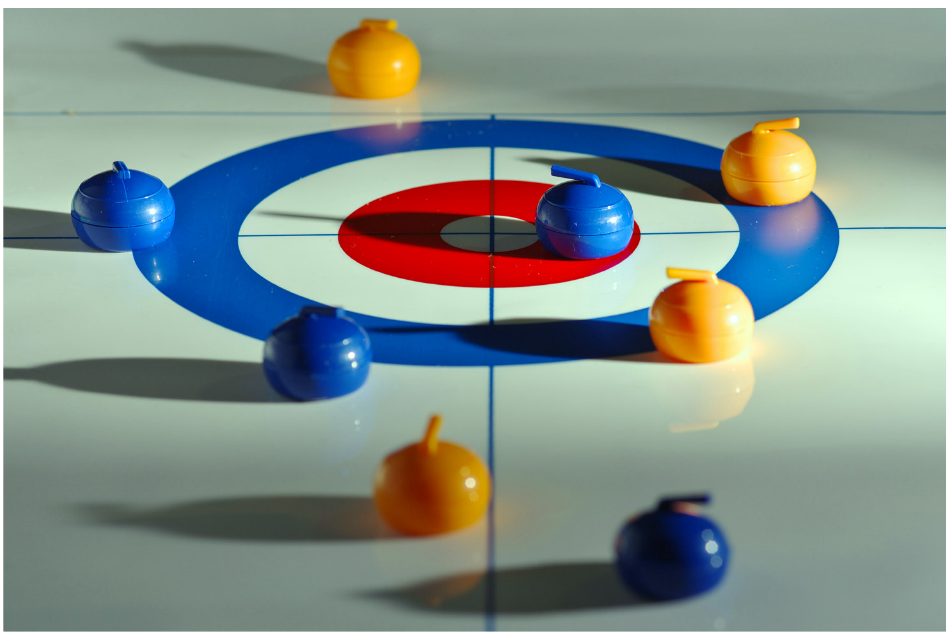
**JOINT TRANSPORTATION RESEARCH PROGRAM**

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

# INDOT Project Change Orders: Root Causes and Recommendations



**Suyash Padhye, Aishwarya Sharma, Hesam Arefkhani, Deepak Benny, Konstantina Gkritza, Samuel Labi, Makarand Hastak**

SPR-4710 • Report Number: FHWA/IN/JTRP-2024/14 • DOI: 10.5703/1288284317747

## RECOMMENDED CITATION

Padhye, S., Sharma, A., Arefkhani, H., Benny, D., Gkritza, K., Labi, S., & Hastak, M. (2024). *INDOT project change orders: Root causes and recommendations* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2024/14). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317747

## AUTHORS

**Suyash Padhye**
Graduate Research Assistant
Lyles School of Civil and Construction Engineering
Purdue University

**Aishwarya Sharma**
Graduate Research Assistant
Lyles School of Civil and Construction Engineering
Purdue University

**Hesam Arefkhani**
Visiting Scholar
Lyles School of Civil and Construction Engineering
Purdue University

**Deepak Benny**
Graduate Research Assistant
Lyles School of Civil and Construction Engineering
Purdue University

**Konstantina Gkritza, PhD**
Professor of Civil Engineering and Agriculture and Biological Engineering
Lyles School of Civil and Construction Engineering
Purdue University

**Samuel Labi, PhD**
Professor of Civil Engineering
Lyles School of Civil and Construction Engineering
Purdue University
(765) 494-5926
labi@purdue.edu
*Corresponding Author*

**Makarand Hastak, PhD**
Professor of Civil Engineering
Lyles School of Civil and Construction Engineering
Purdue University

## JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure. https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at http://docs.lib.purdue.edu/jtrp/.

## NOTICE



## COVER IMAGE

Wegmann, I. (2022, February 7). *A group of balls sitting on top of a table* [Photograph]. Unsplash. https://unsplash.com/photos/a-group-of-balls-sitting-on-top-of-a-table-TW0T1SfKMrk?utm_content=creditShareLink&utm_medium=referral&utm_source=unsplash

# TECHNICAL REPORT DOCUMENTATION PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FHWA/IN/JTRP-2024/14 | | |

| | |
|---|---|
| **4. Title and Subtitle**<br>INDOT Project Change Orders: Root Causes and Recommendations | **5. Report Date**<br>March 2024 |
| | **6. Performing Organization Code** |
| **7. Author(s)**<br>Suyash Padhye, Aishwarya Sharma, Hesam Arefkhani, Deepak Benny, Konstantina Gkritza, Samuel Labi, and Makarand Hastak | **8. Performing Organization Report No.**<br>FHWA/IN/JTRP-2024/14 |
| **9. Performing Organization Name and Address**<br>Joint Transportation Research Program<br>Hall for Discovery and Learning Research (DLR), Suite 204<br>207 S. Martin Jischke Drive<br>West Lafayette, IN 47907 | **10. Work Unit No.** |
| | **11. Contract or Grant No.**<br>SPR-4710 |
| **12. Sponsoring Agency Name and Address**<br>Indiana Department of Transportation (SPR)<br>State Office Building<br>100 North Senate Avenue<br>Indianapolis, IN 46204 | **13. Type of Report and Period Covered**<br>Final Report |
| | **14. Sponsoring Agency Code** |

**15. Supplementary Notes**

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

**16. Abstract**

This study analyzed the historical trends in change orders (COs) associated with the Indiana Department of Transportation (INDOT) highway contracts. It also investigated correlations between COs and base factors (district, project type, contract type, award amount, geographical area (rural vs. urban)), and sought to understand the effect of the root causes but not to predict CO based on root causes. Unlike the base factors, the root causes are unknown prior to construction. The study developed models that forecasted CO characteristics—CO likelihood, CO frequency (count), and CO severity (magnitude) and CO impacts (cost overrun and schedule delay). To address these research questions, the study used INDOT's 2010–2020 highway contract data involving approximately 5,000 contracts worth just over $10B. The CO trends and patterns (including root causes) were analyzed for five project types at the six highway administrative districts in Indiana. The study identified the base factors that generally have higher propensity to experience more frequent and severe COs and analyzed CO impacts on cost and schedule overruns.

The results indicated that 65% of the contracts had at least 1 CO; 30% had at least 5 COs; 10% had at least 12 COs; and 4% had over 20 COs. The study also analyzed the CO impacts by the dominant root causes: changed conditions (9,544 COs, $266M); errors and omissions (6,507 COs, $139M); scope changes (2,371 COs, $109M), and final quantity adjustments (cost adjustment) ($193M). The top five root causes of the COs in each district were identified and good practices and guidelines to help mitigate the incidence and severity of change orders were developed.

The study's diagnostic analysis and prediction models are useful in project planning and management because they (a) help identify the factors that impact CO likelihood, count, and monetary severity, and (b) can enable more reliable forecasting of project cost and schedule. Overall, the study results can help INDOT achieve its strategic goal of "on-time and on-budget project delivery." The effective management of change orders aligns with specific provisions that recur across previous and current federal legislation (the Infrastructure Investment and Jobs Act), which emphasize efficient project management and adherence to budgets and timelines in infrastructure development.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| change orders, cost overruns, root cause, time delay | No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161. |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 92 including appendices | |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

# EXECUTIVE SUMMARY

## Background

This study analyzed historical project data (2010–2020) from INDOT's highway contracts, which involved approximately 5,000 contracts worth a little over $10.13 billion. The study examined data on the change order (CO) frequency (count), severity (magnitude), and the impacts in terms of cost overrun and schedule delay (SD). The study also examined the root causes of CO. This executive summary provides a synopsis of the findings. The main report contains details of the literature review, analysis methods, and modeling results.

## Objectives

The study sought to (1) document the trends, patterns, and root causes of COs associated with INDOT projects over an 11-year period for the different project types and at each of the six districts; (2) identify contract and project types that were more likely to experience change orders; (3) analyze the impact of change orders on the initial project cost and schedule; and (4) develop a set of recommendations or guidelines that could help INDOT reduce the incidence of change orders on their projects.

### *Results I: Literature Review of Root Causes*

From the review of published material, including previous JTRP studies, the primary causes of COs have been the following.

- *Errors and Omissions:* Design errors, errors in the estimate, contract omission, and inconsistencies between contract documents are identified as key contributors to change orders.
- *Changed Conditions:* Unforeseen site conditions, weather variations, natural incidents, changes, or additions caused by utilities, and alterations in work rules and regulations are recognized as factors leading to changes in project conditions.
- *Scope Changes:* Changes in plans or work scope and modifications in materials or procedures are identified as elements that can result in alterations to the project scope.
- *Payment Adjustments:* Financial problems on the part of the owner and delays in progress payments are acknowledged as potential causes for adjustments in project costs.
- *Specification Changes:* Changes in the standard technical detail such as dimensions or material. See Chapters 2 and 3 for more information.

### *Results II: General Distribution of Change Orders*

The descriptive statistics of the COs yielded the following key findings: sixty-five percent (65%) of the contracts had at least 1 CO; 30% had at least 5 COs; 10% had at least 12 COs; and 4% had over 20 COs. As shown in Figure 4.9, the Greenfield District had the most COs—28% of statewide total COs and 29% of the statewide total net monetary value (overrun). On the other hand, Vincennes District had the least (10% of the statewide total count of COs) but accounted for 23% of the total statewide CO amount. This suggests that Vincennes generally had COs of relatively large magnitude compared to other districts. See Chapter 4 of this report.

### *Results III: Pre-Implementation Factors that Affect CO Propensity, Magnitude, and Direction*

Chapter 5 identified a few base attributes (pre-implementation attributes of the contract and the project) that affect the propensity, magnitude, and direction of change orders, and developed models that not only predicted these outcomes but also elucidated the relationships between each of these outcomes and the base attributes. The base attributes are district location, project type, contract type, urban/rural location, and the contract award amount. From a broad perspective considering all the data combined, it was observed that the CO count increases up to a certain threshold of the contract award amount ($54M), and then decreases thereafter.

### *Results IV: Impacts of Change Orders*

Sixty-five (65%) of the contracts experienced cost overruns and 40.4% had schedule delays. The average cost overrun rate across all contracts was 5.61%, with project type specific rates as follows: bridge-related contracts (2.52%); road-related contracts (3.55%); and maintenance/traffic-related contracts (9.20%), excluding projects where COs were related to contract renewals. The average cost overrun rate (percent increase in project cost) due to COs varied across the districts from 3.9% (Seymour) to 11.2% (Greenfield). Generally, districts that experienced higher cost overruns also had longer schedule delays, except for Vincennes which had relatively high average cost overrun rates without a commensurate increase in the average schedule delay. Both Vincennes and Seymour had average cost overruns of 9%–10% but Vincennes's schedule delay (17.6%) was far lower than that of Seymour (33%). See Chapter 5.

### *Results V: Impacts by the Dominant Root Causes of the Change Orders*

1. *Changed Conditions:* Cost overrun amount of $266M (42% of total CO magnitude; 9,544 COs), with the following dominant subcategory impacts.
    - *Constructability-Related:* $117M (19%).
    - *Soils-Related:* $39M (6%).
    - *Environment-Related:* $25M (4%).
2. *Errors and Omissions:* Cost overrun amount of $139M (22% of total CO magnitude; 6,507 COs), with the following dominant subcategory impacts.
    - *Design-Related*: $75M (12%).
3. *Scope Changes:* Cost overrun amount of $109M (17% of the total CO magnitude; 2,371 COs), with the following dominant subcategory impact.
    - *Quantities and Items:* $60M (9%).
4. *Final Quantity Adjustments (Cost Adjustment):* Cost overrun amount of $193M.

The total cost overrun attributed to the above CO categories is $514.22M (81% of all COs) without considering adjustments for final quantity. The district-wise top five root causes of the COs are provided in Figure 7.2. Details are provided in Chapter 6 of the report.

## Recommendations

- *Constructability-Related:* Consultants should have clear and comprehensive plans, conduct detailed reviews, and ensure project specifications align with design requirements. Owners are encouraged to utilize project management software, maintain a log of past change orders, and create checklists. Contractors should prepare work breakdown structures.

- *Soils and Environmental:* Thorough site investigations are recommended. Alternative contract methods like design-build are suggested.
- *Errors and Omissions:* Greater caution regarding potential contract omissions and coordination with owners for project specifications is advocated.
- *Scope and Final Quantity Adjustments:* Recommended actions include ensuring complete detailed engineering before bidding, engaging third-party peer reviews for design and project estimates and providing a comprehensive approach to addressing the identified concerns are recommended.

Chapter 6 presents the details of the recommendations. Chapter 7 discusses the study limitations and identifies opportunities for future work using this data or an expanded set of data.

CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF ACRONYMS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ANOVA | Analysis of Variance |
| CI | Confidence Intervals |
| CO | Change Order |
| COF | Change Order Frequency |
| COR | Cost Overrun Rate |
| COM | Change Order Magnitude |
| COS | Change Order Severity (used synonymously with COM, in this report) |
| DB | Design-build |
| I/D | Incentives/Disincentives |
| LR | Linear Regression |
| MNL | Multinomial Logit Model |
| R/W | Right of Way |
| SD | Schedule Delay |
| SPMS | Structural Number |

# CHAPTER 1. INTRODUCTION

## 1.1 Background and Problem Statement

Construction projects are influenced by a multitude of factors, both controllable and uncontrollable, and stakeholders. One critical aspect is the management of change orders. A change order, in essence, represents a modification to an existing construction contract, leading to adjustments in the scope of work agreed upon (Ahmed et al., 2022; Shrestha, 2016). Typically, these alterations result in an increase in the contract price, an extension of the contract duration, or sometimes both. Change orders can arise due to various reasons, such as constructability issues, design revisions, unforeseen site conditions, or client preferences (Assaad et al., 2022).

It is worth noting that certain types of construction work are more susceptible to change orders than others. Complex projects, such as those involving intricate designs, or those situated in challenging environmental conditions often see a higher frequency of change orders. These modifications can introduce additional risks, affecting project timelines and budgets. However, the repercussions of change orders often extend beyond the cost and schedule metrics. Worker productivity and morale (Moselhi et al., 2005), reduction in work quality, and increase in potential claims and disputes (Zaneldin, 2020) are some of the consequences identified in the literature.

In the context of the Indiana Department of Transportation (INDOT), change orders influence the agency's ability to achieve its strategic objectives. Two of INDOT's primary goals are to deliver projects "On-time and On-budget." Change orders, by their nature, tend to hinder these objectives. They introduce uncertainties, leading to delays and cost overruns, which can challenge INDOT's ability to meet these strategic targets. Furthermore, these challenges in managing change orders align with specific provisions of federal legislation. MAP-21 (Moving Ahead for Progress in the 21st Century Act) and the IIJA (Infrastructure Investment and Jobs Act) emphasize the importance of efficient project management and adherence to budgets and timelines in infrastructure development. By mitigating the impact of change orders, INDOT and other construction stakeholders can better align with these legislative requirements, promoting more effective and cost-efficient project delivery.

## 1.2 Research Needs

The Indiana Department of Transportation (INDOT) recognizes the necessity of evaluating the effectiveness of methodologies to reduce the incidence of change orders, focusing on the factors that can be potentially controlled and managed in a better manner. To achieve this, the research team will analyze historical project data for INDOT's contracts from 2010 to 2020. By examining data related to the number and root causes of change orders, increase in construction costs and schedule from previous projects, INDOT can gain valuable insights for each of their six administrative districts.

INDOT can also benefit from the comprehensive understanding of historical trends in change orders. They can identify patterns, such as the root causes for change orders that frequently lead to cost overruns and schedule delays. Additionally, it can help uncover the correlation between change orders and contract-specific factors (such as district, project type, award amount, and planned duration). By comprehensively studying these trends and their relationships with various change order and contract characteristics, INDOT can enhance its ability to anticipate and estimate the likelihood of change orders for future projects. This predictive capability is invaluable for planning and budgeting purposes, enabling more accurate project cost and schedule forecasts.

