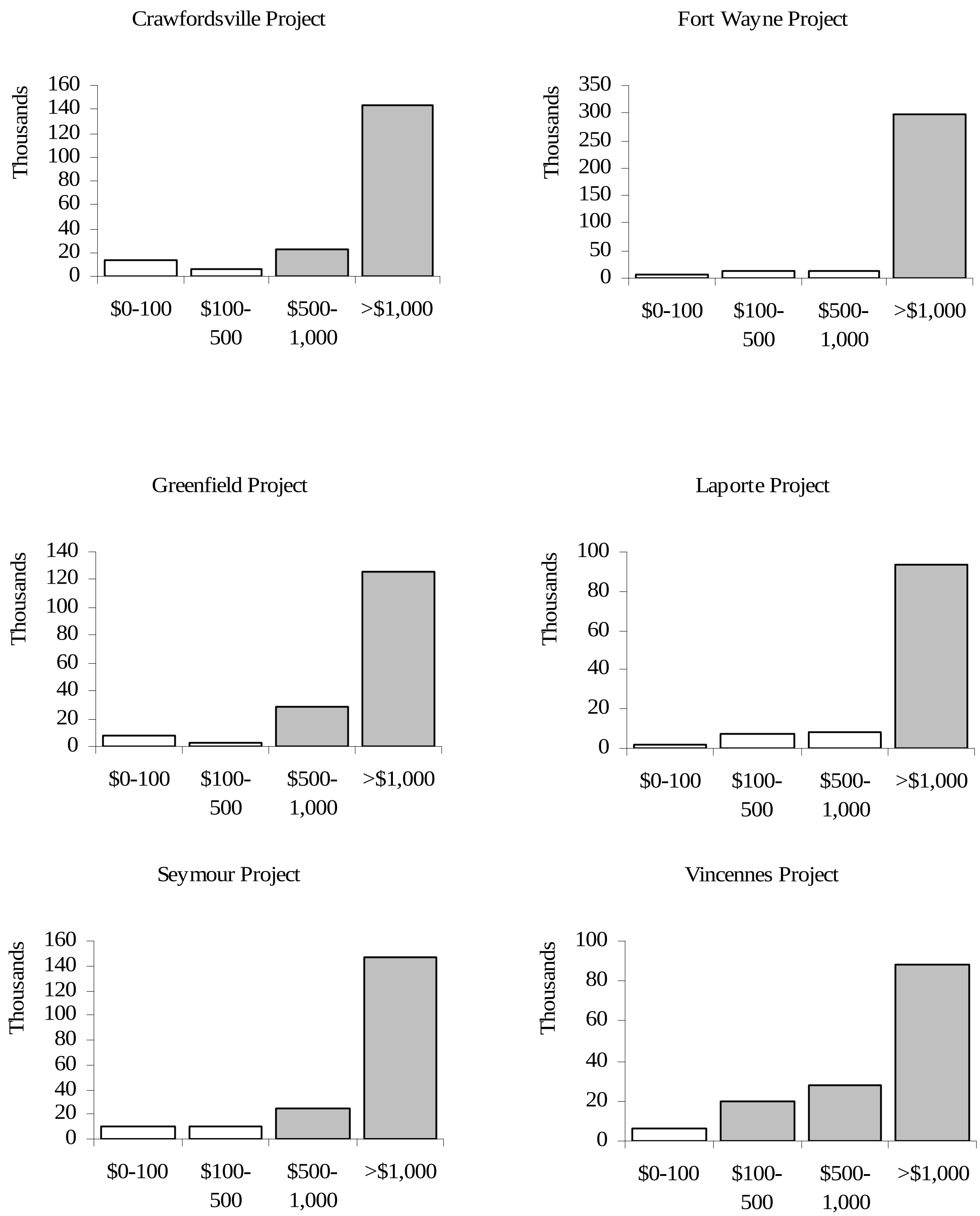

Figure E.7: Distribution of Cost Overrun Amounts ($1,000's) by District and by Bid Amount Category

Appendix E: Additional Descriptive Statistics (Continued)

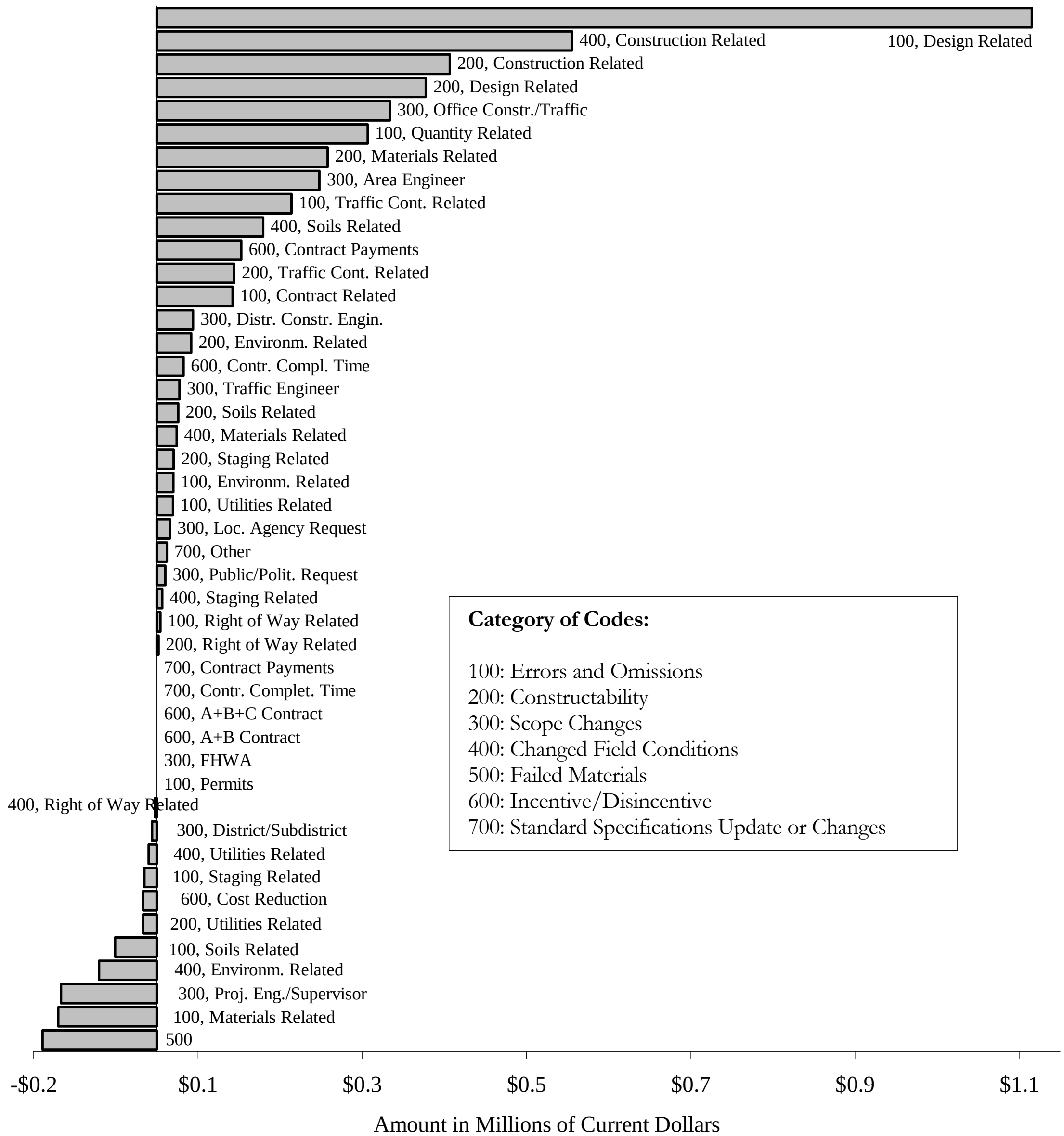

Figure E.8: Reasons for Change Orders in Bridge Projects

Appendix E: Additional Descriptive Statistics (Continued)

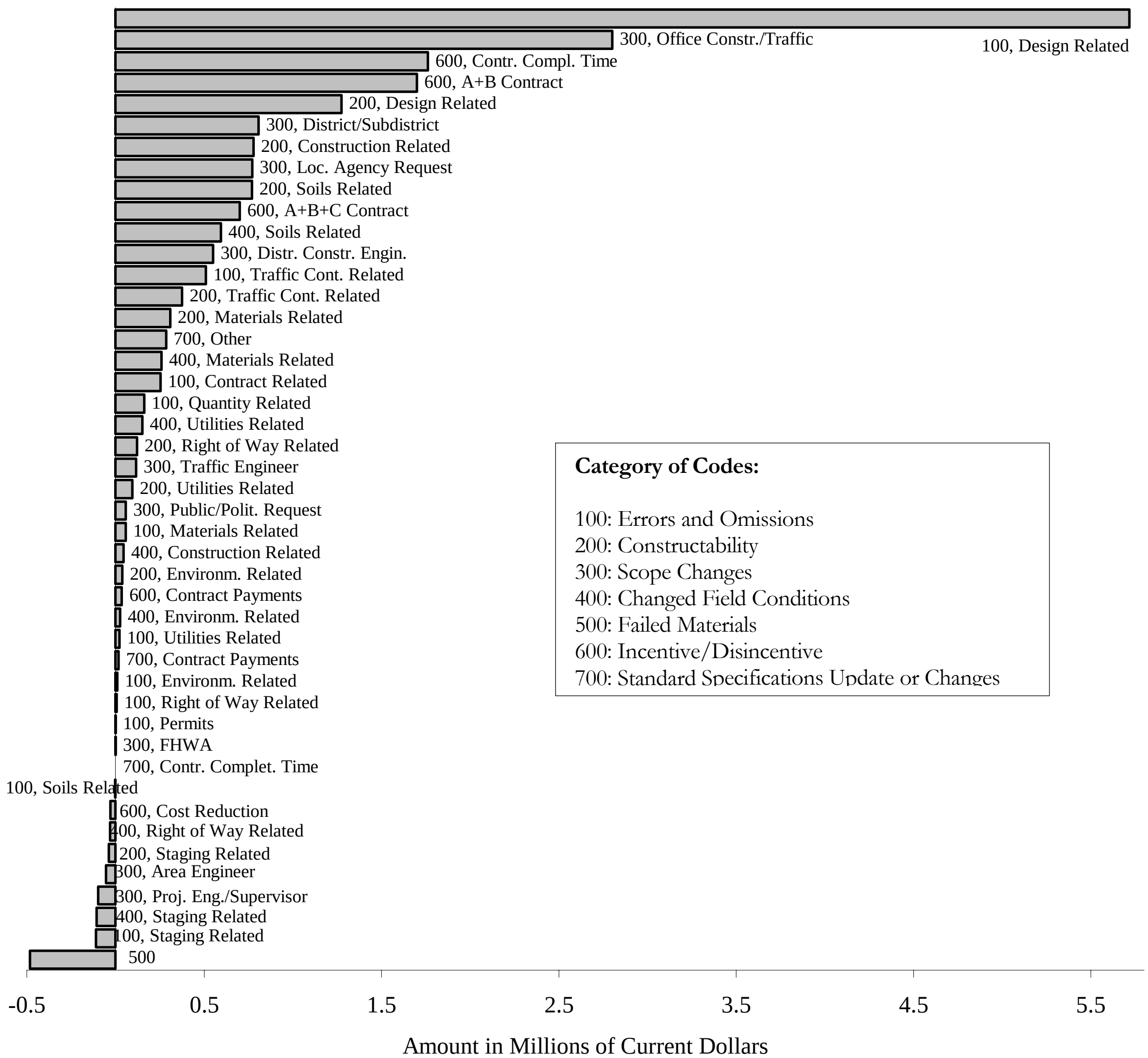

Figure E.9: Reasons for Change Orders in Road Construction Projects

Appendix E: Additional Descriptive Statistics (Continued)