In summary, INDOT's commitment to assessing change order estimation methodologies through historical project data analysis is a proactive step toward better project management. It empowers the agency with the knowledge needed to make informed decisions and mitigate the impact of change orders, ultimately contributing to the successful and efficient delivery of future construction projects.

## 1.3 Objectives

The main objectives of the study are to (1) analyze and document the trends and patterns of the root causes of change orders associated with INDOT projects over a 10-year period for different types of projects with respect to each of the six INDOT administrative districts; (2) identify contract and project types that are more likely to experience change orders; (3) analyze the impact of change orders on initial project cost and schedule; and (4) develop a set of recommendations or guidelines that can help INDOT in reducing the incidence of change orders on their projects. In this report, the terms attribute, factor, and variable are used synonymously.

## 1.4 Scope of Work

This research investigates the root causes of change orders associated with INDOT projects from 2010 to 2022. For the scope of this research, projects are classified into four main categories: road projects, bridge projects, pavement projects, and demolition, maintenance, and traffic projects. The work types included in each of these four categories are included in Appendix A. The datasets shared by INDOT have information related to the category and the sub-category of the reasons that led to change orders. For example, "changed conditions" is a category that consists of sub-categories such as constructability, utilities, and environmental conditions. Therefore, due to this limitation of data granularity, the study team assumes the sub-category to be the root cause of the corresponding change orders. For example, this research can identify whether errors and omissions were caused more by design-related issues or by permit-related issues but cannot exactly point out the exact items under such issues. The recommendations of this study include suggestions to further improve the quality of this dataset. Furthermore, this research systematically analyzed INDOT data to identify factors that lead to change orders in INDOT projects. This is expected to assist INDOT in better implementing process improvement solutions for their administrative districts. The study (a) documents CO trends over the years, and across districts, project types, and CO associations with various root causes (which appear only during the project implementation), (b) develops prediction models for CO outcomes (occurrence probability, direction, and magnitude) based on base pre-implementation attributes of the project and the contract, at a stage where root causes are yet to manifest, (c) describe the relationships between the CO outcomes and the base attributes, and (d) prediction models for schedule delay. The prediction models are useful for project planning and management purposes by enabling more reliable forecasts of project cost and schedule. Also, the study developed guidelines to help mitigate the incidence and severity (positive-direction magnitude) of change orders. The effective management of change orders aligns with specific provisions that recur across previous and current federal legislation (the Infrastructure Investment and Jobs Act) which emphasizes the importance of efficient project management and adherence to budgets and timelines in infrastructure development. Overall, the study results can help INDOT move further towards achieving its strategic goal of "on-time and on-budget project delivery."

### 1.5 Report Organization

Chapter 1 establishes the study background, problem statement, study objectives, and scope, in the context of investigating change orders in construction projects undertaken by the Indiana Department of Transportation (INDOT). Chapter 2 examines INDOT's change order policy from 2014 and examines past research projects to gain insights into the agency's historical approaches and actions regarding change orders. Chapter 3 documents the review of literature from varied sources including ASCE, CII, TRB publications, and others to ascertain the state of the art regarding the causes and impacts of change orders as experienced by other Departments of Transportation (DOTs). Chapter 4 uses descriptive statistics to investigate trends and patterns in change orders, both at the statewide level and at the district level. This allows for the identification of root causes contributing to change orders within each district. Using these results, INDOT could identify areas for increased scrutiny, to facilitate district-specific process improvement. Chapter 5 documents the development of statistical models to analyze INDOT's historical contract and change orders data. The aim is to investigate the relationships between the model outcomes and the base contract- and project-specific factors. Chapter 6 builds upon the findings from the previous chapters and the literature review, to offer recommendations and guidelines. These practical insights can assist INDOT to enhance its project planning, execution, and management, potentially reducing the occurrence and impact of change orders. Lastly, Chapter 7 serves as the conclusion, summarizing key observations and contributions made throughout the research. It also addresses future research directions and acknowledges the study's limitations, providing a comprehensive summary to the research report.

## CHAPTER 2. INDOT CHANGE ORDER POLICY AND PAST STUDIES

This section is culled largely from INDOT Change Order Policy (INDOT, 2014) and has been included in this report to introduce various terminologies (related to change orders) that have been used in the research.

### 2.1 INDOT Definitions and Considerations

#### *2.1.1 Change Orders*

"Change Orders are utilized to document an impact on a Construction Contract and authorize the changes required to mitigate the impact. These changes include, but are not limited to, monetary adjustments, time adjustments, plan revisions, and specification changes. A change order is a written agreement executed by the Department and the Contractor that modifies an existing contract." Each change order is to only address one specific impact to a Contract and clearly identify the reason for the change. Multiple items may be included on a change order, but all are to be related to the same specific impact and are to indicate the same reason for the change."

#### *2.1.2 Reason Codes*

"Codes used to categorize the change orders so that the department can track the cause of change orders, assess the extent and source of accountability and work to minimize similar changes on future contracts."

### 2.2 INDOT Classification of Change Orders (Groups and Subgroups)

INDOT has classified the causes of change orders into different groups as shown in Table 2.1.

### 2.3 INDOT Change Order Policy

#### *2.3.1 INDOT's Definition for a Change Order*

Change orders are used to document the impact on a construction contract and authorize the changes

TABLE 2.1
**INDOT Change Order Categories**

| Category | Sub-Category |
|---|---|
| Errors and Omissions | Design/Plan Related |
| | Specification Related |
| | Special Provision Related |
| | Environmental Related |
| | Item Related |
| | Permits Related |
| | Quantity Related, Minor Quantity Related, Major |
| | R/W Related |
| | Geotechnical Related |
| | Traffic Control Related |
| | Utility Related |
| | Railroad Related |
| | Constructability Related |
| Scope Changes | Work Outside Construction Limits |
| | Work On Private Facilities |
| | Project Acceleration |
| | Project Upgrades |
| | Material Related |
| | Added Quantities/Items |
| | Deleted Quantities/Items |
| Changed Conditions | Constructability Related |
| | Permits Related |
| | Environmental Related |
| | Materials Related |
| | R/W Related |
| | Geotechnical Related |
| | Utility Related |
| | Railroad Related |
| | Weather Related |
| | Quantity Related |
| Payment Adjustments | Quality Related |
| | Material Related |
| | Contract Liens Related |
| Incentive/Disincentive | Contract Completion |
| | Intermediate Completion |
| | Closure Times |
| | Cost Reduction Incentive |
| | A+B Contract |
| | A+B+C Contract |
| Standards/Specifications Change | Time Related |
| | Monetary Related |
| | Time and Monetary Related |
| | Specification Change Only |
| Miscellaneous | Final Quantity Adjustment |
| | Damage to State Property |
| | Contract Renewal |

required to mitigate the impact. These changes include, but are not limited to, monetary adjustments, time adjustments, plan revisions, and specification changes. A change order is a written agreement executed by the department and the contractor that modifies an existing contract. Each change order is to only address one specific impact to a contract and clearly identify the reason for the change. Multiple items may be included in a change order, but all are to be related to the same specific impact and are to indicate the same reason for the change.

### *2.3.2 INDOT's Change Order Approval Requirements*

A change order is not necessary for minor modifications to the existing contract pay item quantities that are typically needed to accomplish the contract's scope and design. Modifications are considered minor if the total impact on the contract is less than $20,000 in increased or decreased costs compared to the currently approved contract amount. After this threshold is surpassed, a change order that includes all increases or decreases in existing contract pay item quantities is needed to authorize the revisions as shown in Table 2.2. Further change orders due to additional modifications to the existing contract pay item quantities are not needed until the $20,000 limit is exceeded again.

In situations where change orders require adjustments to both cost and time, the higher adjustment (cost or time) will determine the necessary level of approval. However, in order to align with INDOT goals, once change order dollar amounts for a contract reach 4% over the original budget, or when time adjustments reach 25 days over the original schedule, the PE/S will need to submit a draft of the change order to the District Construction Director, the Director Division of Construction Management, and the Director of Capital Program Management, at the same time as it is sent to the PM. This is being done to address the cause of the cost or time overrun and to see if any measures can be taken to correct and adjust as necessary to make proper decisions as the contract progresses to completion.

On contracts that have FHWA oversight, prior approval is required before work can begin on changes that are considered major. Changes are considered major if there is a cost increase of 5% of the contract award amount or $250,000, whichever is less. The SiteManager system is the official channel for communicating and approving change orders. Figure 2.1 presents a snapshot of INDOT's current change order approval process.

## 2.4 Existing Studies Sponsored by INDOT

### *2.4.1 SPR-3224: Analysis of Change Orders in Geotechnical Engineering Work*

SPR-3224 (Duvvuru Mohan et al., 2011) formulated guidelines and provided recommendations aimed at reducing the occurrence of change orders related to geotechnical work within INDOT. To achieve this goal, the study delved into change orders associated with geotechnical work in projects completed within the past 5 years. The specific objectives included collecting and organizing data on these geotechnical-related change orders, conducting interviews with project stakeholders

TABLE 2.2
**INDOT Change Order Approval Authority**

| Approval Authority | Max. Cost Adjustment (+/-) | Max. Time Adjustment (+/-) |
|---|---|---|
| Project Engineer/Supervisor | $50,000 | 10 days |
| Area Engineer | $250,000 | 50 days |
| District Construction Director | $750,000 | 100 days |
| State Construction Engineer | $2,000,000 | 200 days |
| Director, Division of CM | Over $2,000,000 | Over 200 days |

for detailed insights, evaluating the quality and appropriateness of geotechnical work performed, and compiling a comprehensive database of these change orders categorized by project details. Furthermore, the research aimed to develop a comprehensive set of guidelines to minimize the occurrence of change orders. These guidelines were crafted based on the analysis of change orders, considering instances where alternative geotechnical approaches could have prevented them or where bureaucratic and process-related issues were evident.

The findings of SPR-3224 revealed several key insights regarding geotechnical change orders within the context of INDOT. On average, geotechnical change orders accounted for approximately 1.34% of the total estimated construction cost per district per year. Notably, these geotechnical change orders constituted a significant portion, representing 10.25% of the average total change order amounts within districts annually. The study identified an average net overrun of $707,000 per district per year attributed to geotechnical change orders. Out of the contracts examined, approximately 28% experienced geotechnical change orders, totaling 158 such changes across 84 contracts. Road contracts comprised the majority, with 64 cases, followed by 16 bridge contracts and 4 resurfacing projects. Furthermore, the study showed that a significant portion of contracts with geotechnical change orders experienced only one such change order (46 out of 84 contracts), while 24 contracts had two geotechnical change orders. Interestingly, geotechnical change orders were more prevalent in road contracts (41% of total road contracts) and bridge contracts (37% of total bridge contracts) compared to other contract types. Finally, the study categorized the reasons for geotechnical change orders, highlighting that errors and omissions in these changes were relatively low, indicating effective management in this aspect.

Several recommendations were proposed to reduce the occurrences of geotechnical change orders. To foster a proactive approach, cultivating the right attitude toward change orders among all stakeholders, including INDOT staff, designers, and contractors, is essential. Planning stages, especially for contracts with large budgets, should involve expert consultation for accurate risk assessment and the allocation of appropriate funds. Developing a checklist based on recurring issues for specific regions, soil types, or work types can aid in addressing problems during the design process. Simplifying the system of reason codes for change orders and enhancing geotechnical reports to discuss potential remedies are crucial. Clear communication through the geotechnical office, analyzing geotechnical specifications, and coordination among personnel are recommended. In road contracts, load considerations, constructability issues, and subgrade quality should be carefully evaluated. Accurate site investigations, flexible approaches, and secondary investigations for long-shelved projects can reduce change orders. Handling moisture content variations, precise rock layer assessments, and piling quantity determination are key. Additionally, anomalies encountered during construction should trigger geotechnical evaluations, and an efficient software system for recording change order information is vital to streamline future assessments and reduce manual data entry efforts.

### *2.4.2 SPR-2811: Analysis of Cost Overruns and Time Delays*

SPR-2811 (Bordat et al., 2004) investigated the growing occurrence of cost overruns and time delays in Indiana Department of Transportation (INDOT) projects and provided recommendations for addressing the issue. The study's specific objectives include identifying the distribution and trends of cost overruns and time delays in INDOT contracts, investigating their causes and responsibilities and through data analysis, comparing INDOT's challenges with those of other highway agencies, conducting statistical analyses to identify influencing factors, and ultimately developing recommendations to help INDOT effectively manage cost overruns, time delays, and change orders in their projects.

The study's analysis revealed that during the period from 1996 to 2001, cost overruns were experienced in 55% of all Indiana DOT contracts, amounting to an overall cost overrun rate of 4.5% of the bid amount. Notably, the average cost overrun amount and rate varied by project type, with bridge projects at 8.1%, road construction at 5.6%, road resurfacing at 2.6%, traffic projects at 5.6%, and maintenance projects at 7.5%. In terms of time delays, 12% of all INDOT contracts encountered delays, with an average delay of 115 days per contract. The study identified "design errors and omissions" as the most prevalent change order category, responsible for incurring the highest costs. It also identified that a significant proportion of change order reasons were attributed to INDOT or

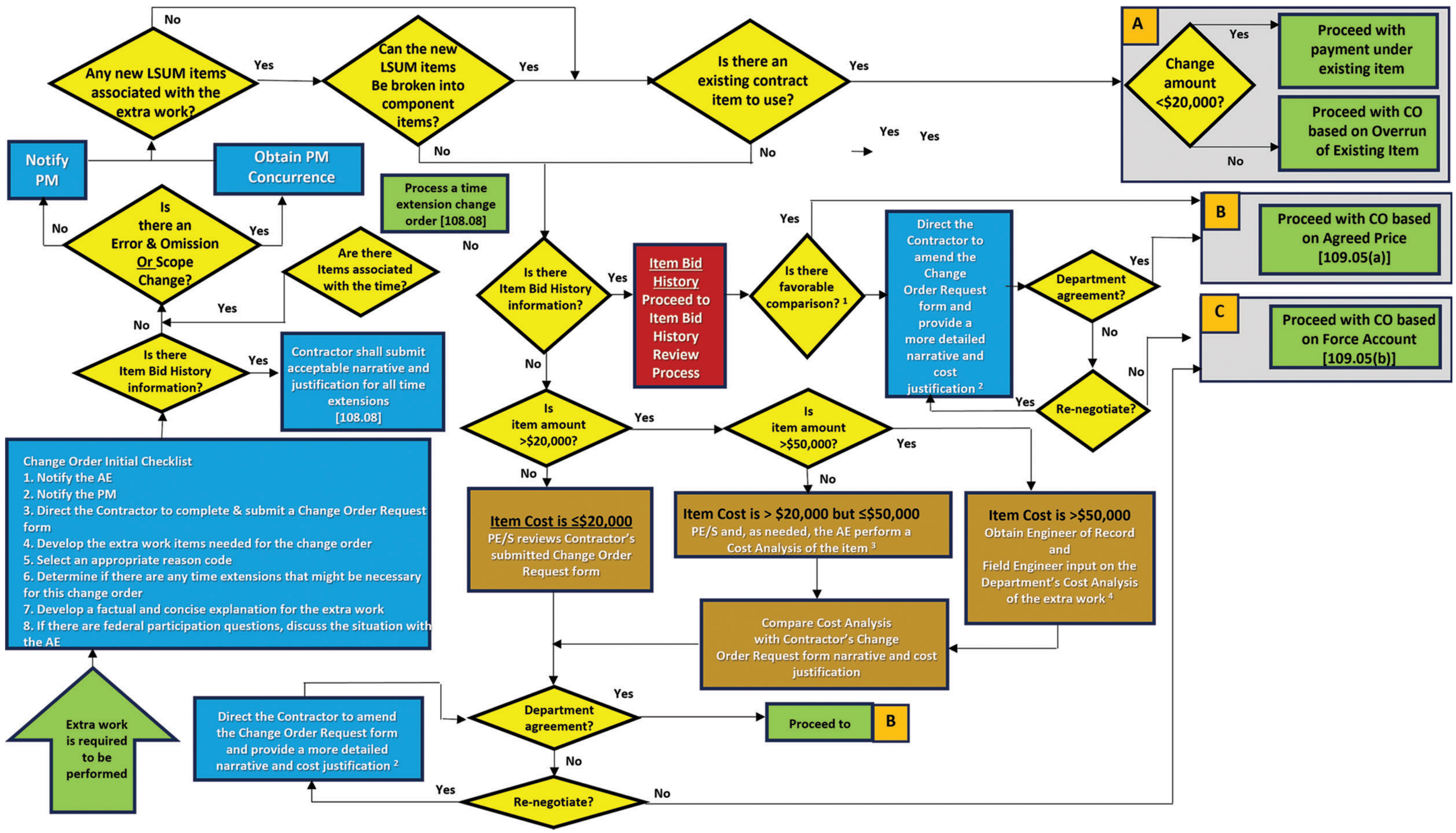



**Figure 2.1** INDOT change order approval process.

its consultants, indicating potential room for improvement in contract management practices. Additionally, regression modeling was used to ascertain the influence of independent variables and estimate future cost overruns, time delays, and change orders. As some models exhibited inconsistent performance in terms of R2 and validation statistics, caution is advised when using them for predictive purposes. Key variables found to be significant included bid amount, project type, district location, weather conditions, and bid comparison factors.

The study's recommendations for INDOT encompass several key areas aimed at improving project management and addressing change order challenges. First and foremost, there is a call to instill a "change order mindset" within the department, emphasizing proactive measures. To enhance data management, the suggestion includes the development of clear procedures and instructions for recording change order information in SiteManager as projects progress. The information from the SiteManager was what we used for our current project. The establishment of a system of controls to efficiently route change order information to relevant personnel in operations support and design divisions is also recommended. Furthermore, the study highlights the need to address the prevalence of "no indicated reason" change orders in the database by reviewing and modifying the coding system and providing clearer instructions. To improve consultant performance, standard reports offering feedback on errors and suggestions for improvement are advised. Lastly, the study recommends the creation of an annual performance review report for consultants, and the development of a communication system to disseminate project information, including cost overruns, time delays, and change orders, to the general public, promoting transparency and awareness.

#### *2.4.3 SPR-2497: An Initial Evaluation of Design-Build Highway Projects Performed by the Indiana Department of Transportation*

SPR-2497 (Tymvios et al., 2002) evaluated INDOT's pre-2002 design-build highway contracts from the perspective of project outcomes including the frequency of change orders. The authors acknowledged that design-build had been an effective contracting method in the private and public arenas. Departments of Transportation had used this contracting method on various projects for a variety of reasons. They found that the Indiana Department of Transportation (INDOT) had used this contract delivery method on a few projects with mixed responses from those involved in the process. According to the study report, INDOT deemed, at the time, that an evaluation of the design-build program was appropriate to determine its future use in Indiana. Their study provided a historical perspective of design-build and how the program has been received and perceived by INDOT. Their study also described the project's survey and the data collected from the designer and contractor perspectives; relates the experiences of other Departments of Transportation with design-build, provided a somewhat limited comparison with the design-bid-build approach; and made recommendations for INDOT's future design-build practices.

## CHAPTER 3. LITERATURE REVIEW

### 3.1 Causes of Change Orders

For any project, the cause of the change order differs based on its nature. Goodrum et al. (2010) assessed the change orders of Kentucky Transportation Cabinet projects, and identified the primary causative factors as follows: contract omission, contract item overrun, owner induced enhancement, and fuel and asphalt adjustments. They also noted that utility issues and geotechnical issues were other factors that affect their projects' change orders. The study concluded that among the numerous factors contributing to change orders in road maintenance contracts, the most significant ones were changes in work scope, errors in estimate, and failure to verify the worksite conditions prior to the contract award.

In Illinois, Assaad et al. (2022) evaluated the state highway agency's transportation infrastructure projects and identified several major causes of change orders, classifying them as: contract administration, allowable contingencies, highway plan quality omissions, variation in site conditions, and design changes. Also, in Ohio, Ahmed et al. (2022) analyzed ten (10) highway transportation projects let by the Ohio Department of Transportation and concluded that the major contract-related cause of change orders is a lack of clarity and comprehensiveness in defining the contract terms. They also found that, in their state, project change orders are also caused by issues related to approvals in accordance with contractual provisions and approvals in light of the applicable laws specified in the contract document.

In their analysis of Indiana's highway construction contract data spanning 5 years, Anastasopoulos et al. (2010) identified design errors, unexpected site conditions, and weather conditions as the primary causes of change orders in these projects. Alleman et al. (2020) analyzed 162 completed U.S. highway projects from 2004 to 2015 and concluded that the primary causes of change orders were unforeseen condition changes and agency-directed changes in work scope. Regarding heavy road projects in Florida, Serag et al. (2010) and Serag and Oloufa (2007) identified the major causes of change orders as the errors and omissions, and work scope changes, and unforeseen conditions.

From an international perspective, researchers have identified similar causes of change orders in road projects in various countries. Halwatura and Ranasinghe (2013) identified 55 causes of change orders (COs) in road construction projects in Sri Lanka, the top five being poor estimation, unforeseen site conditions, political pressure during the construction phase, inadequate site investigations, and changes initiated by the client. In Portugal, Catalão et al. (2019) analyzed 1,091 transport projects spanning 1980–2012, administered at various levels of government. They found that the project change orders are influenced by a combination of project-specific or endogenous factors (including project ownership and size) and exogenous factors (such as economic cycles and fiscal conditions).

In Palestine, Mahamid (2017) identified five common causes of change orders in their highway construction projects: change of project scope by the owner, lack of coordination among construction parties, owner's financial difficulties, changes in materials, and errors and omissions in the design. In their assessment of change orders in highway projects in Kuwait, Khalafallah and Shalaby (2019) identified the key factors of change orders and presented the distribution of change order frequency across the key factors: approximately 29% of their projects faced change orders due to discrepancies in the contract documents; 26% resulted from poorly-defined scope of work; and 23% were attributed to consultant incompetence.

Alshdiefat and Aziz (2018) investigated the causes of change orders in the Jordanian construction industry. They conducted a comprehensive analysis based on responses from 52 workers from construction engineering firms, 40 contractors, and 9 construction management accounts. They placed the change order causes into three categories: engineering causes (design errors, incomplete designs, estimation errors, inconsistency between contract documents), causes related to the client (changes initiated by the client, lack of communication between project parties, time lag between the design and construction phases), and project circumstances (different site conditions, shortages of materials). In a similar study that focused on change orders within public construction projects in Oman (Alnuaimi et al., 2010) the causative factors of change orders were investigated and ranked based on their perceived relative importance. Their research identified the most influential causes of change orders as follows: owner-initiated work scope increase, design modifications, nonavailability of construction manuals and procedures, design errors, and poor communication between relevant project stakeholders.

In their research in Qatar, Senouci et al. (2017) collected and analyzed 1,112 change orders data from 22 residential and commercial construction projects and emphasized that the change orders were largely caused by changes of work plans or scope that were initiated by the owner, differing site conditions, and the contractor's lack of judgment and experience. Hsieh et al. (2004) analyzed 90 change orders associated with metropolitan public works projects in Taipei, Taiwan. They determined that change orders were primarily caused by issues related to planning and design, underground conditions, natural incidents, changes in work rules/regulations, shifts in decision-making authority, and ownership transfers.

Sambasivan and Soon (2007) evaluated data from 67 owners, 48 consultants, and 35 contractors in the Malaysian construction industry. They identified 28 distinct causes of change orders. After examining the responses from the owners and the contractors separately, the researchers identified three leading causes (these were acknowledged by both parties) as follows: inadequate contractor experience, poor site management by the contractor, and problems associated with subcontractors. Yitmen et al. (2006) studied data from North Cyprus and pinpointed the primary causes of change orders in that country's construction industry as follows—design changes, design errors, additions to scope, and unforeseen conditions.

The problem of change orders is pervasive and is prevalent in other sectors also. Regarding the electrical and mechanical industries, Hanna and Iskandar (2017) and Hanna et al. (2002) found out that the major factors contributing to change orders are design changes, design errors, additions to the scope, and unknown conditions. In their examination of design-build-maintain school projects in Puerto Rico, Ramos-Maldonado et al. (2016) determined that direct changes in work scope are the primary cause of change orders, and other significant factors include omissions in contract documents, claims of costs incurred in the project, and the occurrence of unexpected site conditions and events. In a case study involving the GBK Aquatic Stadium Project in Indonesia, Hansen et al. (2020) identified the primary causes of change orders as follows—design/specification changes, scope changes, schedule changes, site condition changes, and policy changes.

Table 3.1 presents a summary of the major causes of change orders that were observed by various researchers. The change order cause categories used in the table are based on the categories listed in INDOT's Change Order Policy document.

### 3.2 A Review of Past Methods Used to Analyze Change Order Data

Over the past few decades, researchers have used a variety of methods to analyze change order data. Table 3.2 presents these methods.

Shrestha et al. (2019) carried out both predictive and diagnostic analysis of change order data associated with school building projects. Regarding the former, they developed models to predict the frequency of change orders based on attributes of the project and contract. Regarding the latter, they conducted hypothesis tests to identify the strength of the relationship between change orders and cost overruns, and that between change orders and schedule growth. In a similar effort, Senouci et al. (2017) used hypothesis testing to make cost-impact comparisons between different causes of change orders and various work categories.

Hsieh et al. (2004) used analysis of variance (ANOVA) to assess variations in mean costs across different project categories. Shrestha et al. (2022)

TABLE 3.1
**Major Causes of Change Orders**

| Specific Cause of Change Order | Related Research in Published Literature |
|---|---|
| **(a) Change Order Cause Category: Errors and Omissions** | |
| Design Errors | Anastasopoulos et al. (2010), Alshdiefat and Aziz (2018), Alnuaimi et al. (2010), Assaad et al. (2022), Hanna and Iskandar (2017), Hanna et al. (2002), Hsieh et al. (2004), Mahamid (2017), Yitmen et al. (2006) |
| Errors in the Estimate | Shrestha (2016), Alshdiefat and Aziz (2018), Halwatura and Ranasinghe (2013) |
| Contract Omission | Goodrum et al. (2010), Ramos-Maldonado et al. (2016), Serag et al. (2010) |
| Inconsistency Between Contract Documents | Alshdiefat and Aziz (2018), Khalafallah and Shalaby (2019) |
| **(b) Scope Changes** | |
| Plans or Work Scope Changes | Shrestha (2016), Senouci et al. (2017), Hanna and Iskandar (2017), Hanna et al. (2002), Keane et al. (2010), Ramos-Maldonado et al. (2016), Serag et al. (2010), Yitmen et al. (2006), Hansen et al. (2020), Khalafallah and Shalaby (2019) |
| Materials or Procedure Changes | Keane et al. (2010), Al-Dubaisi (2000) |
| **(c) Changed Conditions** | |
| Unexpected Site Conditions | Anastasopoulos et al. (2010), Senouci et al. (2017), Alleman et al. (2020), Assaad et al. (2022), Ramos-Maldonado et al. (2016), Serag et al. (2010), Halwatura and Ranasinghe (2013), Serag and Oloufa (2007) |
| Weather Conditions | Anastasopoulos et al. (2010) |
| Natural Incidents | Hsieh et al. (2004) |
| Utility Caused Changes or Additions | Assaad et al. (2022) |
| Work Rules/Regulations Changes | Hsieh et al. (2004) |
| **(d) Payment adjustments** | |
| Owner's Financial Problems | Keane et al. (2010), Mahamid (2017) |
| Delay in Progress Payments | Assaf and Al-Hejji (2006) |
| **(e) Others** | |
| Specification Changes | Assaad et al., 2022; Hansen et al., 2020; Khalafallah and Shalaby (2019) |
| Design Changes | Alnuaimi et al. (2010), Assaad et al. (2022), Hanna and Iskandar (2017), Hanna et al. (2002), Yitmen et al. (2006), Hansen et al. (2020) |
| Contractor's Lack of Judgement and Experience | Senouci et al. (2017), Sambasivan and Soon (2007) |
| Problems with Subcontractors | Sambasivan and Soon (2007) |
| Shortages of Materials | Alshdiefat and Aziz (2018) |
| Lack of Communication Between Project Parties | Alshdiefat and Aziz (2018), Alnuaimi et al. (2010), Assaf and Al-Hejji (2006), Mahamid (2017), Al-Dubaisi (2000), Khalafallah and Shalaby (2019) |
| Delay in Site Handover to the Contractor | Assaf and Al-Hejji (2006), Patil et al. (2013) |
| Time Lags Between the Design and Construction Phases | Alshdiefat and Aziz (2018) |
| Inadequate Project Objectives | Keane et al. (2010) |
| Contract Item Overrun | Goodrum et al. (2010) |
| Delayed Decision-Making (Client) | Keane et al. (2010), Sambasivan and Soon (2007) |
| Political Issues | Halwatura and Ranasinghe (2013), Catalão et al. (2019) |

formulated six research hypotheses to examine the performance trends related to the growth of construction costs, change orders, and schedules in Texas DOT highway construction projects. The authors also used ANOVA to investigate the associations between cost, schedule, change order growth, and the year of project completion. Shrestha and Maharjan (2018) also used hypothesis testing to examine the correlation between the growth of change orders and the number of change orders with cost growth, schedule growth, and construction intensity. Using ANOVA, Randolph et al. (1987) found that project cost changes are influenced by factors such as the contractor's identity, the nature of the work, the bid year, and the bid cost.

Questionnaire surveys of construction managers and engineers have been an effective tool in several change order studies. For example, Alshdiefat and Aziz (2018) administered a questionnaire survey of construction company personnel, contractors, and construction management workers to develop a severity index for the different causes of change orders. Similarly, Alnuaimi et al. (2010) carried out a survey of clients, contractors, and consultants to ascertain the relative importance index of various change order causes. Additionally, Keane et al. (2010) used survey responses from construction project managers, quantity surveyors, and architects to identify the common causes of change orders in construction projects. Patil et al.

TABLE 3.2
**Methods that Have Been Used to Analyze Change Orders**

| Model Type | Variables | Outcome | Reference(s) |
|---|---|---|---|
| Multiple Linear Regression | Timing of the CO; reason for the CO; party causing the CO; approved CO hours; work stoppage; work season; way CO expended; restricted access; way CO compensated; stacking of trades; extension | Percentage increase in the contract price due to change orders | Serag et al. (2010); Serag and Oloufa (2007) |
| Linear Regression | Percent CO initiated by the owner; Productivity tracking; turnover; percent of time spent by the project manager on the project; overmanning | Cumulative impact of changes in productivity in electrical and mechanical projects | Hanna and Iskandar (2017) |
| Simple Linear Regression | Contract value | Cost overrun percentage | Senouci et al. (2017) |
| Linear Regression | Rework cost as percent of contract price | Number of change orders | Mahamid (2017) |
| Logistic Regression | Hours needed to complete the project; percent of submitted change order hours approved by owner; overtime; manpower shortage | Whether a project was impacted by change orders | Hanna et al. (2002) |
| Non-Linear Regression | Cumulative probability of change order occurrence; cost growth; schedule growth | Percentage of change order occurrence; Percentage of cost growth; Percentage of schedule growth | Shrestha et al. (2019) |
| Artificial Neural Network | Work category; site accessibility; weather condition; road surface type; road condition; location name; activity bid amount | Prediction of change order percentage for road maintenance contracts | Shrestha (2016) |
| System Dynamics | Scope change; temperature; labor crowding; overtime; fatigue; learning effects | Impact on productivity, labor hours needed to finish and deliver the project on time, and the rate of work done | Al-Kofahi et al. (2022) |
| BP, NB, ZINB, ZIP[1] | Contract duration; award amount | The number of change orders in any highway construction project | Anastasopoulos et al. (2010) |
| Pareto Diagrams | Amount of cost increase and schedule delay corresponding to different change order causes | The most significant causes for change orders | Ramos-Maldonado et al. (2016) |

[1]BP: Basic Poisson; NB: Negative binomial; ZINB: Zero-inflated negative binomial; and ZIP: zero-inflated Poisson.