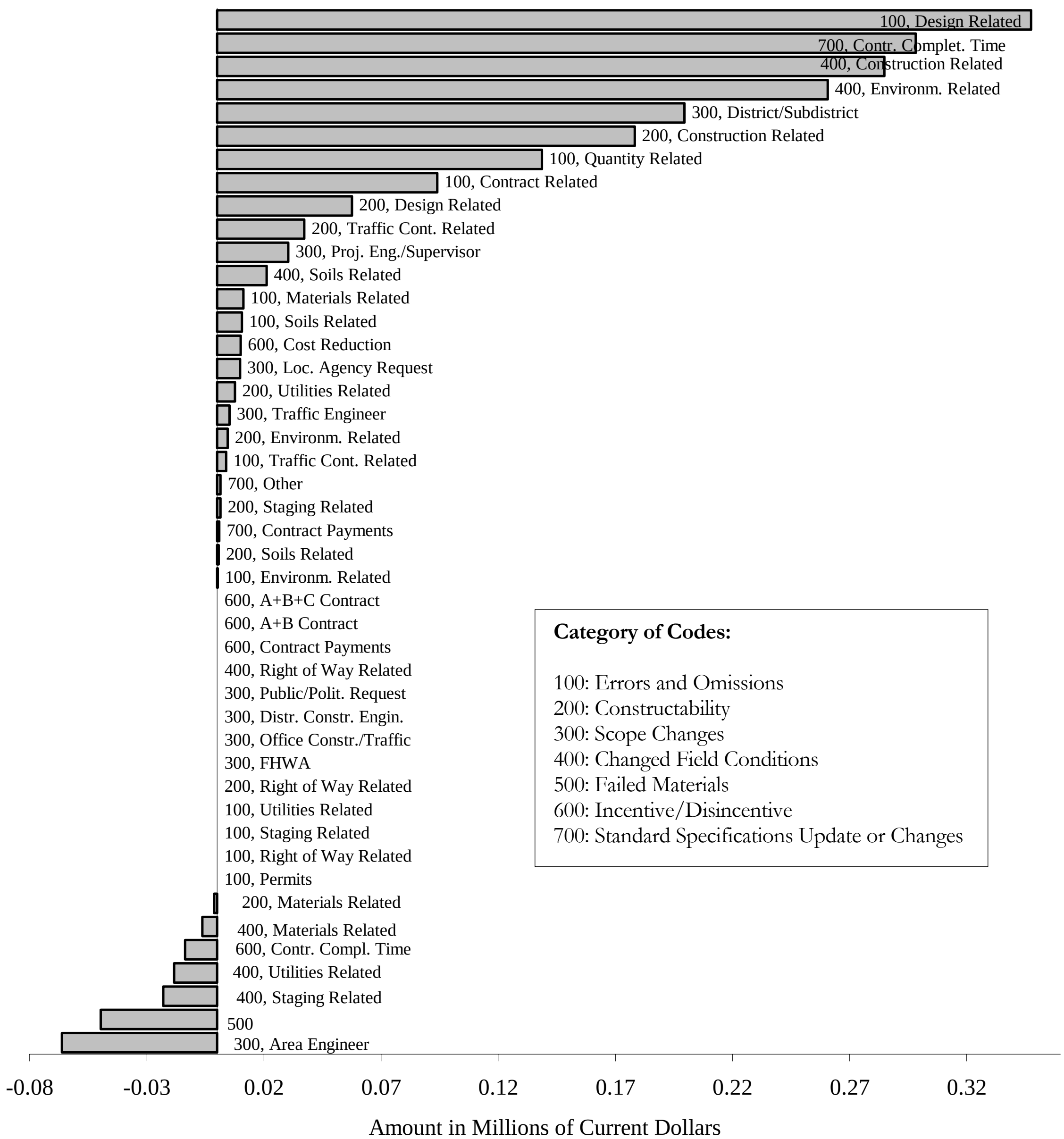

Figure E.10: Reasons for Change Orders in Maintenance Projects

Appendix E: Additional Descriptive Statistics (Continued)

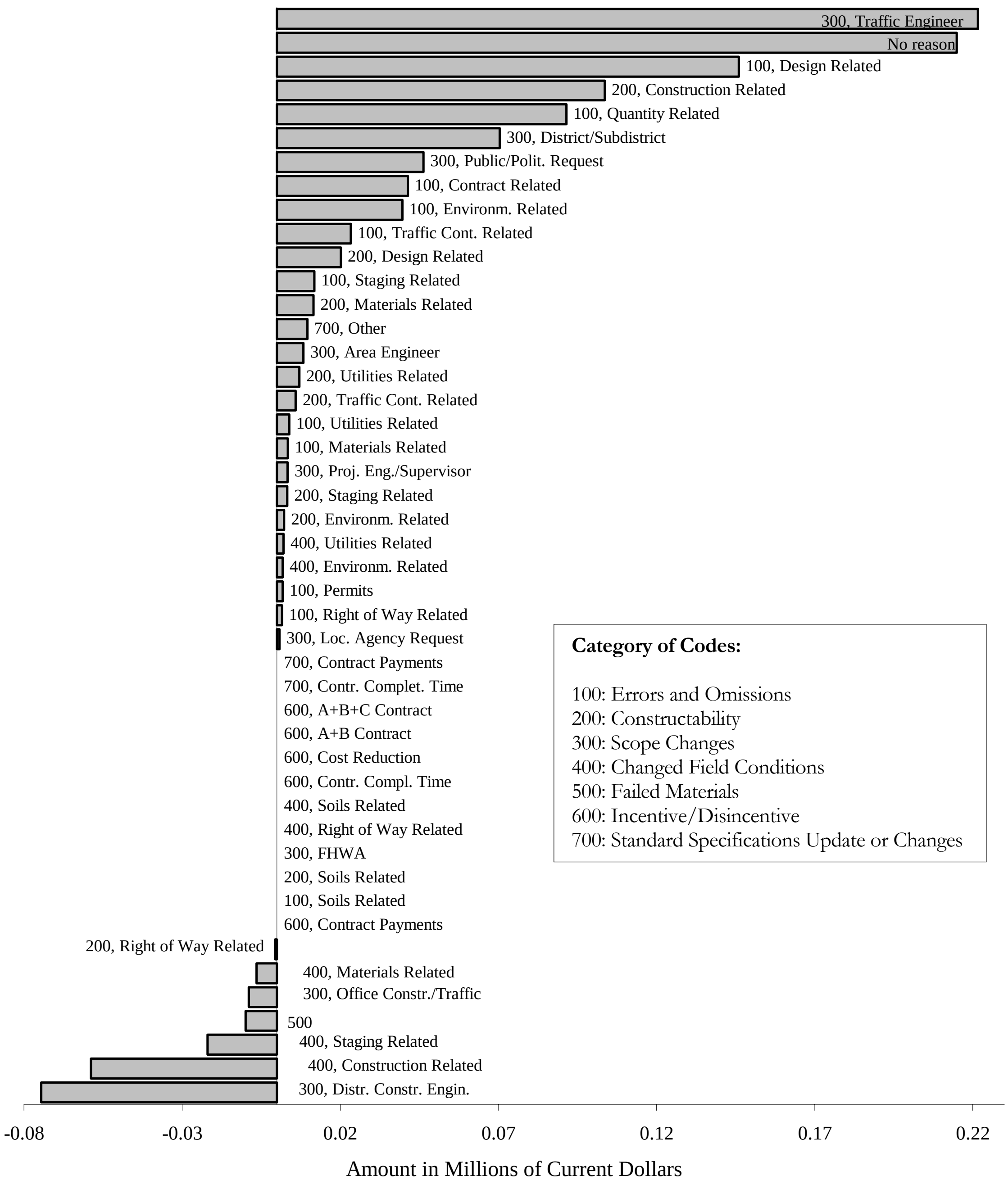

Figure E.11: Reasons for Change Orders in Traffic Projects

Appendix E: Additional Descriptive Statistics (Continued)