(2013) analyzed survey responses to develop a relative importance index (RII) for distinct causes of project adversity. Sambasivan and Soon (2007) administered a questionnaire survey of clients, consultants, and contractors that work in the Malaysian construction industry. Assaf and Al-Hejji (2006) also conducted a survey of individuals (owners, contractors, and consultants) involved in large construction projects in Saudi Arabia, and investigated the trends using various indices, including frequency, severity, and importance.

## 3.3 Impacts of Change Orders

The impacts of change orders have been the subject of extensive research and study. The impacts include the following (Bordat et al., 2004).

- Increase in project cost (cost overrun).
- Extension of construction period (time delay).
- Decrease in work quality (except in cases where the change order was done to specifically to ensure high quality of work).
- Worsened public relations between the project stakeholders.
- Reduced credibility of the owner (as a diligent steward of the taxpayers' infrastructure.

A few of these are discussed below.

### *3.3.1 Cost Overrun*

A major impact of change orders is the increase in the overall cost of the project. Shrestha and Maharjan (2018) examined 185 large Texas highway projects with over $10M cost and found that when the number of change orders surpassed 20, both cost and schedule growth increased significantly. In investigating other projects in Texas in 1987–2015, Shrestha et al. (2022) investigated 3,957 highway construction projects (of total value $21.15B). They found that the change orders led to a significant increase in project costs. Shrestha's (2016) assessment of 575 road maintenance contracts found that approximately 14% of the contract with change orders experienced increased cost; 39 contracts had negative change orders, suggesting cost savings below budget, with average of -5.64%. They also found that of the project types, culvert installation projects experienced the highest frequency of change orders.

Such effects have also been observed internationally. Shrestha et al. (2017) evaluated 614 road maintenance projects in Kenya and observed that project-level change orders caused approximately 13% cost escalation, schedule delays, and reduced worker productivity. Their results also indicated that as project size increases, the percentage of change orders decreases. In Portugal, Catalão et al. (2019) examined 1,091 government-financed transportation projects and found that the weighted mean cost deviation percentage stood at +17.8%. Also, Hsieh et al. (2004) evaluated 90 metropolitan public works projects in Taipei, Taiwan, and determined that change orders caused the total project cost to increase by approximately 13% for roadway construction and 12% for bridge and culvert construction.

In the Ibbs (2012) analysis of 226 construction projects, it was revealed that the average cost overrun across these projects was 9%. Furthermore, 20% of the projects experienced cost overruns exceeding 45%, while 10% of the projects had cost overruns of at least 83%. Also, Senouci et al. (2017) examined 22 Qatari residential and commercial construction projects and analyzed 1,112 change orders to find out that the change orders due to owners caused a 44.97% cost increase on average, and that by contractors and consultants caused 36.68% and 18.53% cost increase on average, respectively. Changes in plans and scope by the owner was found to cause a 16.6% increase in the total cost, while differing site conditions and lack of contractor's experience were found to cause an average percent cost increase of 10.9% and 10.8%, respectively. In their case study of a road project, the final cost of the project exceeded the original cost of the project by 35.6%. Using highway construction project data from Indiana, Gkritza and Labi (2008) determined that for contracts that incur cost overruns, the cost overrun rate decreases nonlinearly with increasing contract size up to a certain point after which the cost overrun rate increases with increasing contract size.

Such impacts have been observed in various project types beyond highway projects. Ramos-Maldonado et al. (2016) analyzed design-build-maintain projects in schools of Puerto Rico to and found that change orders resulted in a cost overrun of $23.8M, representing an approximate 13% increase in the total cost for all projects under consideration. Similarly, by investigating new public school building projects, Shrestha et al. (2019) concluded that such products experienced an approximate 59% increase in the total cost. Alleman et al. (2020) discovered that on average, the cost growth for design-build-bid projects attributable to unforeseen conditions amounted to 2.4%.

### 3.3.2 Schedule Delay

Another major impact of change orders is the delay in the completion of the project. Shrestha et al. (2022) analyzed 3,957 highway construction projects managed by Texas DOT and revealed that change orders caused a 5.8% schedule delay for projects completed between 2011 and 2015. Likewise, Khalafallah and Shalaby (2019) assessed highway projects in Kuwait and identified that, on average, change orders resulted in schedule delays of 17.3% and cost overruns of 30.3%. Bordat (2004) found that 79.44% of projects from ODOT and 52.93% of projects from Texas DOT faced schedule overruns. Similarly, by evaluating transportation infrastructure projects in western Maharashtra, India, Patil et al. (2013) determined that a significant majority, specifically 72% of these infrastructure projects, experienced schedule overruns.

In the Ibbs (2012) analysis of 226 construction projects, it was observed that the average project exceeded the originally planned schedule duration by 16%. Notably, around 7% of these projects encountered schedule overruns exceeding 50%. In a similar manner, Assaf and Al-Hejji (2006) assessed large construction projects in Saudi Arabia, revealing that a mere 30% of these projects were completed on schedule. Most of the projects experienced schedule overruns, leading to an increase in project duration ranging from 10% to 30%. Also, Chen (1992) noted that change orders that occur later in the project tend to have a more substantial and adverse effect on both cost and schedule performance.

Such impacts have been observed in various project types beyond highway projects. Ramos-Maldonado et al. (2016) analyzed design-build-maintain projects in schools of Puerto Rico and found that the schedule was delayed by 7,378 calendar days for these projects, which translated to approximately 30% increase in the scheduled time. Similarly, by investigating new public school building projects, Shrestha et al. (2019) concluded that such products experienced an approximate 59% increase in the total cost and a 7.4% increase in the scheduled time due to change orders. Another interesting finding from their research was that when the amount of change orders exceeded 4%, the impacts of change orders on schedule overruns became significantly more pronounced, i.e., the more the number of change orders the more the schedule overrun. However, no such pattern was observed for cost overruns.

Through a case study of the GBK Aquatic Stadium Project in Indonesia, Hansen et al. (2020) identified that change orders were a significant contributing factor to delays in the project's completion. Also, in the analysis conducted by Alnuaimi et al. (2010) on change orders in public construction projects in Oman, a case study involving a building project revealed that the project's construction time was doubled as a result of change orders.

### 3.3.3 Loss in Productivity and Morale

Frequent changes in the work may lead to a loss in productivity and the morale of the workers. In Ibbs (2012) analysis of 226 construction projects, it was revealed that a considerable number of these projects experienced 20% or more loss in productivity. Such substantial productivity losses significantly diminished the likelihood of project success. Moreover, the allocation of work hours to changes resulted in a reduction in productivity ranging from 10% to 20%. Similarly, Hanna and Iskandar (2017) predicted a 33.2% loss in overall productivity attributable to change orders in the electrical and mechanical industry.

Al-Kofahi et al. (2022) developed a system dynamics model to elucidate the impacts of change orders, particularly how they could result in disruptions, delays, and subsequent productivity loss and schedule delays. Kermanshachi et al. (2022) also developed a system dynamics model demonstrating that the imperative to adhere to a specific schedule contributes to heightened labor productivity. However, an increase in the number of change orders induces employee frustration, subsequently leading to a decline in labor productivity. Moselhi et al. (1991) observed a clear and substantial correlation between change orders and decreased productivity. Moselhi et al. (2005) developed a neural network model to illustrate the importance of factors such as the number, timing, and frequency of change orders in influencing labor productivity.

#### *3.3.4 Claims and Disputes*

The occurrence of change orders may lead to misunderstandings between various parties involved and subsequently lead to claims and disputes. Drawing from 10 case studies of ODOT highway transportation projects, Ahmed et al. (2022) have explored how ambiguity surrounding contract clauses and definitions contributed to change orders, subsequently giving rise to lawsuits and disputes. Fisk and Reynolds (1997) have also highlighted that construction changes often serve as a significant catalyst for construction disputes. Furthermore, according to Zaneldin (2020), change orders are identified as the leading cause of claims within the United Arab Emirates.

Assaad et al. (2022) conducted a study involving various case studies from Illinois DOT, where disputes arose because of issues related to approval procedures, compensation considerations of change orders, and laws governing design agreements. Similarly, Zhao et al. (2013) have elaborated on how client-induced variations can alter the work allocation structure in joint ventures or when subcontractors are engaged, potentially resulting in claims, disputes, and work disruptions.

#### *3.3.5 Adverse Effects in the Work Quality*

Different studies have explored the effects of change orders in the work quality. Frequent variations in the work can have an adverse impact on the quality of work, as noted by Fisk and Reynolds (1997). In their analysis of change orders in public construction projects in Oman, Alnuaimi et al. (2010) identified that these change orders resulted in cost overruns, schedule overruns, and had a negative impact on labor morale and work quality. They observed that change orders often exerted pressure on all project parties to expedite work completion, which sometimes led to rushed and lower-quality work, particularly during the final stages of the project. Similarly, Naji et al. (2022) have emphasized that inadequate management of change orders can significantly impact quality, time, and cost in construction projects.

### 3.4 Remedies for Change Orders

Numerous studies have been dedicated to devising strategies for mitigating the impacts and reducing the frequency of change orders in various industries. According to the findings in Goodrum et al. (2010), it is recommended that particular attention be directed towards addressing potential contract omissions, contract item overruns, and owner-induced enhancements. As these factors emerge as major contributors to the occurrence of change orders, focusing on proactive measures and effective management of these aspects can aid in minimizing the disruptive effects of change orders. However, Hsieh et al. (2004) recommend focusing special attention on addressing issues related to planning and design to minimize the occurrence of change orders.

Based on the data collected from 33 maintenance engineers representing various Department of Transportations (DOTs) across the United States, Kumar Shrestha (2016) identified key remedial measures to address change orders. The participants in the study predominantly agreed that reviewing project specifications, preparing accurate estimates, and reviewing design drawings before bid solicitation were among the most effective measures for mitigating the occurrence of change orders. Similarly, maintaining meticulous records of daily operations and keeping a comprehensive log of all previously executed change orders were the recommended remedial measures by Serag et al. (2010) after analyzing change orders in heavy roadwork constructions in Florida.

In their analysis of 10 highway transportation projects within ODOT, Ahmed et al. (2022) found that a thorough and effective grasp of contractual provisions and a clear awareness of their rights and responsibilities as outlined in the contract documents played a significant role in reducing the occurrence of change orders. Likewise, Choi et al. (2021) conducted a study to assess the effectiveness of various contract methods in reducing change orders. Their findings revealed that using incentives/disincentives (I/D) was associated with a reduction in schedule overruns. Lump-sum contracting emerged as an effective option for minimizing cost overruns. However, they noted that cost-plus-time bidding was more likely to result in change orders related to cost overruns compared to conventional contracting methods. Among the alternatives, I/D contracts were the preferred choice for expediting project duration while simultaneously minimizing cost overruns.

According to Mahamid (2017), several strategies can be used to reduce the frequency of change orders in construction projects. These include selecting qualified subcontractors, fostering effective communication among all project stakeholders, promoting a sense of teamwork among team members, clearly communicating the expected quality standards to the contractor, thorough project planning during the initial stages, and conducting comprehensive site investigations before entering the design phase. Also, following their analysis of various public construction projects in Oman, Alnuaimi et al. (2010) proposed several remedies to address the challenges posed by change orders. These recommendations encompass conducting comprehensive technical assessments of consultant companies, creating standardized and detailed documents for all project stages, establishing a shared learning database system for governmental units, ensuring that designers possess professional licenses, conducting timely reviews and updates of general conditions, and developing a standard construction procedure manual.

According to the findings of Assaad et al. (2022), effective strategies for reducing the occurrence of change orders in construction projects include thorough examination of the standard specifications within construction documents and fostering clear communication among various project stakeholders. This communication should encompass information flow, task understanding, and understanding the dependencies throughout different stages of the project. Similarly, Ramos-Maldonado et al. (2016) emphasized the importance of enhancing communication and coordination among all relevant project stakeholders, particularly during the planning stage, in mitigating the occurrence and frequency of change orders. They also highlighted the significance of creating clear and explicit project documents from the project's outset, outlining the expectations of users and ensuring alignment among all parties involved.

After assessing large construction projects in Saudi Arabia, Assaf and Al-Hejji (2006) underscored the significance of the following measures to mitigate change orders: creating clear and comprehensive designs, evaluating contractor capabilities beyond just the lowest bid amount, and promptly assigning administrative and technical staff when a project is awarded to minimize delays. Sambasivan and Soon (2007) also recommend evaluating the financial and technical capabilities of contractors before awarding contracts for the mitigation of change orders. Additionally, they suggest that clients should avoid excessive interference in the work, make decisions promptly, and ensure timely payments.

Randolph et al. (1987) proposed that tailoring monitoring efforts to the specific type of work and contractor can significantly reduce change orders and subsequent cost overruns. After evaluating 3,957 large highway projects spanning 28 years, Shrestha and Maharjan (2018) concluded that the adoption of modern computer-based project management software may have contributed to a decrease in the frequency of change orders and cost overruns, highlighting the effectiveness of such software in project management.

A summary of the major remedies for change orders is presented as follows.

1. Place strong emphasis on creating clear and comprehensive plans and designs (Assaf & Al-Hejji, 2006; Hsieh et al., 2004; Mahamid, 2017; Goodrum et al., 2010).
2. Carefully examine project specifications (Shrestha, 2016).
3. Strive for precise and accurate cost estimates (Shrestha, 2016).
4. Exercise caution regarding potential contract omissions and item overruns (Goodrum et al., 2010).
5. Consider the contractor's and subcontractor's capabilities, manpower, and resources when awarding contracts (Assaf & Al-Hejji, 2006; Mahamid, 2017; Sambasivan & Soon, 2007).
6. Assess consultant companies' technical capabilities through registration (Alnuaimi et al., 2010).
7. Mandate professional licensing for design engineers (Alnuaimi et al., 2010).
8. Develop comprehensive standardized documents outlining rights, obligations, project tasks, dependencies, and end user expectations (Ahmed et al., 2022; Alnuaimi et al., 2010; Assaad et al., 2022; Ramos-Maldonado et al., 2016).
9. Foster clear communication, sense of teamwork, and understanding among project stakeholders (Ahmed et al., 2022; Mahamid, 2017; Ramos-Maldonado et al., 2016).
10. Ensure contractors create specific work plans and communicate them clearly to clients (Sambasivan & Soon, 2007).
11. Prepare a construction procedure manual with standardized specifications (Alnuaimi et al., 2010; Assaad et al., 2022).
12. Assign specialized quantity surveyors, project managers and technical staff for large-scale construction projects immediately upon contract award (Alnuaimi et al., 2010; Assaf & Al-Hejji, 2006).
13. Conduct thorough site investigations to minimize unexpected conditions (Mahamid, 2017)
14. Maintain detailed records of daily operations (Serag et al., 2010).
15. Keep a well-organized log of previously executed change orders (Serag et al., 2010).
16. Adjust monitoring efforts based on the type of work and contractor (Randolph et al., 1987).
17. Utilize computer-based project management software (Shrestha et al., 2022).
18. Consider alternative contract methods like incentives/disincentives, lump-sum, etc., where suitable to tackle cost overruns and schedule delays (Choi et al., 2021).
19. Ensure prompt decision-making by clients when needed (Sambasivan & Soon, 2007).
20. Apply effective control and management practices to small projects, similar to large ones (Khalafallah & Shalaby, 2019).

### 3.5 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.

## CHAPTER 4. DESCRIPTIVE STATISTICS

### 4.1 Introduction

#### *4.1.1 Description of the Data*

Table 4.1 provides an overview of four key datasets shared by INDOT, spanning from 2008 to 2023. These datasets offer crucial insights into contract awards, construction projects, and change orders, facilitating a comprehensive analysis of the change orders (COs) across various types of projects performed by INDOT. The research team obtained four major datasets from INDOT as described in Table 4.1.

The research used a set of contract-related variables: contract ID, work type, and award amount. The data included a range of change order (CO)-related variables, such as CO category, CO amount, and CO reason, facilitating an in-depth analysis of the factors affecting these contracts. These variables collectively constitute a comprehensive dataset for studying contract and project inputs and outcomes. The next section provides details on the available variables, data reliability, and the data cleaning and preprocessing steps taken in this study. Working with the four datasets outlined in Table 4.2, contract- and change order-related variables were extracted. These variables (Table 4.2) were then used to create two separate datasets: a contract-related dataset and change order-related dataset.

#### *4.1.2 Data Reliability, Cleaning, and Preprocessing*

DOT contracts often involve substantial public funds and maintaining data reliability is essential to uphold transparency and public trust in government processes. Accurate data helps DOTs track project progress, manage resources efficiently, and make informed decisions that benefit both the government and the public they serve. Recent studies including Padhye and Hastak (2024) and Manege and Kennedy (2022) highlighted the concerns related to credibility of information and information sources in the construction industry; and have further elaborated on potential cost and schedule implications of unreliable data. In the present study, the primary objective is to identify the root causes of change orders in INDOT projects. Therefore, any insights from the data analysis are only as credible as the original data. To refine the dataset and thereby ensure data reliability, the research team defined a set of cleaning and processing criteria. To do this, concerns such as missing data and inconsistent values and formatting across multiple datasets, were addressed.

The following steps are the criteria for contract-related data.

1. *Select Relevant Contracts:* Choose contracts that contain all contract-related variables as specified in Table 4.2.
2. *Filter Completed Contracts:* Include only the contracts that were completed between 2010 and 2020.
3. *Data Integration:* Merge data from INDOT Projects Full List and Construction Data using "Contract Number" as the common identifier (that is, the primary key).
   - Cross-verify the consistency of overlapping variables (such as work type and district) across the datasets.
4. *Calculate Percent Cost Overrun:* Determine the percentage of cost overrun for each contract using one of two methods.
   - Calculate the difference between award amount and current adjusted amount.

TABLE 4.2
**INDOT Data: Available Variables**

| **(a) Contract-Related Variables** |
|---|
| Contract ID and District |
| Work Type |
| Award Amount |
| Award Date |
| Original Completion Date |
| Current Adjusted Amount (As-built) |
| Actual Completion Date |
| Designer ID - Anonymous |
| Contractor ID - Anonymous |
| Urban/Rural/Small Urban Location |
| Functional Class |
| Program Class |
| **(b) Change Order (CO)-Related Variables** |
| Contract Number and Change Order ID |
| District and Work Type |
| CO Category |
| CO Reason/Sub-Category/Root Cause |
| CO Amount |
| CO Approval Date |
| CO Description (Textual) |

TABLE 4.1
**INDOT Data Description**

| Title | Year | Description | Content |
|---|---|---|---|
| INDOT Projects Full List | 2010–2023 | Variables: Time of award | 6,370 Contracts[1] |
| Construction Data | 2008–2023 | Variables: Time of completion | 7,826 Contracts at $21.54B |
| Change Orders General Data | 2008–2023 | All change orders processed | 35,992 COs at $936.97M |
| Change Order Remarks | 2008–2023 | Textual description of COs | 2,649 COs |

[1]The number of contracts were found to vary across dataset 1 and datasets 2–4 due to differences in their time spans.

- Calculate the sum of the award amount and the total change order (CO) amount; both methods should yield the same result.

5. *Calculate Percent Schedule Delay:* Compute the percentage of schedule delay for each contract by finding the difference between the actual completion date and the original completion date.
6. *Group Work Types:* The original dataset consists of 266 unique Work Types. For the ease of the analysis and to help with null values (i.e., contracts that did not have a specified work type but had a work category in another column), the research team consolidated these into four categories The detailed groupings are included in Appendix A. The projects were classified as follows.
   - Road-related (added travel lanes, new road construction, etc.).
   - Bridge-related (new bridges, bridge repair/rehabilitation, etc.).
   - Pavement-related (pavement repair/rehabilitation, patching, etc.).
   - Demolition, maintenance, and traffic-related (roadside maintenance, safety improvements, etc.).

The following steps are the criteria for change order-related data.

1. *Status of the CO:* Unlike approved COs (pending and draft CO are not considered here).
2. *Subset Data by Timeframe:* Narrow down the change order general data to match the timeframe of the contracts-related data (2010 to 2020).
3. *Compatibility Check:* Ensure compatibility by verifying that.
   - All contracts in the CO data exist in the contracts-related data.
   - Overlapping variables (work type and district) are consistent between the two datasets.
   - Create new columns for additional variables linked to the "Contract Number."
4. *Create "CO Range" Column:* In alignment with the approval authorities outlined in the 2014 INDOT Change Order Policy, establish a new column called "CO Range" that categorizes change orders into specific thresholds (e.g., below \$20k, \$50k, \$250k, etc.).
   - Maintain separate categories for positive and negative COs, as such categorization could facilitate identification of root causes and project types associated with larger or smaller magnitude COs.

These data cleaning and preprocessing steps are essential to ensure the quality and consistency of the data, allowing for accurate analysis and insights in the context of INDOT contracts and change orders. The descriptive analysis in this chapter is organized as follows.

- *Part I (Section 4.2):* General descriptive analysis (contract size per district and project type).
- *Part II (Section 4.3):* CO frequency and categories (CO trends and patterns, statewide).
- *Part III (Section 4.4):* Distribution of change order-related outcomes (cost overrun and schedule delay) across districts and project types.
- *Part IV (Section 4.5):* Change order root cause trends and patterns.

## 4.2 General Descriptive Analysis (Contract Size per District and Project Type)

INDOT awarded the substantial number of 4,998 contracts, spanning from 2010 to 2020. These contracts collectively have a total award amount of \$10.313 billion. Greenfield was awarded the greatest number of contracts (22%) and has the highest total award amount (23%). On the lower end, Vincennes shares 13% of the total number of contracts and 17% of the total awarded amount. The pie charts in Figure 4.1, provide a concise overview of the distribution of contracts and award amounts among these administrative districts with respect to INDOT contracts from 2010 to 2020. In several subsequent charts, the bar representing "demolition, maintenance, and traffic-related" has been abbreviated as "demolition, maintenance, a..." or demolition, maintena ..."

The bar graph in Figure 4.2 presents the distribution of contracts by project type, from 2010 to 2020. It is observed that the project class with the least number of contracts is the road-related category, even though they account for the maximum share in award amount (\$3.67B). Also, INDOT awarded a significantly higher number of bridge-related contracts compared to road- or pavement-related contracts. Figure 4.3 provides further details on the distribution of contracts across the six administrative districts and project classes.

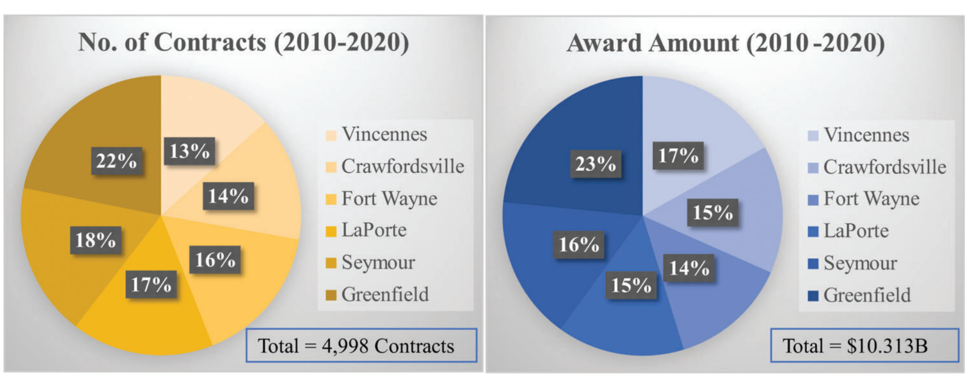



**Figure 4.1** District-wise contracts (2010–2020).

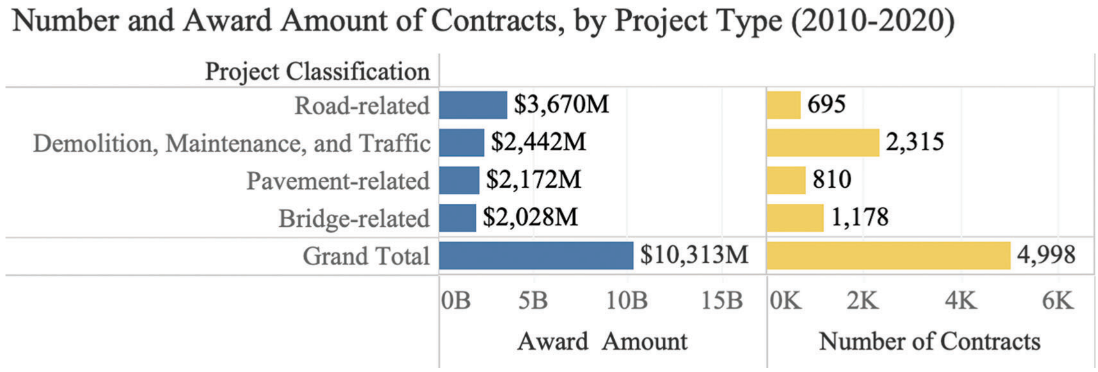



**Figure 4.2** Type of projects (2010–2020).

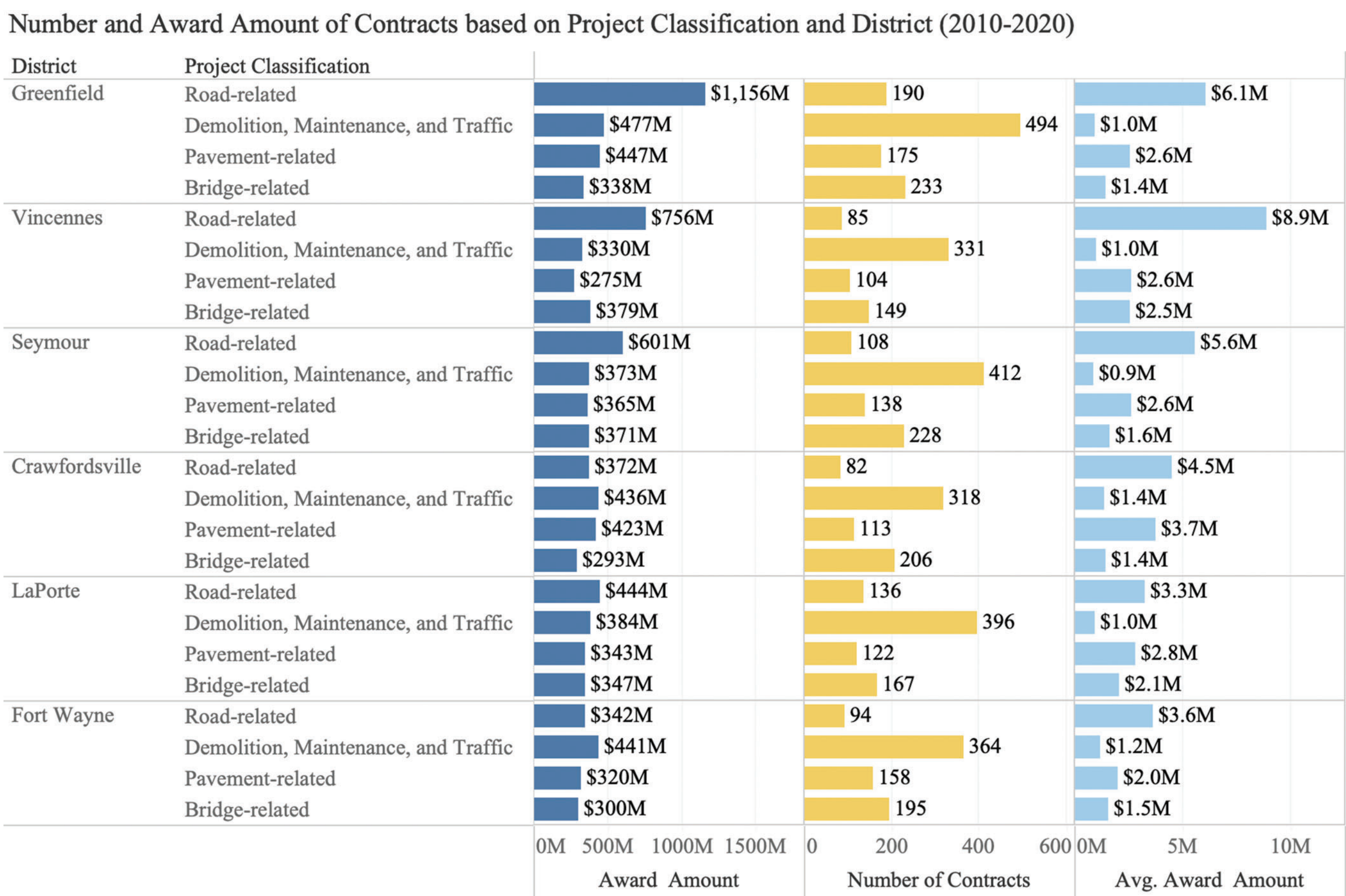



**Figure 4.3** Distribution of contract frequencies and sizes by project class and district.

From 2010 to 2020, the Greenfield District had the highest number (190) and size ($1.15B) of road-related contracts. The distribution of total and average award amounts is similar for the project types across the six districts. The Vincennes District stands out as having the highest average award amount for road-related contracts, averaging $8.9 million. This suggests that Vincennes may have awarded a few exceptionally large-sized projects, setting them apart from other districts. Alternatively, this observation could be suggesting that executing road-related contracts in Vincennes District is more expensive on an average, compared to other districts.

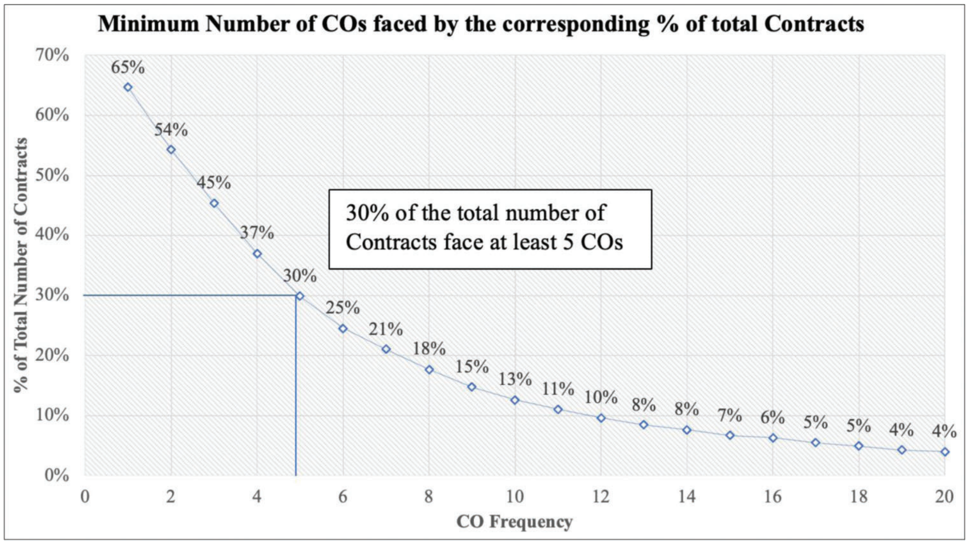



**Figure 4.4** Distribution of change orders across contracts.

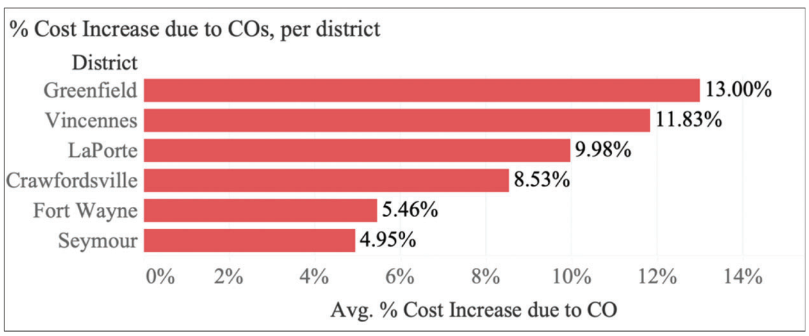



**Figure 4.5** District-wise average cost overruns.

## 4.3 Change Order Frequency and Categories (Statewide CO Trends and Patterns)

### *4.3.1 Distribution of Change Order Frequencies Across the Contracts*

A significant majority, comprising 65% of the awarded contracts, have experienced at least one change order during their execution as illustrated in Figure 4.4. This distribution suggests that a smaller percentage of contracts face a more substantial volume of change order-related adjustments. For example, a relatively small fraction of the awarded contracts (4%), have received more than 20 change orders. From 2010 to 2020, INDOT approved a total of 22,681 change orders (COs), totaling $415.23 million in adjustments based on the preprocessed dataset.