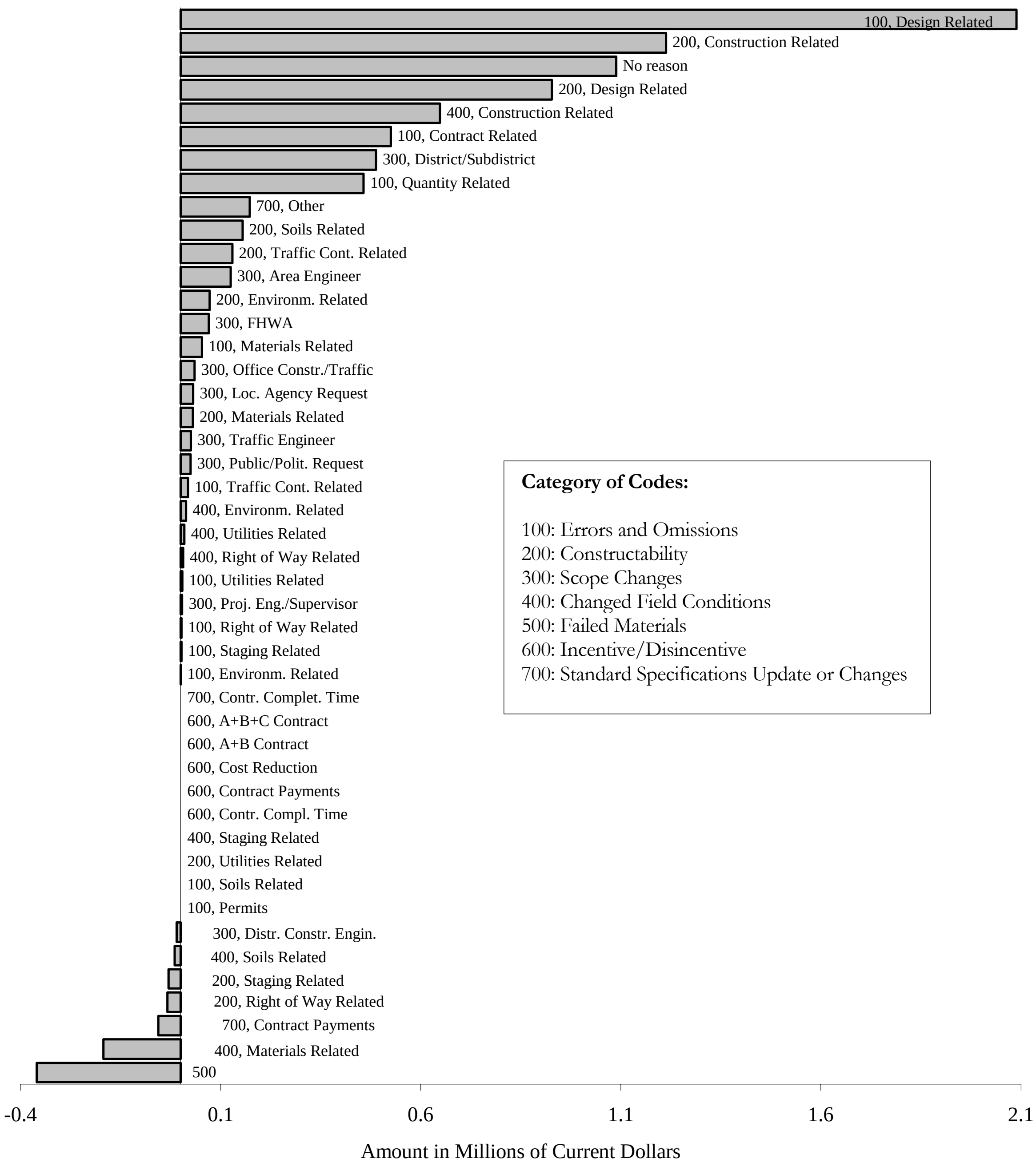

Figure E.12: Reasons for Change Orders in Resurfacing Projects

Appendix E: Additional Descriptive Statistics (Continued)

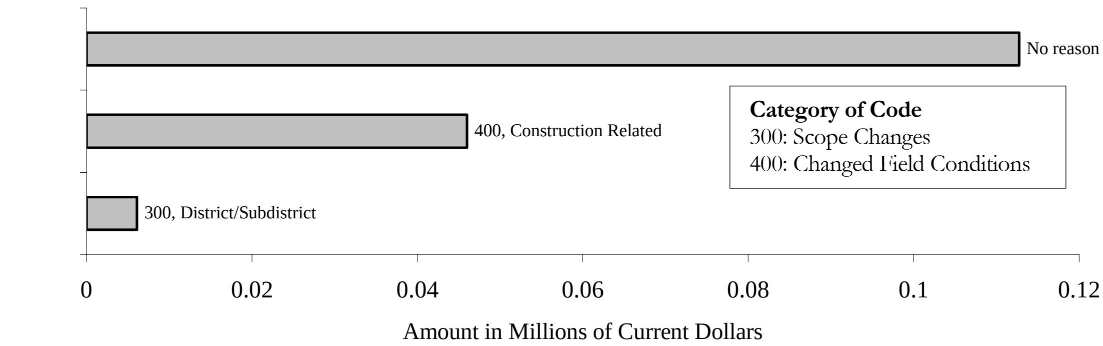

Figure E.13: Reasons for Change Orders in Traffic Maintenance Projects

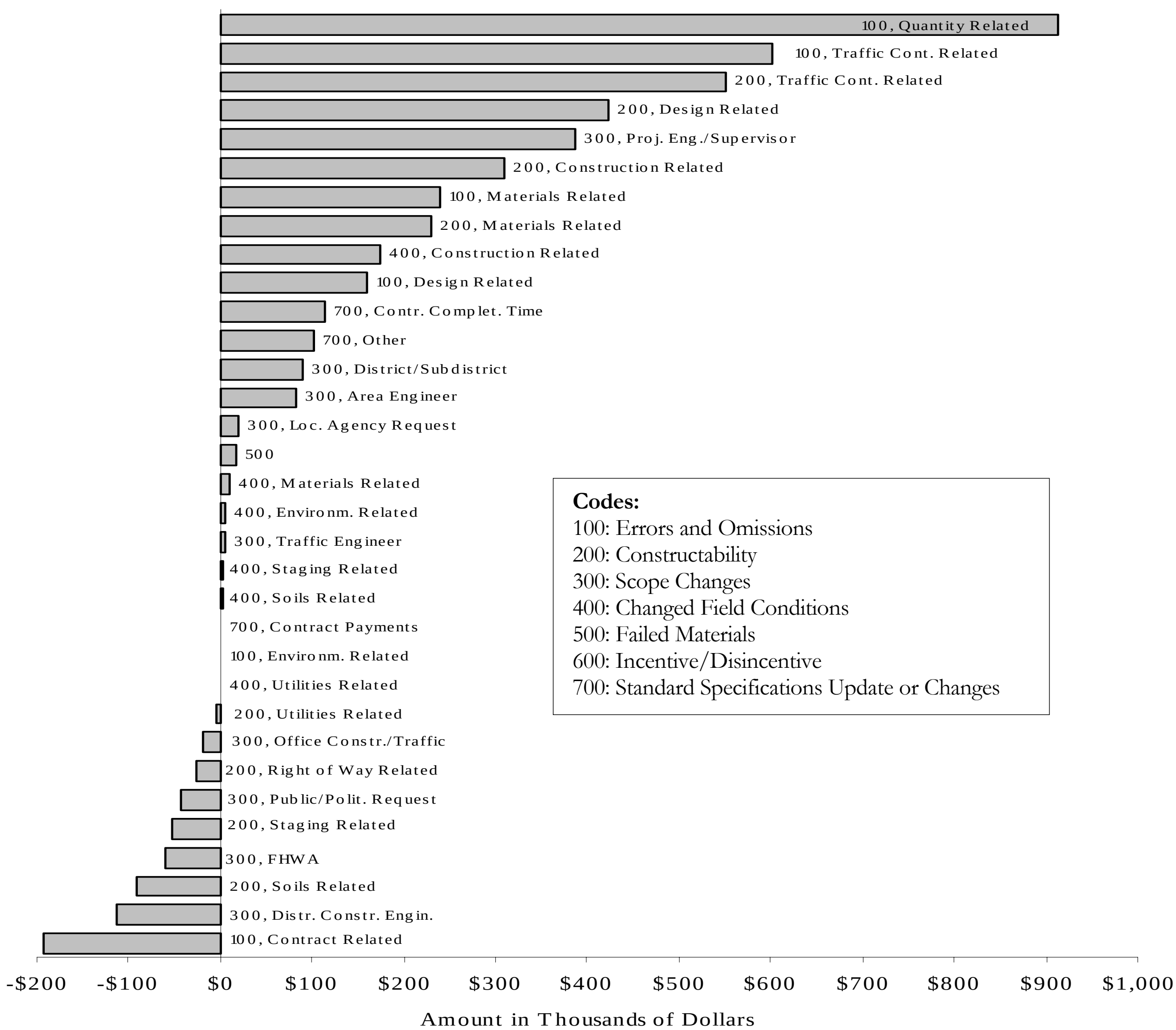

Figure E.14: Reasons for Change Orders in Crawfordsville District

Appendix E: Additional Descriptive Statistics (Continued)

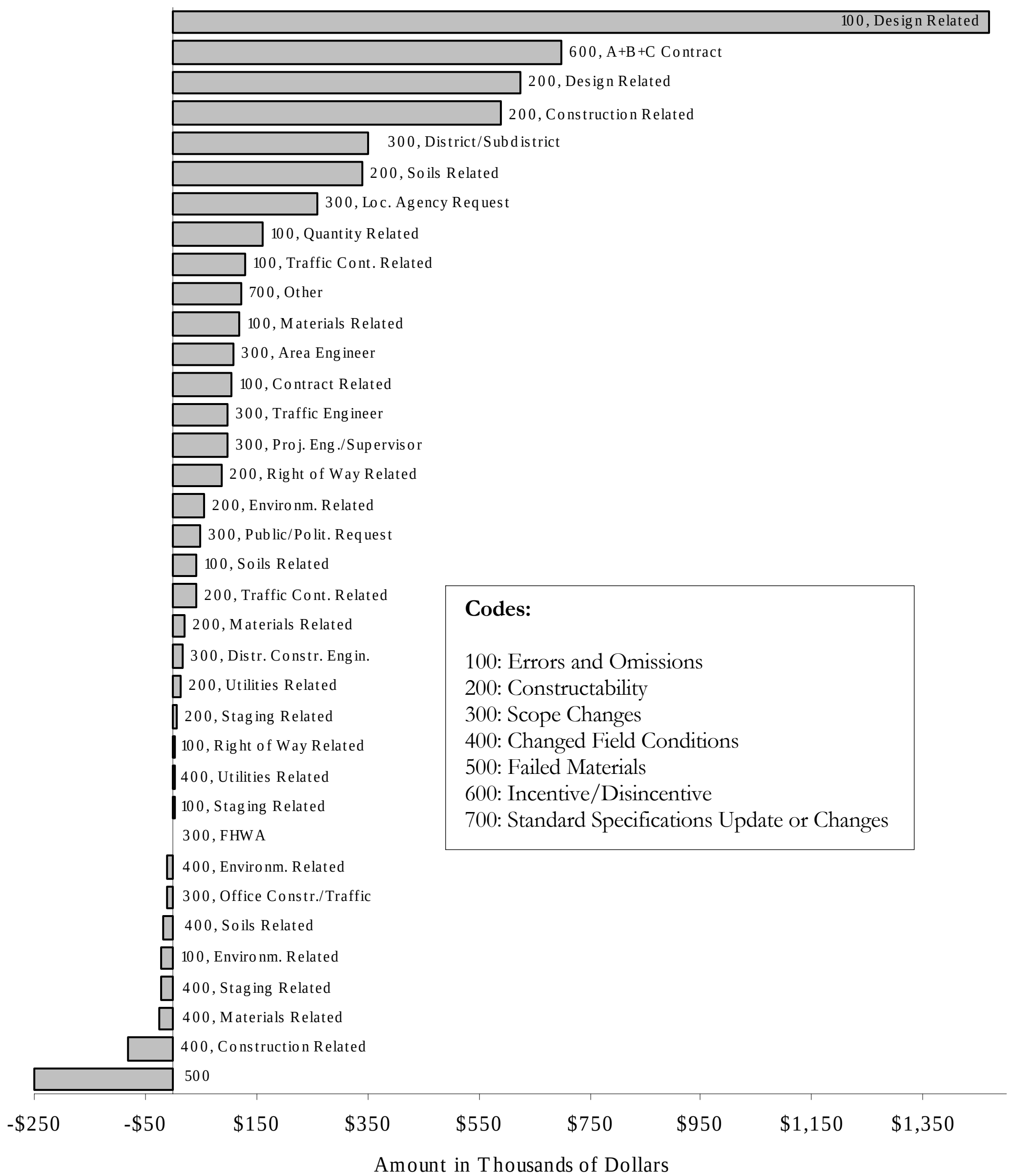

Figure E.15: Reasons for Change Orders in Fort Wayne District

Appendix E: Additional Descriptive Statistics (Continued)