The next section addresses a detailed analysis of change orders, exploring trends and patterns from 2010 to 2020 across various project types and districts, and providing additional insights about the categories and range of COs across INDOT contracts.

### *4.3.2 Change Order Frequency by District and Project Type*

Figure 4.5 presents the varying percentages of cost overruns associated with COs across the six administrative districts. It is evident that Greenfield District has the highest average percentage of cost overruns (13%) that are caused due to COs, followed closely by Vincennes at 11.83% and LaPorte at 10%. In contrast, Seymour outperforms other administrative districts, demonstrating a relatively lower average cost overrun of approximately 5%.

Figure 4.6 suggests that bridge-related projects consistently exhibit higher cost overruns compared to other project types, with bridge maintenance and repair projects standing out at approximately 16.6% over their original award amount. Similarly, pavement-related projects also experience significant cost overruns, averaging around 9%. In contrast, within the category of road-related projects, the average percentage cost overrun is relatively lower, at about 6%, when compared to bridge- or pavement-related projects.

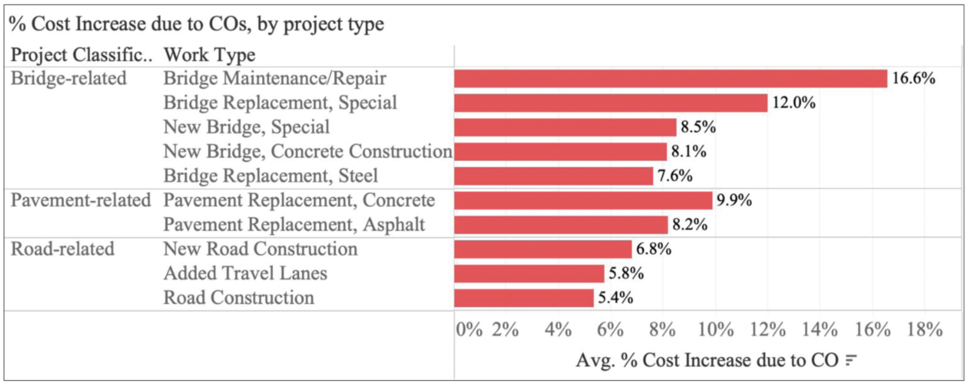



**Figure 4.6** Project-wise average cost overruns.

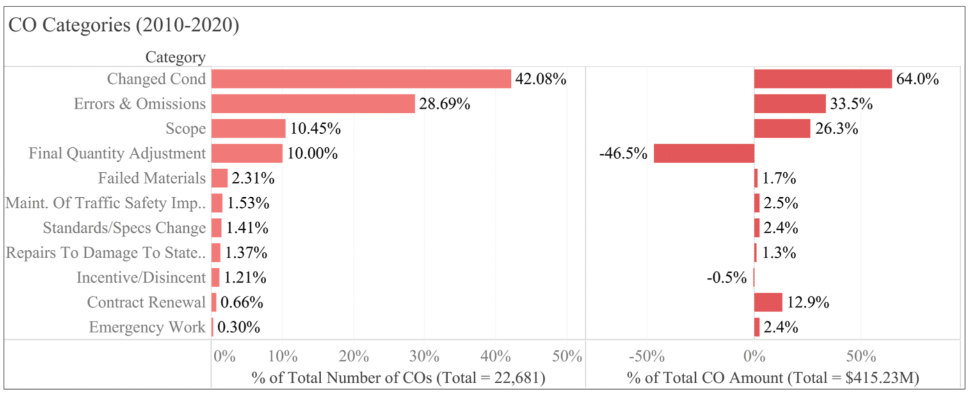



**Figure 4.7** Distribution of change order categories.

These COs are placed into 11 major categories, with "changed conditions" and "errors & omissions" emerging as the most frequent and significant categories, collectively constituting 71% of the total number of COs. Notably, negative COs are primarily driven by "final quantity adjustments." Excluding these final quantity adjustments-related COs, the effective total CO amount stands at approximately $600 million from 2010 to 2020, offering a clearer view of the financial implications of these change orders. Figure 4.6 provides the exact distribution of these 11 categories with respect to their frequency and cost implications.

### *4.3.3 Distribution of Change Orders by Change Order Category*

As evident from Figure 4.7, "changed conditions" stand out as the most influential category, constituting 42% of the total number of COs and 64% of the total CO amount, approximately $266 million. The second major category, "errors & omissions," leads to 29% of the total number of COs and contributes 34% to the total CO amount, approximately $141 million. Following closely are "scope" related change orders, contributing 26.3% of the total CO amount, equivalent to approximately $110 million.

Furthermore, according to the INDOT Change Order Policy outlined in Chapter 2, specific official positions at INDOT are authorized to approve specific CO amount and schedule delay. For example, the project engineer can authorize COs up to $20,000 only. Figure 4.8 provides a visual representation of this range of COs across various CO categories, offering valuable insights to INDOT personnel by illustrating the distribution of COs across different categories and their respective financial impacts, ranging from negative COs exceeding $2 million to positive-value COs exceeding the same threshold.

Figure 4.8 presents the magnitudes of the change orders. A substantial majority of the change orders (COs), specifically 12,538 out of a total of 22,681, fall within the range of 0 to $20,000, representing over 50% of all COs. However, when considering the magnitude or the total amount of COs, it is noteworthy that "changed conditions" and "errors & omissions" emerge as the predominant factors contributing to COs exceeding $500,000.

Subsequent figures in this chapter offer an overview of the distribution of both the number and monetary value of COs across the six INDOT districts. This analysis will facilitate an evaluation of the performance of these districts in the context of change orders administration and provide valuable insights for INDOT personnel.

Range of COs (from $2M to Negative ($2M): 2010-2020)

| Category | Neg(> 2M) | Neg(750.1k - 2M) | Neg(250.1k - 750k) | Neg(50.1k - 250k) | Neg(20.1k - 50k) | Neg(0 - 20k) | 0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | > 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CO Range | | | | | | | | | | | | |
| Changed Cond | 2 | 6 | 50 | 267 | 288 | 753 | 5,765 | 1,244 | 991 | 132 | 32 | 14 | 9,544 |
| Errors & Omissions | | 2 | 20 | 102 | 96 | 285 | 4,441 | 872 | 591 | 84 | 12 | 2 | 6,507 |
| Scope | | 3 | 10 | 75 | 77 | 210 | 1,280 | 314 | 300 | 72 | 21 | 9 | 2,371 |
| Final Quantity Adj.. | 5 | 49 | 178 | 654 | 490 | 168 | 227 | 251 | 206 | 31 | 8 | 1 | 2,268 |
| Failed Materials | | 1 | 6 | 50 | 64 | 147 | 106 | 50 | 88 | 9 | 3 | | 524 |
| Maint. Of Traffic .. | | | | 1 | 4 | 9 | 247 | 44 | 38 | 2 | 1 | 1 | 347 |
| Standards/Specs C.. | | | 1 | 8 | 12 | 57 | 147 | 44 | 41 | 8 | 1 | | 319 |
| Repairs To Damag.. | | | | 1 | 1 | 4 | 248 | 40 | 14 | 3 | | | 311 |
| Incentive/Disincent | | 5 | 6 | 33 | 31 | 66 | 39 | 27 | 58 | 7 | 2 | | 274 |
| Contract Renewal | | | 1 | | | | | 4 | 63 | 64 | 17 | | 149 |
| Emergency Work | | | | | | | 38 | 9 | 13 | 4 | 2 | 1 | 67 |
| Grand Total | 7 | 66 | 272 | 1,191 | 1,063 | 1,699 | 12,538 | 2,899 | 2,403 | 416 | 99 | 28 | 22,681 |

**Figure 4.8** Dollar range of change orders.

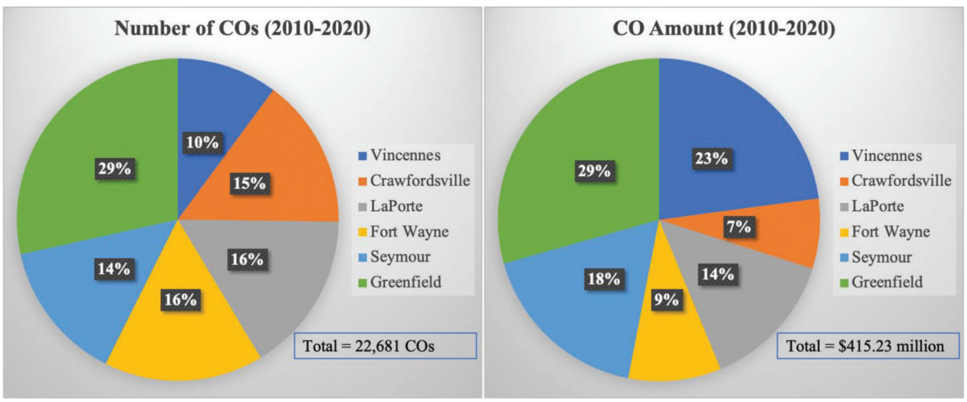



**Figure 4.9** District-wise distribution of COs.

*4.3.4 Change Order Counts and Amount by District*

Figure 4.9 indicates that Greenfield District has the highest share of COs: 28% of the CO count and 29% of the total CO amount. Conversely, LaPorte, Fort Wayne, Crawfordsville, and Seymour districts have lower but similar share of CO counts and amounts. Notably, Vincennes District, while contributing 10% to the total CO count, accounts for 23% of the total CO amount, suggesting a pattern where Vincennes has approved COs of larger magnitude compared to other districts.

The heat map shown in Figure 4.10 provides deeper insight into the change order count and amount per contract across the six administrative districts from 2010 to 2020. Notably, Vincennes stands out with the lowest average count of COs per contract (about 5), while exhibiting the highest average CO amount per contract ($232,000). For more comprehensive analysis, Section 4.4 addresses the specific reasons and root causes underlying the change orders in each of these six districts. Moreover, the subsequent section provides additional granularity from the perspective of the project classes and the six administrative districts.

*4.3.5 Count and Amount of Change Orders by Project Type*

Based on the project classification depicted in Figure 4.11, road-related projects face 19 COs per contract each amounting to approximately $24,000. That indicates that road-related projects, based on historical data, have had COs worth $456,000 per contract (total = 19*24,000 = $456,000/contract). Pavement- and bridge-related projects have faced similar count and magnitude ($ amount) of COs within the study period.

*4.3.6 Change Order Distribution Per Contract by District and Project Type*

Figure 4.12 further expands on the discussion of district-wise trends across these project types. This data could help INDOT's contracts personnel to better understand the trends and patterns of COs based on the district where the award was made. Vincennes, Seymour, Greenfield, and LaPorte have the highest magnitude of COs. Road-related projects in the Vincennes District have historically faced a large magnitude of COs as illustrated in Figure 4.12 which indicates 17 COs per road-related contract and $67,000

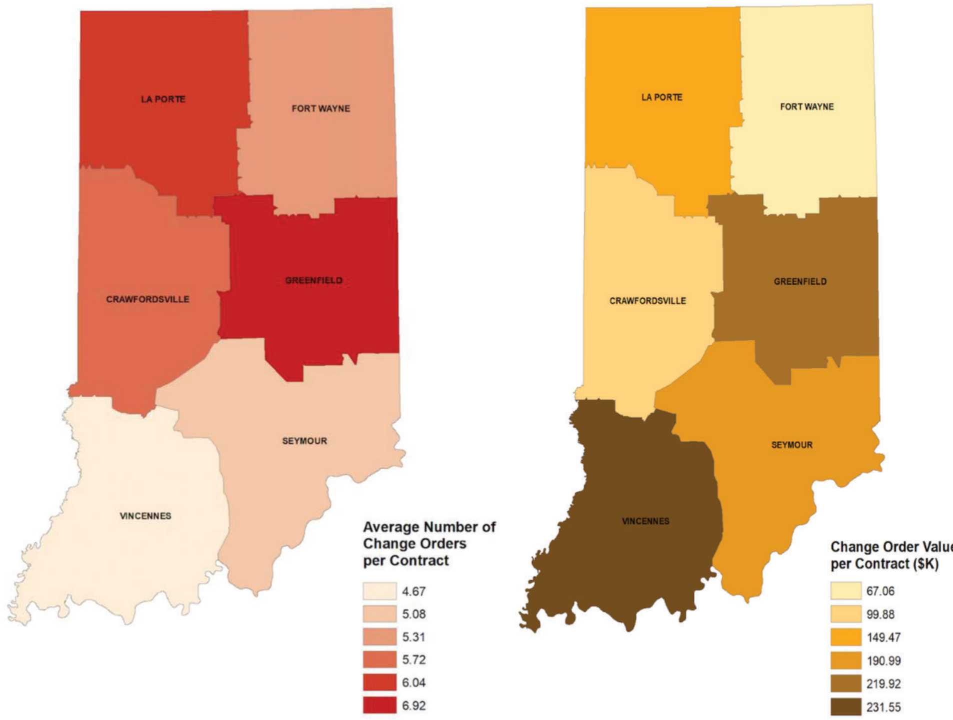



**Figure 4.10** Heatmap of district-wise distribution of COs.

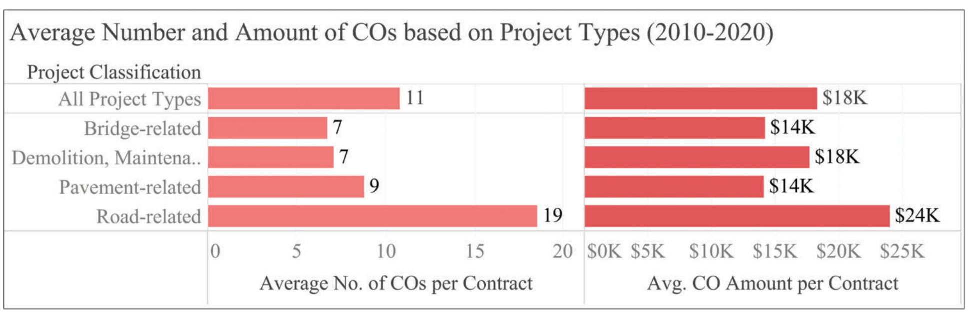



**Figure 4.11** Project-wise distribution of COs.

per CO (total = 17*67,000 = $1.14M/contract). Section 4.6 provides information about the root causes of these COs. Similarly, bridge-related projects in Vincennes have a large monetary magnitude of COs compared to other districts. Greenfield District has a higher magnitude of COs for their pavement-related projects than road-related projects. However, it performs well with respect to bridge-related projects compared to the other districts.