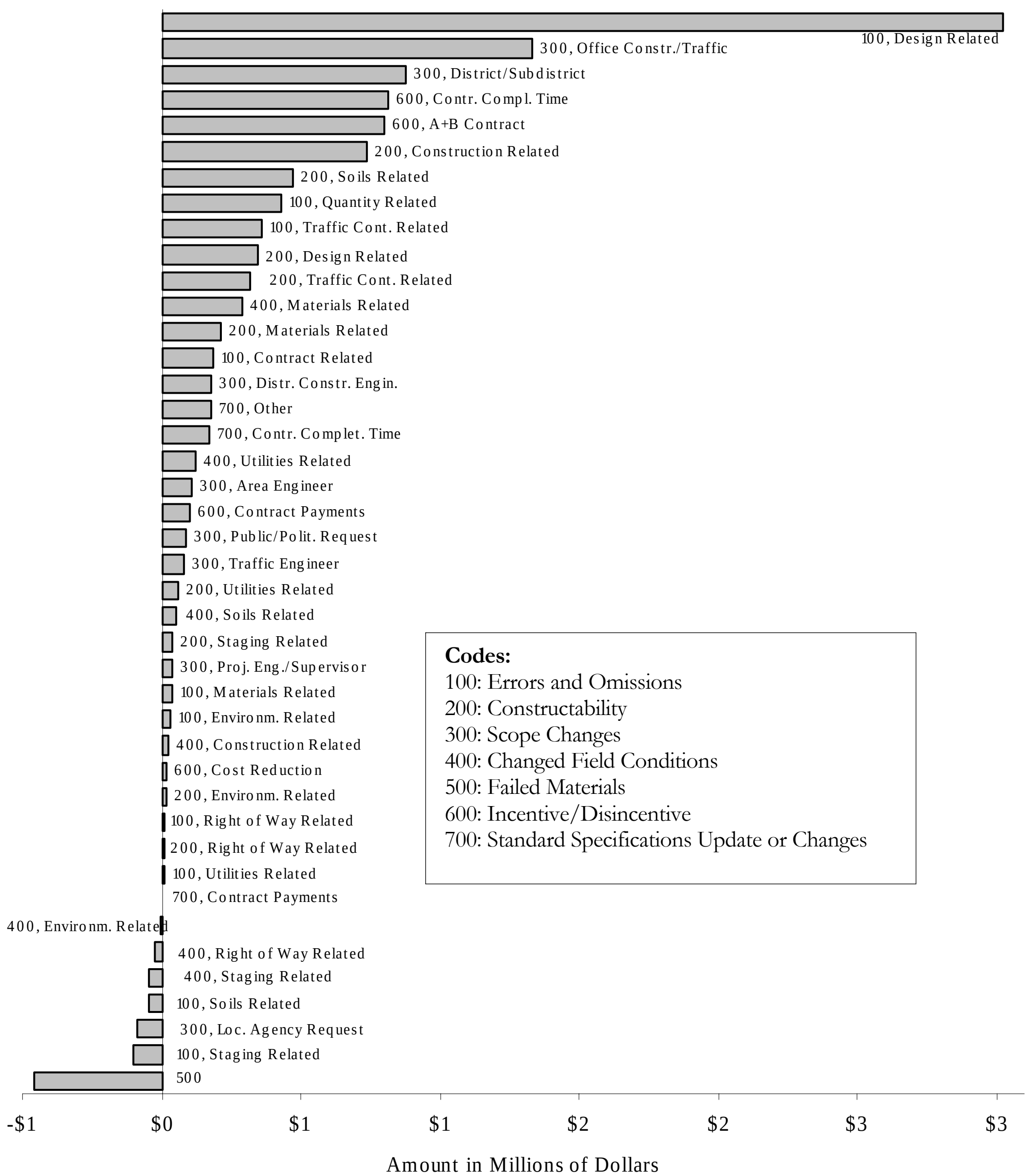

Figure E.16: Reasons for Change Orders in Greenfield District

Appendix E: Additional Descriptive Statistics (Continued)

Figure E.17: Reasons for Change Orders in La Porte District

Appendix E: Additional Descriptive Statistics (Continued)

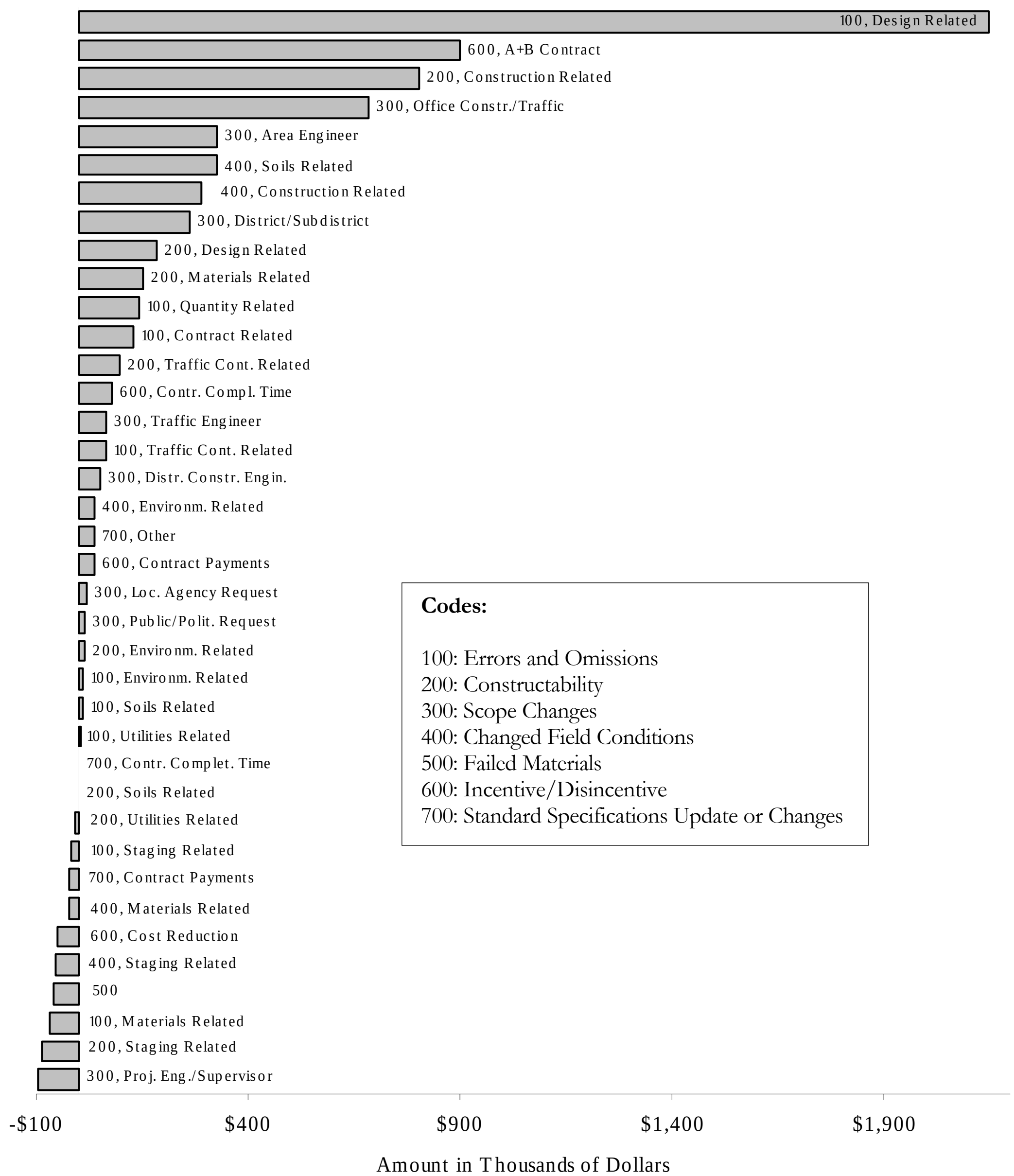

Figure E.18: Reasons for Change Orders in Seymour District

Appendix E: Additional Descriptive Statistics (Continued)

Figure E.19: Reasons for Change Orders in Vincennes District

Appendix E: Additional Descriptive Statistics (Continued)

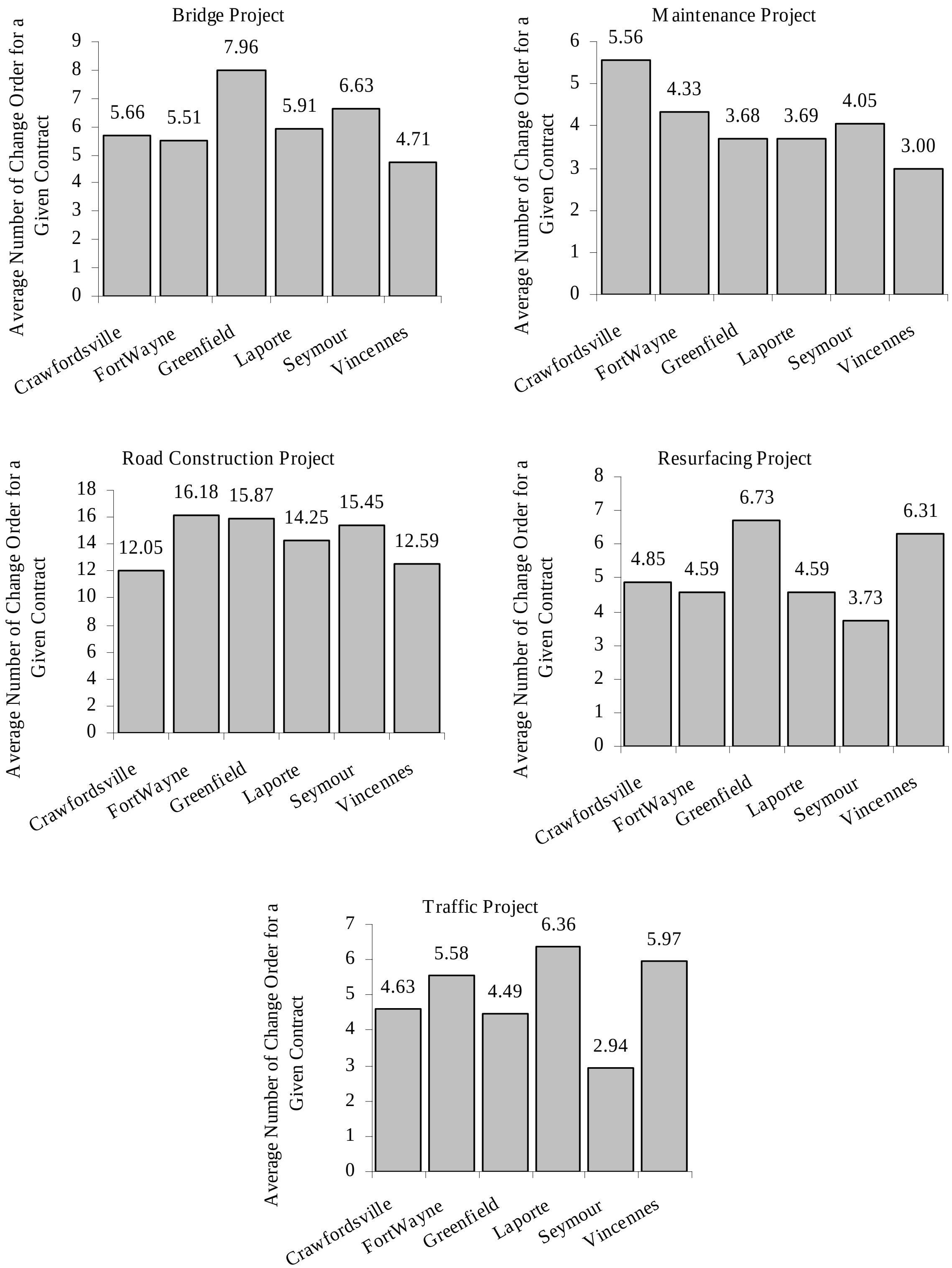

Figure E.20: Distribution of the Average Number of Change Orders by Project Type and by District

Appendix E: Additional Descriptive Statistics (Continued)

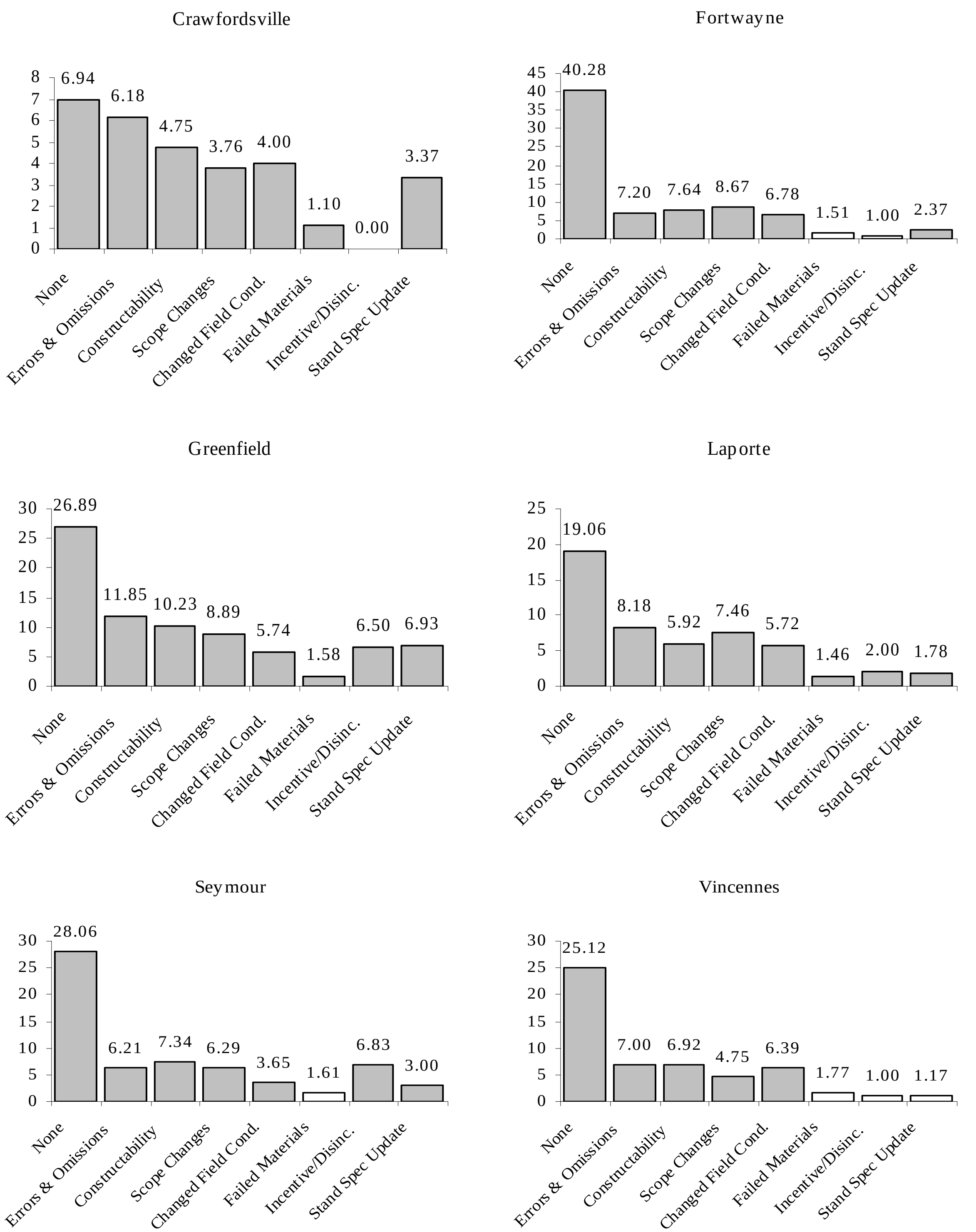

Figure E.21: Distribution of the Average Number of Change Orders by District and by Reason Category

Appendix E: Additional Descriptive Statistics (Continued)

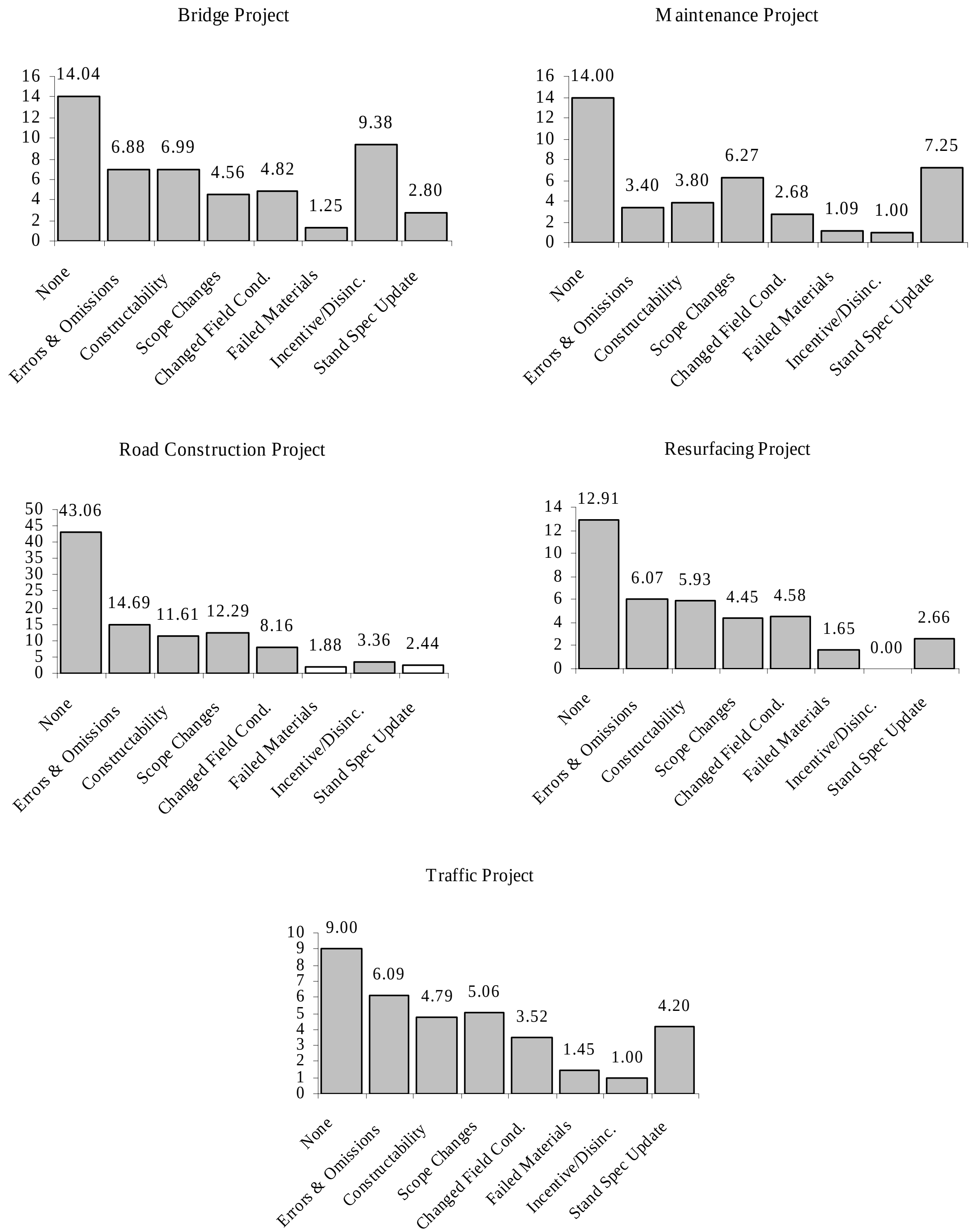

Figure E.22: Distribution of the Average Number of Change Orders by Project Type and by Reason Category