## 4.4 Distribution of Change Order-Related Outcomes (Cost Overrun and Schedule Delay) Across District and Project Type

### *4.4.1 Contract Size, Cost Overruns, and Schedule Delay Trends Across the Districts*

Figure 4.13 provides a visual representation of the contract sizes and corresponding change orders (COs) across various INDOT districts. While Greenfield notably stands out in terms of the size of contracts, the CO trends do not consistently align with the award trends, showcasing differences in performance among districts. Furthermore, the average percentage cost increase due to COs varies across the six administrative districts, ranging from a lower bound of 3.9% for Seymour to an upper bound of 11.2% for Greenfield. This inconsistency in cost increases is also reflected in the percentage schedule delays, with districts experiencing higher cost overruns also facing longer delays, except for Vincennes. Vincennes, in contrast, has seen COs of greater magnitude without resulting in schedule delays as substantial as those in comparable districts. For example, both Vincennes and Seymour exhibit cost overruns of approximately 9%–10%, but Vincennes averages a schedule delay of 17.6%, lower than Seymour's average delay of about 33% of the original contract period. These insights highlight the complexity of CO-related cost and schedule dynamics across INDOT districts, with Seymour and Vincennes exhibiting a unique pattern compared to their counterparts.

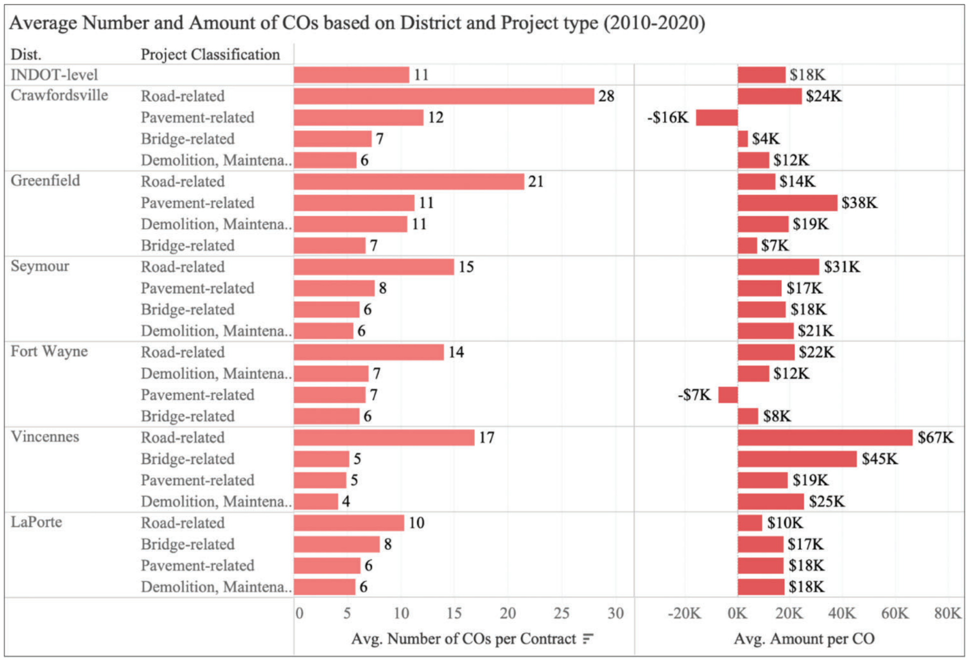



**Figure 4.12** District and project-wise distribution of COs.

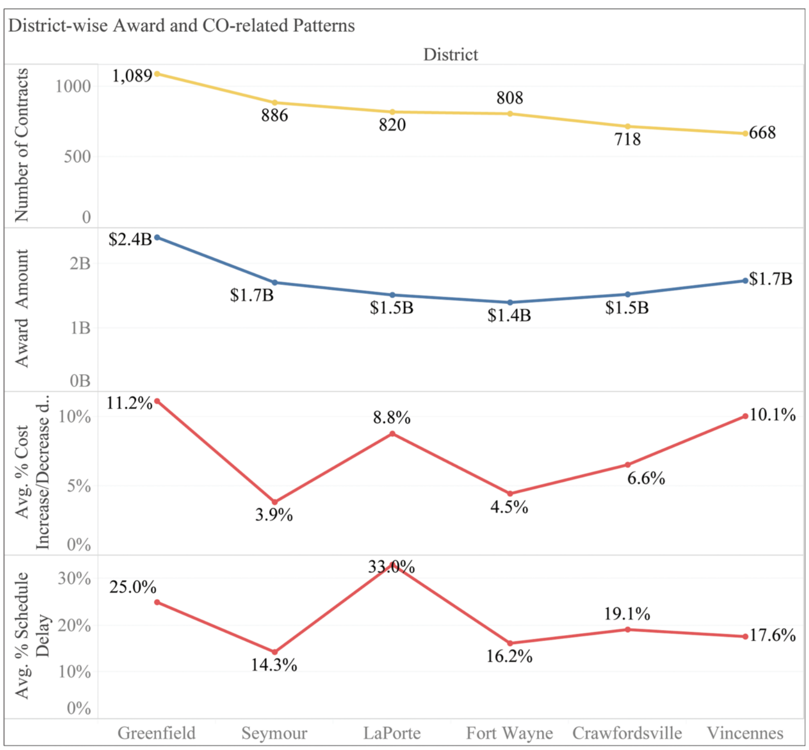



**Figure 4.13** District-wise comparison of overruns and delays.

### *4.4.2 Contract Size, Cost Overruns, and Schedule Delay Trends Across Project Type*

Figure 4.14 provides a visual representation of the contract sizes and corresponding change orders (COs) across various project types. While demolition, maintenance, and traffic-related projects stand out in terms of number of contracts, the majority of change orders in these projects are associated with "contract renewals." These types of change orders may not necessarily indicate concern as they are annual contract renewals and are unrelated to root causes such as construct-

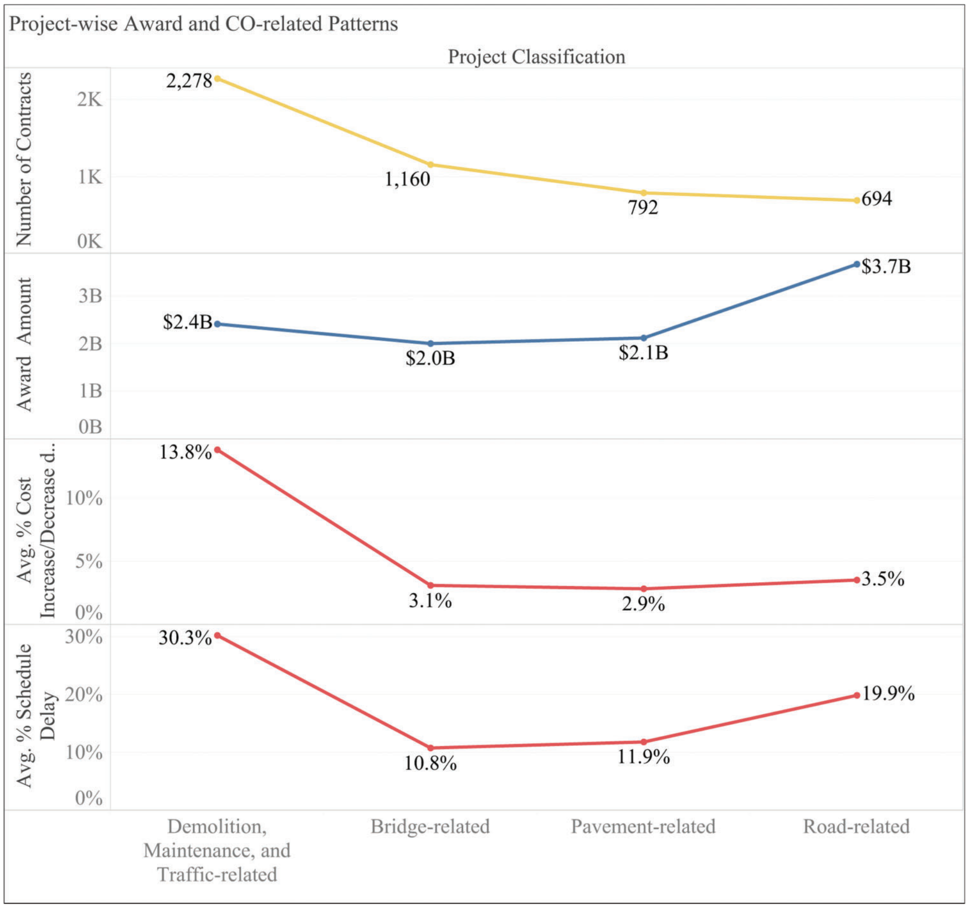



**Figure 4.14** Trends of cost overrun and delay across project types.

ability, errors, and omissions. Road-related projects have the highest share of the award amount. On average, road-related projects face 3.5% cost overruns and 20% schedule delays. This indicates that a 2-year road project might face a 4-month schedule delay, based on the historical average. This is twice as severe as those faced by bridge or pavement projects. Bridge and pavement projects face an average of 3% cost escalation and 11% schedule delay. Due to data limitations, the research team could not directly associate this delay with any particular root cause. However, preliminary statistics suggest that the majority of these are caused by change orders related to design and constructability issues. The next section outlines the top 10 root causes of change orders from 2010 to 2020.

## 4.5 Change Order Root Cause Trends and Patterns

### *4.5.1 The Top Ten Root Causes of Change Orders*

As depicted in Figure 4.15, the primary change order categories include "changed conditions," "errors & omissions," and "scope issues." Notably, "constructability issues" account for approximately $120 million in cost overruns, constituting roughly 30% of the total change order amount from 2010 to 2020. "Design-related issues" are responsible for $75 million in cost overruns, making up around 20% of the total change order costs. Additionally, change orders linked to factors like "soils," "environmental," "right-of-way (R/W)," and "material" also significantly impact the overall project cost. In Chapter 6, "recommendations and guidelines," we propose best practices for INDOT to implement in their project delivery processes to reduce the incidence and impact of these change order root causes. The subsequent section describes the specific influence of each of these root causes on the final project as-built cost across the six INDOT districts. This is to ascertain whether any root cause impacts a specific district greater than it does at the other districts.

### *4.5.2 Cost Overrun Rates Due to Root Causes, Per District*

As indicated in Figure 4.16, soils-related change orders have a greater impact on the Vincennes and LaPorte districts, resulting in an approximate 8% increase in project costs. In practical terms, when a soil-related change order occurs in these districts, it

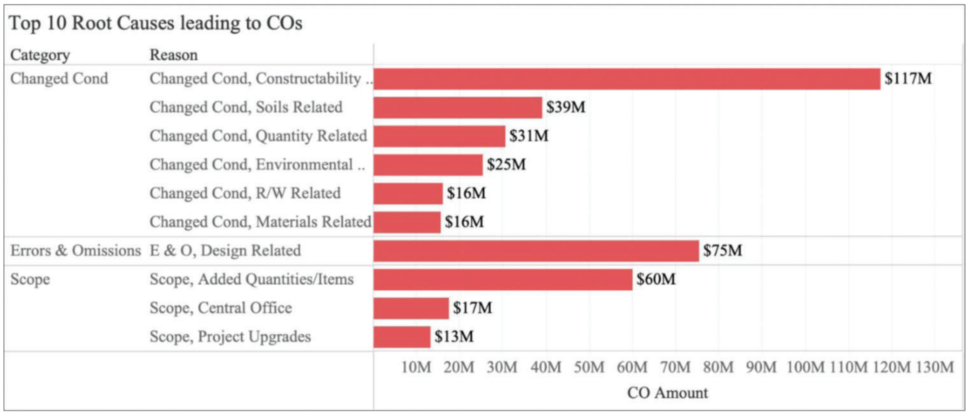



**Figure 4.15** Top 10 root causes of change orders.

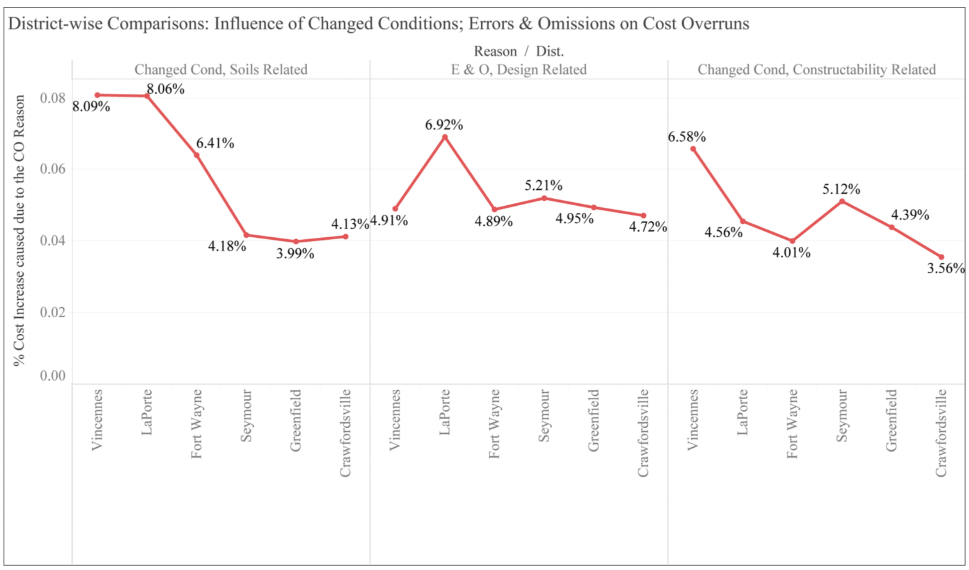



**Figure 4.16** District-wise cost impacts of root causes.

tends to lead to an 8% average cost overrun in comparison to the 4% average seen in Seymour, Greenfield, and Crawfordsville. Likewise, design-related errors and omissions have a more significant influence in the LaPorte District, resulting in an average cost overrun of 7%, whereas the other five districts experience around 5% on average. Constructability issues, on the other hand, generally contribute to cost overruns within a range of 3.5% to 7%. Notably, the Vincennes District tends to experience cost overruns on the higher end of this range.

An interesting observation is that while Greenfield records the highest number and total amount of change orders, the individual impact of the most frequent root causes is comparatively less severe than in the other districts. Table 4.3 provides a comparison overview of these key statistics from 2010–2020 vs. 1996–2001. This can help INDOT personnel to map their current state-of-the-art with respect to the historical trends.

### 4.6 Comparison of INDOT Trends Across Two Eras (1996–2001 vs. 2010–2020)

According to the statistics presented in Table 4.3, approximately 65%, have experienced cost overruns. This percentage is slightly higher than 55% during the 1996–2001 timeframe. In contrast, the incidence of schedule delays has significantly risen over the years. Approximately 40% of INDOT contracts now face schedule delays, compared to about 12% during the 1996–2001 period. Several factors could contribute to this notable increase, including the growing complexity of projects, increasing traffic conditions, unpredictable weather events, and challenges within the supply chain. The average rate of cost overruns has decreased over time, with the exception of maintenance and traffic-related projects. However, as specified in Table 4.3, the change orders associated to this project classification originate mainly from “contract renewals” that are essentially annual renewal of contracts.

TABLE 4.3
**INDOT (2010–2020 vs. 1996–2001)**

| Description | 1996–2001[1] | 2010–2020 |
|---|---|---|
| Percent of Total Contracts Facing Cost Overruns | 55% | 65% |
| Percent of Total Contracts Facing Schedule Delays | 12% | 40.4% |
| Overall Avg. Cost Overrun | 4.5% | 8.3% |
| Bridge-Related | 8.1% | 3.54% |
| Road-Related | 4.1% | 3.77% |
| Maintenance/Traffic-Related | 6.6% | 14.02% (also includes COs related to contract renewals) |

[1]1996–2001 statistics are from a previous JTRP study (SPR-2811: Analysis of Cost Overruns and Time Delays)

# CHAPTER 5. STATISTICAL MODELLING OF CHANGE ORDER COUNTS AND AMOUNTS

## 5.1 Introduction

### *5.1.1 Model Types*

The previous chapter presented some general evidence on the factors that affect the propensity and magnitude of change orders. In this chapter, more detailed analysis is carried out using INDOT-provided data to quantify the relationships between these explanatory factors and the two outcomes. Also, the impacts on the extended outcomes (in terms of the schedule delay and cost overrun) are investigated. The objectives of the modeling process are as follows.