Appendix F: Statistical Analysis

Table F.1: Analysis of Means of the Combination of 5 Variables

Values of the Dummy Variable	Proportion of Inclement Days	Bid Amount	Level of Competition	Proportion of the Difference between the First and Second Bids	Proportion of the Difference between the Bid and Engineer's Estimate		Cost Overrun	Amount of Change Order	Number of Change Orders
						Mean	-$4,994	$125,913	28
1	1	1	1	1	1	N	16	16	7
						Std. Deviation	$23,529	$208,032	19
						Mean	$4,715	$107,751	14
2	2	1	1	1	1	N	21	21	10
						Std. Deviation	$24,018	$212,482	12
						Mean	-$180,692	$78,515	19
3	1	2	1	1	1	N	18	18	10
						Std. Deviation	$813,479	$91,124	14
						Mean	$11,079	$89,165	15
4	1	1	2	1	1	N	23	23	6
						Std. Deviation	$27,712	$100,679	16
						Mean	$16,440	$74,981	27
5	1	1	1	2	1	N	14	14	4
						Std. Deviation	$77,430	$119,807	18
						Mean	-$1,749	$103,942	4
6	1	1	1	1	2	N	10	10	3
						Std. Deviation	$29,782	$132,293	1
						Mean	-$61,304	$162,970	31
7	2	2	1	1	1	N	40	40	12
						Std. Deviation	$544,241	$367,981	39
						Mean	$2,997	$257,371	44
8	2	1	2	1	1	N	25	25	12
						Std. Deviation	$46,160	$878,659	87
						Mean	-$16,097	$149,959	18
9	2	1	1	2	1	N	25	25	12
						Std. Deviation	$66,673	$269,729	14
						Mean	-$6,266	$49,812	11
10	2	1	1	1	2	N	14	14	4
						Std. Deviation	$43,354	$52,685	8
						Mean	$88,684	$87,350	21
11	1	2	2	1	1	N	19	19	6
						Std. Deviation	$155,447	$121,458	28

Appendix F: Statistical Analysis (continued)

Table F.2: Analysis of Means of the Combination of 5 Variables (continued)

						Mean	$17,705	$168,835	23
12	1	2	1	2	1	N	13	13	6
						Std. Deviation	$125,284	$291,000	24
						Mean	$27,423	$32,946	3
13	1	2	1	1	2	N	10	10	2
						Std. Deviation	$103,725	$47,005	3
						Mean	$715	$39,338	31
14	1	1	2	2	1	N	8	8	6
						Std. Deviation	$14,511	$130,707	33
						Mean	$9,202	$15,146	11
15	1	1	2	1	2	N	40	40	14
						Std. Deviation	$34,037	$27,496	14
						Mean	-$980	$94,898	6
16	1	1	1	2	2	N	25	25	8
						Std. Deviation	$32,747	$359,242	6
						Mean	$81,090	$56,103	15
17	2	2	2	1	1	N	35	35	16
						Std. Deviation	$302,818	$120,501	17
						Mean	$53,718	$36,825	9
18	2	2	1	2	1	N	20	20	8
						Std. Deviation	$141,988	$60,113	7
						Mean	$7,438	$69,796	32
19	2	1	2	2	1	N	19	19	8
						Std. Deviation	$50,019	$134,364	49
						Mean	$265,718	$140,254	12
20	1	2	2	2	1	N	5	5	2
						Std. Deviation	$560,792	$159,312	11
						Mean	-$38,604	$151,591	9
21	2	2	1	1	2	N	15	15	4
						Std. Deviation	$101,747	$261,754	11
						Mean	-$2,239	$30,314	10
22	2	1	2	1	2	N	34	34	18
						Std. Deviation	$35,677	$46,016	7
						Mean	$57,063	-$8,848	4
23	1	2	2	1	2	N	12	12	3
						Std. Deviation	$232,396	$86,294	2
						Mean	-$1,443	$60,082	11
24	2	1	1	2	2	N	17	17	6
						Std. Deviation	$30,904	$75,891	19
						Mean	$184,081	$19,130	11
25	1	2	1	2	2	N	9	9	4
						Std. Deviation	$272,348	$40,568	12

Appendix F: Statistical Analysis (continued)

Table F.3: Analysis of Means of the Combination of 5 Variables (continued)

26	1	1	2	2	2	Mean	-$296	$19,510	6
						N	51	51	14
						Std. Deviation	$19,617	$37,084	6
27	2	2	2	2	1	Mean	$52,020	$387,481	27
						N	18	18	7
						Std. Deviation	$107,799	$1,099,122	32
28	2	2	2	1	2	Mean	$106,089	$219,572	11
						N	19	19	5
						Std. Deviation	$284,326	$874,671	6
29	2	2	1	2	2	Mean	-$60,108	$49,723	12
						N	21	21	8
						Std. Deviation	$324,985	$117,681	12
30	2	1	2	2	2	Mean	$13,052	$150,577	5
						N	36	36	7
						Std. Deviation	$23,966	$780,786	4
31	1	2	2	2	2	Mean	$95,070	$4,265	4
						N	4	4	2
						Std. Deviation	$223,658	$4,662	1
32	2	2	2	2	2	Mean	$57,578	$97,147	6
						N	23	23	7
						Std. Deviation	$135,200	$270,181	4
Total						Mean	$11,834.32	$98,155.23	16.54
						N	659	659	241
						Std. Deviation	$236,294.19	$382,784.62	27.59

N: Number of observations

Appendix F: Statistical Analysis (continued)

Table F.4: Analysis of Means of the Combination of Three Variables

Values of the Dummy Variable	Proportion of Inclement Days	Bid Amount	Project Duration		Cost Overrun	Change Order Amount	Number of Change Order	Time Delay
				Mean	$18,720	$179,450	17	224
1	1	1	1	N	136	136	55	136
				Std. Deviation	$60,177	$608,941	26	177
				Mean	$2,276	$90,937	13	52
2	2	1	1	N	459	459	178	459
				Std. Deviation	$29,981	$571,477	17	54
				Mean	$26,483	$80,618	15	233
3	1	2	1	N	160	160	64	160
				Std. Deviation	$173,599	$198,187	16	131
				Mean	$43,463	$267,168	50	143
4	1	1	2	N	164	164	18	164
				Std. Deviation	$215,445	$762,879	37	182
				Mean	$7,984	$124,529	22	104
5	2	2	1	N	178	178	68	178
				Std. Deviation	$249,861	$428,465	25	63
				Mean	-$1,235	$319,306	86	7
6	2	1	2	N	177	177	26	177
				Std. Deviation	$23,773	$1,004,387	100	46
				Mean	$159,903	$280,464	49	183
7	1	2	2	N	480	480	79	480
				Std. Deviation	$626,856	$1,197,695	50	199
				Mean	$36,971	$221,914	41	36
8	2	2	2	N	194	194	22	194
				Std. Deviation	$224,851	$658,118	37	69
				Mean	$51,378	$194,670	27	118
		Total		N	1948	1948	510	1948
				Std. Deviation	$343,901	$816,090	41	154

Appendix F: Statistical Analysis (continued)

Table F.5: Pair-wise Comparison of Cost Overrun by Bid Amount

Low Bid Amount Contracts		High Bid Amount Contracts		$x = CO_{highbid} - CO_{low\ bid}$
Inclement Days	Cost Overrun	Inclement Days	Cost overrun	
0.00	$37,930	0.01	$2,824,638	$2,786,708
0.05	$73,446	0.04	$3,677,451	$3,604,005
0.08	$299,875	0.07	$514,309	$214,435
0.08	$53,415	0.07	$514,309	$460,894
0.09	$164,567	0.07	$514,309	$349,742
0.12	$26,250	0.13	$632,958	$606,708
0.13	$25,000	0.13	$1,251,777	$1,226,777
0.14	$56,800	0.14	$3,774,226	$3,717,426
0.27	$91,740	0.22	$449,190	$357,450
0.28	$100,552	0.23	$650,905	$550,353
0.28	$154,500	0.23	$1,525,794	$1,371,294
0.30	$326,754	0.33	$2,207,406	$1,880,652
0.31	$93,220	0.33	$2,207,406	$2,114,186
0.32	$19,834	0.33	$2,207,406	$2,187,572
0.32	$60,000	0.33	$2,207,406	$2,147,406
0.32	$60,025	0.33	$2,207,406	$2,147,381
0.33	$157,778	0.33	$2,207,406	$2,049,628
0.37	$51,355	0.36	$384,796	$333,441
0.38	$92,233	0.38	$1,083,608	$991,376
0.39	$66,329	0.38	$1,083,608	$1,017,279
0.42	$333,718	0.42	$1,990,781	$1,657,063

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = 1873888.42$$

n = 21

$\bar{x}$ = $1,512,942

t-stat = 3.7

$t_{(0.05,20)} = 2.09$

|t-stat| is greater than $t_{(0.05,20)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ is rejected.

Appendix F: Statistical Analysis (continued)

Table F.6: Pair-wise Comparison of Time Delay by Bid Amount

Low Bid Amount Contracts		High Bid Amount Contracts		$x = TD_{highbid} - TD_{low\ bid}$
Duration	Time Delay	Duration	Time Delay	
30	168	30	136	-32
50	161	50	180	19
59	166	55	57	-109
60	208	65	238	30
76	118	70	70	-48
76	118	70	298	180
76	118	75	101	-17
76	118	75	323	205
76	118	75	117	-1
83	520	80	252	-268
95	426	100	192	-234
110	70	110	128	58
112	13	120	283	270
129	180	123	111	-69
129	180	131	38	-142
129	180	131	53	-127
129	180	136	112	-68
129	180	140	11	-169
129	180	142	105	-75
129	180	143	39	-141
205	41	160	518	477
205	41	168	143	102
205	41	185	133	92
205	41	218	82	41
236	13	221	41	28
236	13	261	298	285
236	13	266	31	18
418	380	521	473	93
418	380	544	137	-243

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = 168.17$$

$n = 29$

$\bar{x} = 5.34$

t-stat = 0.17

$t_{(0.05,28)} = 2.05$

|t-stat| is not greater than $t_{(0.05,28)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ cannot be rejected.

Appendix F: Statistical Analysis (continued)

Table F.7: Pair-wise Comparison of Number of Change Orders by Bid Amount

Low Bid Amount Contracts		High Bid Amount Contracts		$x = ChO_{highbid} - ChO_{low\ bid}$
Proportion of Inclement Days	Number of Change Orders	Proportion of Inclement Days	Number of Change Orders	
0.12	5	0.03	17	12
0.14	4	0.04	40	36
0.28	49	0.18	9	-40
0.31	25	0.34	44	19
0.32	17	0.34	44	27
0.32	25	0.34	44	19
0.37	48	0.35	16	-32
0.38	7	0.47	26	19

$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2}$ = 28.97, n = 8, $\bar{x}$ = 7.5, t-stat = 10.93, $t_{(0.05,7)}$ = 2.37, |t-stat| is greater than t, so the hypothesis H_0: $\mu_A - \mu_B = 0$ is rejected

Table F.8: Pair-wise Comparison of Time Delay by Duration

Low Duration Contracts		High Duration Contracts		$x = TD_{high\ dur} - TD_{low\ dur}$
Bid Amount	Time Delay	Bid Amount	Time Delay	
$60,025	70	$60,000	13	-57
$73,446	229	$66,329	13	-216
$157,778	208	$154,500	180	-28
$164,567	161	$154,500	180	19
$333,718	166	$326,754	41	-125
$349,815	136	$355,749	38	-98
$370,789	252	$376,075	31	-221
$384,796	70	$376,075	31	-39
$449,190	180	$514,309	112	-68
$632,958	238	$650,905	53	-185
$1,157,880	323	$1,083,608	11	-312
$1,329,502	192	$1,251,777	283	91
$1,378,000	117	$1,525,794	41	-76
$1,990,780.79	57	$1,800,395.70	143	86
$2,207,405.80	128	$2,824,638.16	518	390
$2,268,327.80	298	$2,824,638.16	518	220

$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2}$ = 179.78

n = 16, $\bar{x}$ = -38.69, t-stat = -0.86, $t_{(0.05,15)}$ = 2.13

|t-stat| is not greater than $t_{(0.05,15)}$, so it shows that in these conditions, the hypothesis cannot be rejected.

Appendix F: Statistical Analysis (continued)

Table F.9: Pair-wise Comparison of Cost Overrun by Proportion of Inclement Weather Days

Low Proportion of Inclement Days Contracts		High Proportion of Inclement Days Contracts		$x = CO_{high\ prop} - CO_{low\ prop}$
Bid Amount	Cost Overrun	Bid Amount	Cost Overrun	
$25,000	$23,500	$20,000	-$1,458	-$24,958
$26,250	$1,609	$20,000	-$1,458	-$3,067
$37,930	$55,560	$33,800	$0	-$55,560
$53,415	$53,415	$54,574	$377	-$53,038
$56,800	$56,800	$56,579	-$2,307	-$59,107
$73,446	$147	$70,773	-$9,635	-$9,782
$164,567	-$2,247	$157,778	-$3,839	-$1,592
$299,875	$163,271	$298,348	-$36,815	-$200,086
$370,789	-$13,598	$376,075	$14,064	$27,662
$449,190	-$3,213	$494,637	$49,522	$52,735
$514,309	$27,095	$563,805	$121,273	$94,178
$632,958	$24,563	$664,860	$134,268	$109,705
$650,905	$724	$664,860	$134,268	$133,544
$709,989	$57,704	$683,060	-$54,108	-$111,812
$1,157,880	$121,108	$1,221,284	$31,697	-$89,411
$1,251,777	$56,448	$1,221,284	$31,697	-$24,751
$1,329,502	$161,027	$1,294,730	$79,242	-$81,785
$1,525,794	$166,319	$1,765,197	$52,440	-$113,879
$1,800,396	$280,388	$1,765,197	$52,440	-$227,948
$1,863,220	$33,253	$1,990,781	-$299,693	-$332,945
$2,268,328	-$603,942	$2,135,460	$97,522	$701,464
$2,824,638	$738,290	$2,878,030	-$794,847	-$1,533,137

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = \$386,596$$

n = 22

$\bar{x}$ = -$81,980.60

t-stat = -0.99

$t_{(0.05,21)} = 2.08$

|t-stat| is not greater than $t_{(0.05,21)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ cannot be rejected.

Appendix F: Statistical Analysis (continued)

Table F.10: Pair-wise Comparison of Time Delay by Proportion of Inclement Weather Days

Low Proportion of Inclement Days Contracts		High Proportion of Inclement Days Contracts		$x = TD_{high\ prop} - TD_{low\ prop}$
Bid Amount	Time Delay	Bid Amount	Time Delay	
$25,000	894	$20,000	-36	-930
$26,250	118	$33,800	118	0
$53,415	520	$54,574	-65	-585
$56,800	426	$56,579	36	-390
$73,446	229	$70,773	9	-220
$164,567	161	$157,778	208	47
$299,875	380	$298,348	17	-363
$370,789	252	$376,075	31	-221
$449,190	180	$494,637	-2	-182
$514,309	112	$494,637	-2	-114
$632,958	238	$664,860	149	-89
$650,905	53	$664,860	149	96
$709,989	82	$683,060	105	23
$1,157,880	323	$1,221,284	-7	-330
$1,251,777	283	$1,221,284	-7	-290
$1,329,502	192	$1,294,730	-34	-226
$1,525,794	41	$1,378,000	117	76
$1,800,396	143	$1,765,197	111	-32
$2,268,328	298	$2,207,406	128	-170
$2,824,638	518	$2,207,406	128	-390

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = 331.35$$

n = 20

$\bar{x}$ = -214.5

t-stat = -2.89

$t_{(0.05,19)}$ = 2.09

|t-stat| is greater than $t_{(0.05,19)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ is rejected.

Appendix F: Statistical Analysis (continued)

Table F.11: Pair-wise Comparison of Cost Overrun by Level of Competition

Low Level of Competition Contracts		High Level of Competition Contracts		$x = CO_{high\ lev} - CO_{low\ lev}$
Bid Amount	Cost Overrun	Bid Amount	Cost Overrun	
$47,438	$1,525	$45,897	-$6	-$1,531
$68,966	-$18,852	$68,184	-$3,052	$15,800
$87,716	-$1,484	$83,469	$4,685	$6,169
$95,535	-$1,297	$109,627	-$38,841	-$37,544
$158,719	-$13,535	$160,800	$9,339	$22,874
$218,861	$36,172	$230,150	$12,296	-$23,876
$275,696	$36,495	$278,815	$27,313	-$9,181
$289,775	-$3,215	$293,961	-$2,232	$983
$321,111	-$31,466	$324,002	-$17,244	$14,222
$333,063	-$333,063	$351,705	$65,842	$398,905
$787,791	$8,424	$784,892	$8,991	$567
$799,830.07	$58,373	$784,892	$8,991	-$49,382
$844,536.42	$50,475	$784,892	$8,991	-$41,484
$954,261.25	$150,902	$914,029	$101,152	-$49,750
$1,210,478.00	$341,522	$1,135,999	-$8,244	-$349,766
$1,345,130.20	$185,325	$1,135,999	-$8,244	-$193,569
$1,659,635.91	-$7,719	$1,553,340	$135,908	$143,627
$2,398,743.45	$262,411	$2,490,470	$316,622	$54,211
$2,559,114.38	-$41,544	$2,490,470	$316,622	$358,166

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = \$163,384$$

n = 19

$\bar{x}$ = $13,655

t-stat = 0.364

$t_{(0.05,18)} = 2.1$

|t-stat| is not greater than $t_{(0.05,18)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ cannot be rejected.

Appendix F: Statistical Analysis (continued)

Table F.12: Pair-wise Comparison of Number of Change Orders by Level of Competition

High Level of Competition Contracts		Low Level of Competition Contracts		$x = ChO_{high\ lev} - ChO_{low\ lev}$
Bid Amount	Number of Change Orders	Bid Amount	Number of Change Orders	
$47,438	22	$52,250	3	-19
$68,966	59	$68,184	3	-56
$158,719	16	$181,518	7	-9
$218,861	37	$243,870	21	-16
$275,696	58	$293,961	12	-46
$289,775	18	$293,961	12	-6
$333,063	10	$351,705	28	18
$1,210,478	10	$1,099,659	9	-1
$1,659,636	16	$1,553,340	2	-14
$2,559,114	60	$2,490,470	36	-24

$$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = 28.05$$

n = 10

$\bar{x}$ = -17.3

t-stat = -1.95

$t_{(0.05,9)}$ = 2.26

|t-stat| is not greater than $t_{(0.05,9)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ cannot be rejected.

Appendix F: Statistical Analysis (continued)

Table F.13: Pair-wise Comparison of Cost Overrun by Proportion of the Difference between the First and Second Bid

Low First and Second Contracts		High First and Second Contracts		$x = CO_{high\ prop} - CO_{low\ prop}$
Bid Amount	Cost Overrun	Bid Amount	Cost Overrun	
$47,438	$1,525	$51,205	$2,4612	$936
$95,535	-$1,297	$87,716	-$1,484	-$187
$148,767	-$23,065	$125,290	$0	$23,065
$171,375	-$9,092	$176,181	$11,203	$20,294
$206,323	$14,805	$196,405	-$12,628	-$27,433
$212,894	-$13,692	$218,861	$36,172	$49,863
$221,854	-$3,586	$218,861	$36,172	$39,758
$281,325	$86,699	$274,696	-$21,712	-$108,411
$289,775	-$3,215	$297,000	-$160	$3,055
$351,977	$6,258	$333,063	-$333,063	-$339,320
$354,737	-$14,237	$333,063	-$333,063	-$318,825
$374,321	$8,424	$333,063	-$333,062	-$341,487
$397,842	-$23,099	$406,470	-$56,557	-$33,458
$415,480	-$93,293	$406,470	-$56,557	$36,736
$595,304	$63,6134	$570,247	-$8,959	-$72,572
$687,444	-$13,226	$665,551	$6,353	$19,579
$690,314	-$42,846	$665,551	$6,353	$49,199
$777,922	$14,711	$787,791	$8,424	-$6,287
$788,912	$27,283	$787,791	$8,424	-$18,859
$859,312	$77,554	$844,536	$50,475	-$27,078
$869,273	-$180,615	$844,536	$50,475	$231,090
$896,017	-$2,483	$924,815	-$181,869	-$179,386
$1,308,800	-$35,393	$1,250,449	$216,030	$251,423
$1,345,130	$185,325	$1,360,891	$30,612	-$154,712
$1,564,035	$605,794	$1,579,812	$221,319	-$384,475
$1,605,823	-$112,336	$1,579,812	$221,319	$333,655
$2,398,743	$262,411	$2,559,114	-$41,544	-$303,956
$5,589,000	$386,246	$5,436,363	-$258,966	-$645,212

$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2}$ = $219,693.58

n = 28

$\bar{x}$ = -$67,964.52

t-stat = -1.64

$t_{(0.05,27)} = 2.05$

|t-stat| is not greater than $t_{(0.05,27)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ cannot be rejected.

Appendix F: Statistical Analysis (continued)

Table F.14: Pair-wise Comparison of Time Delay by Proportion of the Difference between the First and Second Bid

Low First and Second Contracts		High First and Second		$x = TD_{high\ prop} - TD_{low\ prop}$
Bid Amount	Time Delay	Bid Amount	Time Delay	
$171,375	50	$196,405	197	147
$212,894	74	$264,778	64	-10
$354,737	16	$321,111	215	199
$374,321	18	$321,111	215	197
$382,510	60	$321,111	215	155
$385,051	7	$321,111	215	208
$415,480	59	$514,001	30	-29
$1,564,035	66	$1,250,449	54	-12
$2,246,000	101	$2,559,114	378	277
$2,398,743	25	$2,559,114	378	353

$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2} = 202.69$

n = 10

$\bar{x} = 148.5$

t-stat = 2.32

$t_{(0.05,9)} = 2.26$

|t-stat| is greater than $t_{(0.05,9)}$

Appendix F: Statistical Analysis (continued)

Table F.15: Pair-wise Comparison of Cost Overrun by Proportion of the Difference between the Bid and the Engineer's Estimate

Low Bid and Engineer		High Bid and Engineer		$x = CO_{high\ prop} - CO_{low\ prop}$
Bid Amount	Cost Overrun	Bid Amount	Cost Overrun	
$40,046	$1,332	$49,349	-$7,954	-$9,286
$50,624	-$7,222	$49,349	-$7,954	-$732
$107,231	-$12,589	$110,535	-$110,535	-$97,947
$108,666	$8,230	$110,535	-$110,535	-$118,766
$111,493	-$11,572	$110,535	-$110,535	-$98,963
$111,743	-$106	$110,535	-$110,535	-$110,429
$160,568	$64,629	$154,087	$64,940	$312
$163,745	-$32,601	$165,438	-$5,029	$27,572
$214,307	$3,598	$219,993	$53,543	$49,945
$220,950	$6,614	$219,993	$53,543	$46,929
$222,729	$6,639	$219,993	$53,543	$46,904
$222,928	$1,046	$219,993	$53,543	$52,497
$258,715	$30,314	$257,420	-$123,949	-$154,262
$297,600	-$20,226	$257,420	-$123,949	-$103,723
$299,263	$22,737	$257,420	-$123,949	-$146,686
$648,159	-$51,441	$635,916	$141,152	$192,593
$733,820	$21,715	$768,272	$128,054	$106,338
$734,473	-$34,928	$768,272	$128,054	$162,982
$756,861	-$9,970	$768,272	$128,054	$138,024
$779,079	-$9,717	$768,272	$128,054	$137,771
$1,177,461	$107,468	$1,234,770	-$133,610	-$241,077
$1,654,231	$180,076	$1,648,050	-$13,851	-$193,927
$1,707,4856	-$2,061	$1,648,050	-$13,851	-$11,790
$3,550,067	$603,123	$4,197,041	$308,228	-$294,896

$s_x = \sqrt{\frac{1}{n-1}\sum\left(x-\bar{x}\right)^2}$ = \$133,201.78

n = 24

$\bar{x}$ = -\$25,859.06

t-stat = -0.95

$t_{(0.05,23)} = 2.07$

|t-stat| is not greater than $t_{(0.05,23)}$, so the hypothesis H_0: $\mu_A - \mu_B = 0$ cannot be rejected

Appendix G: Arizona Department of Transportation Management of Cost and Time Overrun

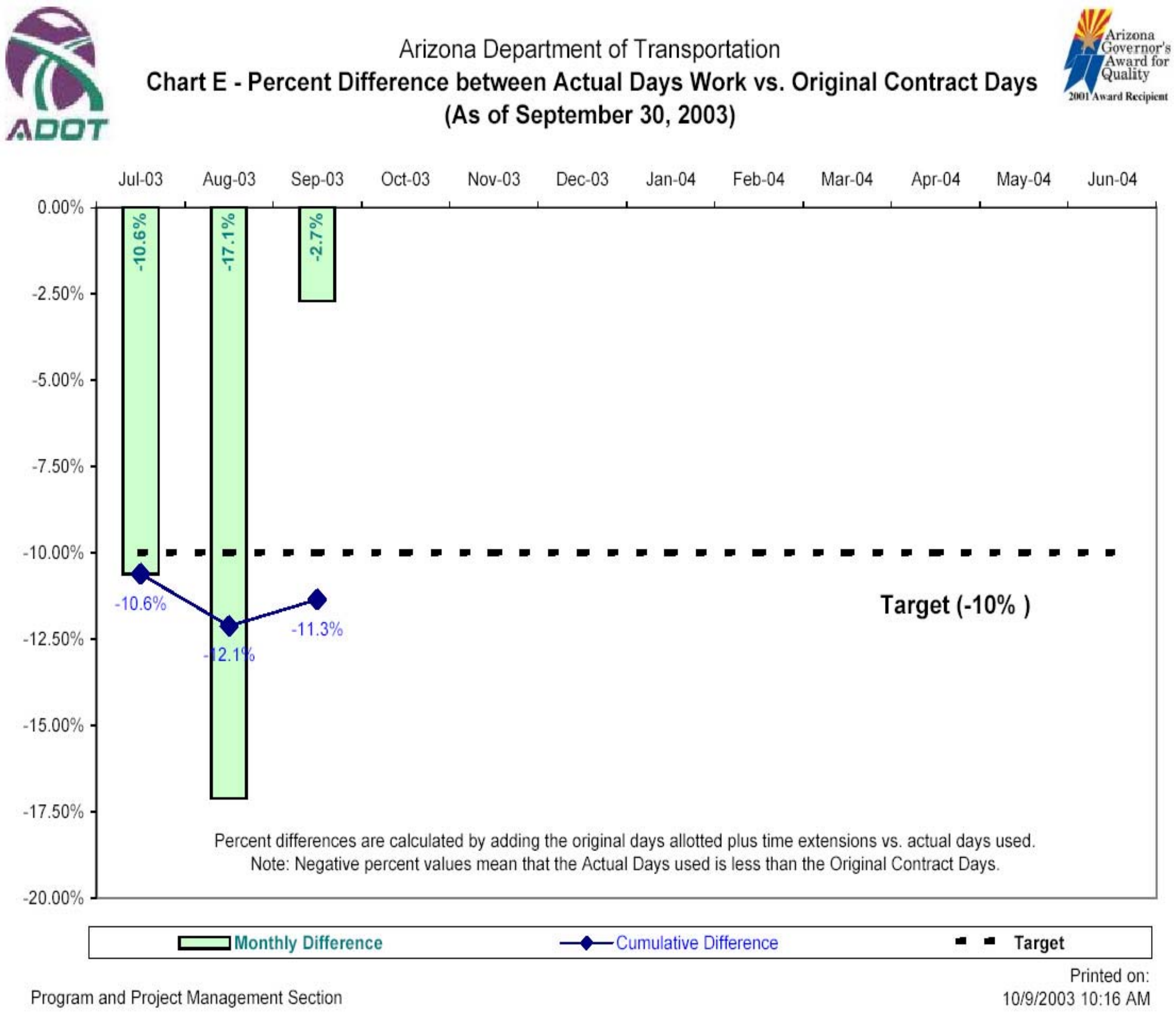

Figure G.1: Arizona Time Overrun Management

Appendix G: Arizona Department of Transportation Management of Cost and Time Overrun

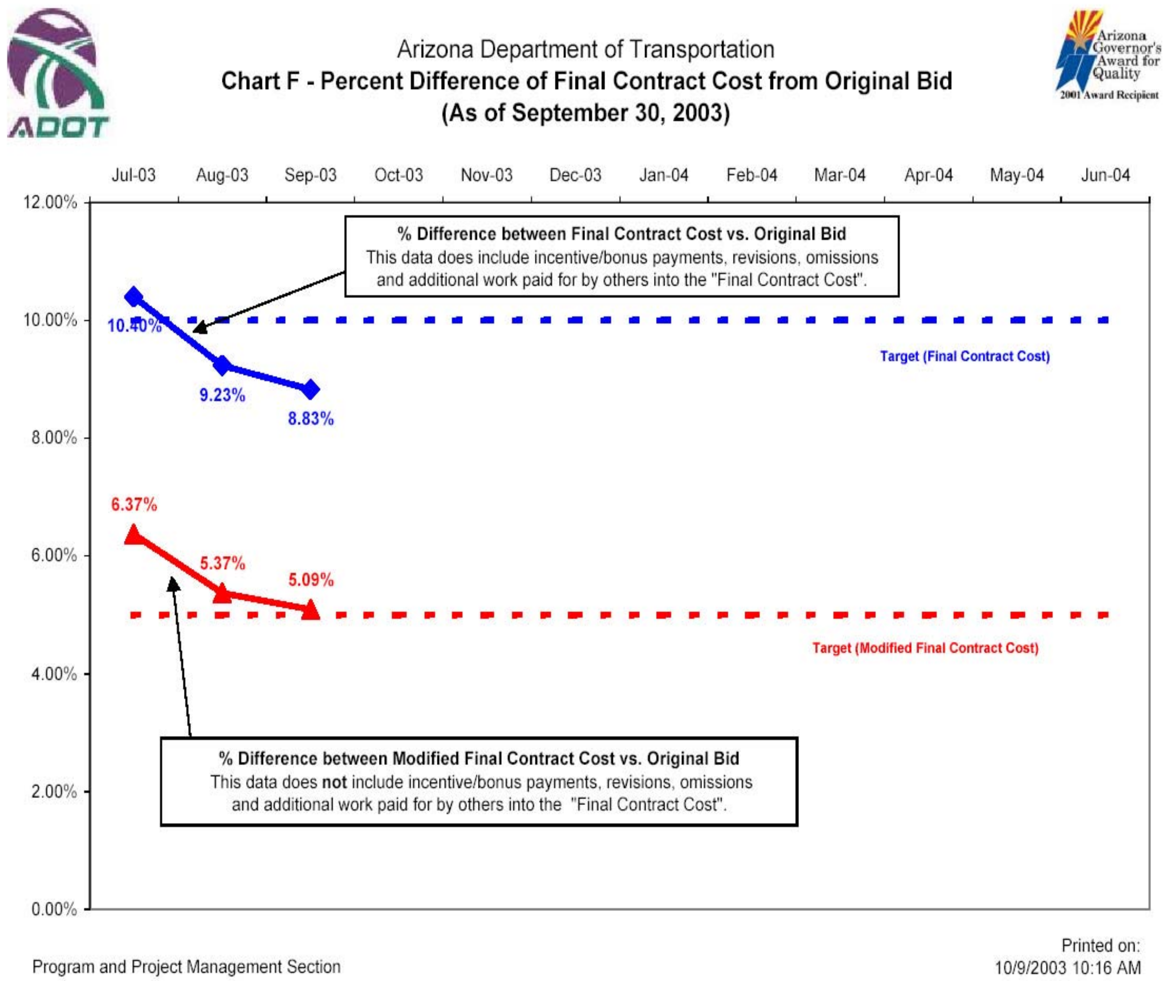

Figure G.2: Arizona Cost Overrun Management