#### 5.1.1.1 Predict the nature of change orders

- *Propensity or Likelihood of Change Orders for a Given Contract:* This category of models can help INDOT to forecast, for a given prospective contract, the probability of it will incur at least one change order, given the attributes of the prospective contract such as the district, contract award amount, geographical area (urban vs. rural), dominant project type (bridge, pavement, traffic-related, etc.) and contract type.
- *Predicting the Count, Net Direction, and Net Dollar Amount Change Orders for a Given Contract:* This category of models can help INDOT to forecast or predict the likelihood, for a given prospective contract, the expected number (count) of change orders; the net direction of the change orders (positive or negative, that is, increased project cost or decreased project cost, respectively); and the net magnitude (dollar amount). This can facilitate understanding of the impact of a project's change orders.

#### 5.1.1.2 Predicting the cost and time overruns due to change orders

- *Schedule Delay Resulting from Change Orders:* The group of models estimates the extension to the contract period that can be attributed to change orders.
- *Cost Overruns Resulting from Change Orders:* The group of models estimates the cost overrun that can be attributed to change orders.

The outcome prediction models offer INDOT's project managers, valuable information for quantifying the magnitude of schedule disruptions due to project scope changes, and for assessing the ramifications in terms of road user cost and community adversities (access to businesses, and so forth). Section 5.1.2 presents the overall modeling structure. Section 5.1.3 discusses data preprocessing and cleaning. Section 5.2 discusses the first two classes of models, and Section 5.3 discusses the third class of models.

### *5.1.2 Overall Modeling Structure*

The structure used for modeling in this study is shown in Figure 5.1.

### *5.1.3 Data Preprocessing and Cleaning*

Two datasets were developed using data provided by INDOT. Contracts awarded in 2021 and 2022 which are still in progress, were excluded. Also, the dataset included only contracts whose award dates are between the start of 2010 and the end of 2020. One of the datasets is contract-specific and the other is change order-specific. In the contract dataset, each row represents a specific contract with its corresponding attributes (e.g., award amount and date, total monetary value of all change orders in the contract, and highway district). In the change order dataset, each row represents a change order, and attributes include the change order's reason and total monetary value. Each change order (each row) is linked to its parent contract through a unique identifier, i.e., the contract number. Inconsistent and missing records were expunged, yielding 4,982 records in the contract dataset and 22,659 records in the change order dataset.

### *5.1.4 Description of the Variables Used in the Analysis*

Table 5.1 describes the dependent variables (i.e., the outcomes) and Table 5.2 describes the independent variables.

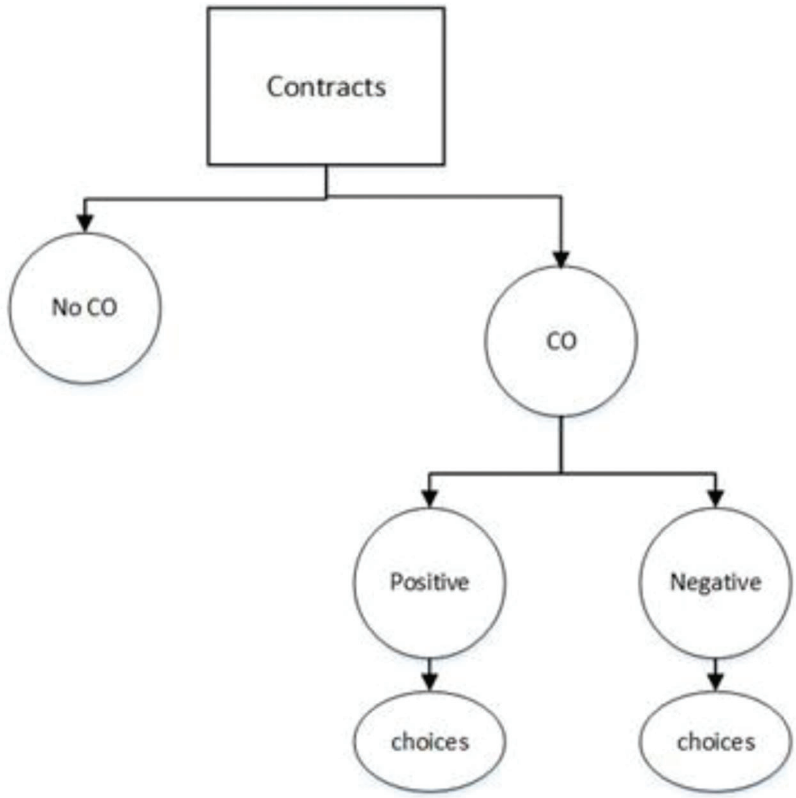



**Figure 5.1** Categories of models developed.

TABLE 5.1
**Description of the Dependent Variables (i.e., the Outcomes): Predictions for Each Contract**

| Outcome (Dependent Variable) | Type of the Dependent Variable | Levels and Codes | Form of the Model Used |
|---|---|---|---|
| *Change Order Propensity* (Likelihood That a Change Order Will Occur) | Binary (0 vs. 1) | No change order will occur 0<br>At least one change order will occur 1 | Binary Logit |
| *Number of Change Orders* | Count variable (but, may be considered continuous) | N/A | Regression |
| *Number of Change Orders* | Binary (0 vs. 1) | Less than 10 change orders occur 0<br>At least 10 change orders occur 1 | Binary Logit |
| *Net Direction of the Cost Impact* of the Change Order(s) | Binary (0 vs. 1) | Positive-value direction (a net increase in contract *cost*) 0<br>Negative-value direction (a net decrease in contract *cost*) 1 | Binary Logit |
| *Net Magnitude of the Cost Impact* of the Change Order(s) | Continuous | N/A | Regression |
| *Net Direction of the Time Impact* of the Change Order(s) | Binary (0 vs. 1) | Positive-value direction (a net increase in contract *time*) 0<br>Negative-value direction (a net decrease in contract *time*) 1 | Binary Logit |
| *Net Magnitude of the Time Impact* of the Change Order(s) | Binary (0 or 1) | N/A | |

## 5.2 Predicting the Nature of Change Orders for a Given Contract

"Nature" here refers to the propensity and count of change orders, and the net direction and net dollar amount associated with a contract that experienced change orders. This section discusses the models developed to help INDOT assess these outcomes for a given contract (Section 5.2.1). Then the section discusses the models developed to help INDOT forecast the count, net direction, and net dollar amount change orders for a given contract (Section 5.2.2).

TABLE 5.2
**Description of the Independent Variables**

| Variable | Description | Type | Levels and Codes |
| --- | --- | --- | --- |
| Contract District | District where the contract was carried out | Multinary (multiple categorical levels) | LaPorte: 1<br>Crawfordsville: 2<br>Seymour: 3<br>Fort Wayne: 4<br>Vincennes: 5<br>Greenfield: 6 |
| Geographical Area | Built-up nature of the work area | Multinary (multiple categorical levels) | Small Urban:1<br>Urban: 2<br>Rural: 3 |
| Contract Class | Dominant work type in the contract. | Multinary (multiple categorical levels) | Bridge-related: 1<br>Pavement-related: 2<br>Road-related: 3<br>Demolition, maintenance, and traffic-related: 4 |
| Design-Build | Delivery approach used for the contract | Binary (0 or 1) | Not design-build: 0<br>Design-build: 1 |
| Contract Award Amount | Contract award amount in $M. | Continuous | $0 to unlimited |

### *5.2.1 Propensity or Likelihood of Change Orders for a Given Contract*

**5.2.1.1 The model**. First, a binary logit model is created to predict the likelihood that a given contract will experience no change order vs. at least one change order. Second, a binary logit model is created to predict the likelihood of at least one positive-value change order (i.e., a change order that will cause higher project cost) vs. one negative-value change order (i.e., a change order that will cause lower project cost). The dependent variable is whether a contract incurred a CO or otherwise (0–1). Table C.1 in Appendix C presents the full details of the results of the binary logit model for CO occurring likelihood. The model results indicate that all the independent variable levels are significant at 99% level of confidence, except for the variables representing LaPorte District and Crawfordsville District location. The reference level for the dependent variable is 0. For example, the coefficient of the contract award amount variable is positive. This means that a higher contract award amount is associated with a higher occurrence likelihood of a change order. Also, the variable representing design-build has a negative sign, which suggests that design-build contracts are associated with a lower probability occurrence of change orders. The geographical area variables "small urban and urban" are positive; this suggests that compared to rural contracts, small urban and urban contracts are more prone to occurrence of change orders. This could be due to the limited space to set up the construction site, logistical challenges, and coordination (between different stakeholders and authorities) challenges. The developed model for the probability that a change order occurs can be re-stated here as a horizontal string as follows:

$$CO\ Probability = 1/(1+exp(-f(x)))$$

Where: $f(x) = 0.79268 - 0.00553 \cdot LP - 0.05211 \cdot CV - 0.52208 \cdot SM - 0.26762 \cdot FW - 0.81635 \cdot VC + 0.45447 \cdot SU + 0.26177 \cdot UR - 0.39544 \cdot BR - 0.70344 \cdot PR - 1.15561 \cdot RR - 1.86902 \cdot DB + 1.50032 \cdot CA$

*Where:*
*CO Probability* = probability that a given contact will incur a change order
$LP$ = Location in LaPorte District
$CV$ = Location in Crawfordsville District
$SM$ = Location in Seymour District
$FW$ = Location in Fort Wayne District
$VC$ = Location in Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

Sample Calculation:
Consider a $3M design-build bridge contract slated for implementation in a rural area in Seymour District. The probability that the contract will incur at least one change order is the following.

*CO Probability* = $1/[1+exp(-f(x)] = 1/[1 + exp\{0.79268 - 0.00553 \cdot (0) - 0.05211 \cdot (0) - 0.52208 \cdot (1) - 0.26762 \cdot (1) - 0.81635 \cdot (1) + 0.45447 \cdot (0) + 0.26177 \cdot (0) - 0.39544 \cdot (1) -$

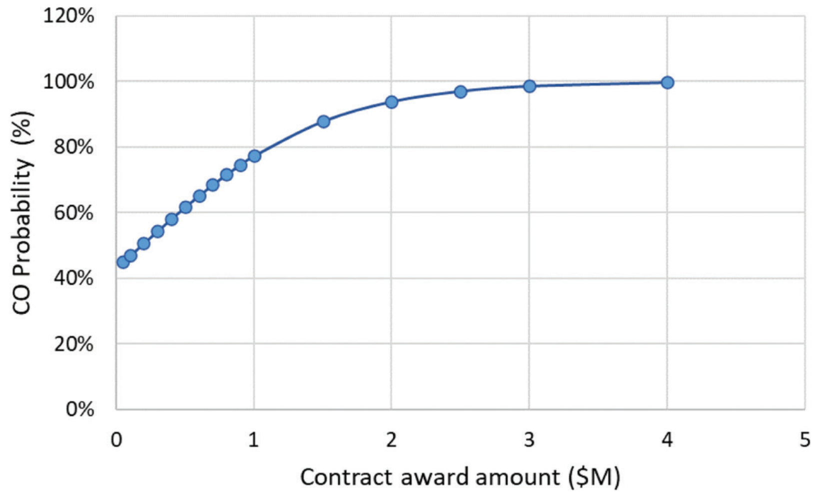



**Figure 5.2** Probability of change order vs. contract award amount for the Vincennes District, small urban area, pavement, and non-design-build.

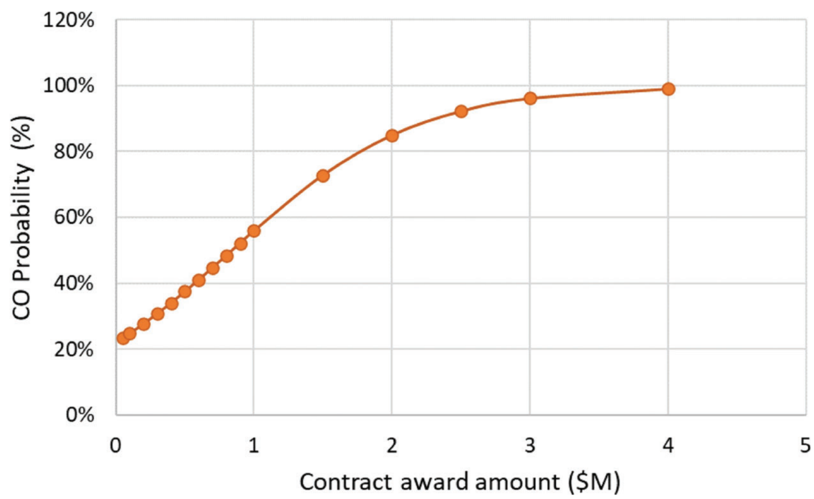



**Figure 5.3** Probability of change order vs. contract award amount for the Crawfordsville District, urban area, bridge, and design-build.

0.70344·(0) – 1.15561·(0) – 1.86902·(1) – 1.50032·(3)}]=
1/[1+exp{–2.97707}] = 96.15%

In other words, the contract will have a 95.15% chance of incurring at least one change order.

Figure 5.2 and Figure 5.3 shows the effect of contract award amount of the probability of CO occurrence under two different cases. They demonstrate that projects with higher contract award are more likely to experience CO. In all the figures indicating plots of the developed models, the dots shown are not raw observations but rather, points along the model lines, calculated using the model equation.

Figure 5.4 presents the relationship between the nature of the geographic area of a contract location and the CO probability. This is done for a hypothetical $2M bridge project in Crawfordsville District. The figure suggests that a bridge construction project in rural area is far less likely to have CO compared to urban areas.

**5.2.1.2 Marginal effects: The sensitivity of change order occurrence likelihood to the factors**. The sensitivity of change order propensity to the influential factors were analyzed by calculating marginal effects (the results are presented in Table C.2 in Appendix C). The results of Table C.2 are shown in Figure 5.5. The marginal effect reflects the extent to which the dependent variable (probability of change order occurrence) will change if the independent variable changes by 1 unit. For example, from Table C.2, it is seen that the sensitivity of the contract award amount variable is 0.19246. This suggests that if the contract award amount increases by $1M, there is a 0.19246 or (19.25%) increase in the probability that a change order will occur. When the independent variable is a

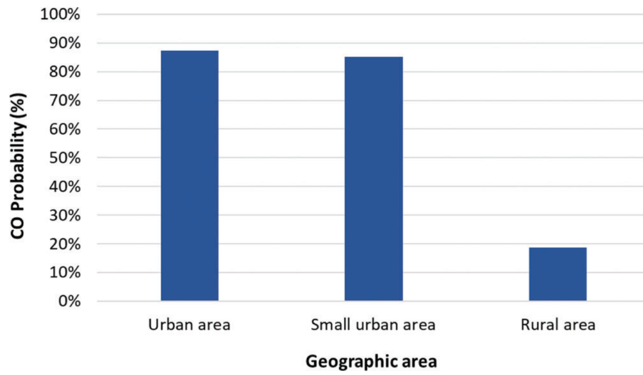
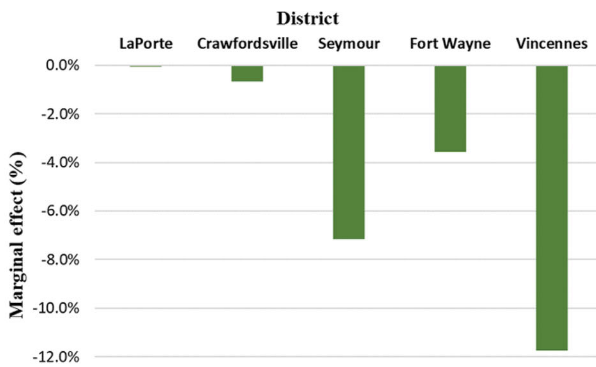
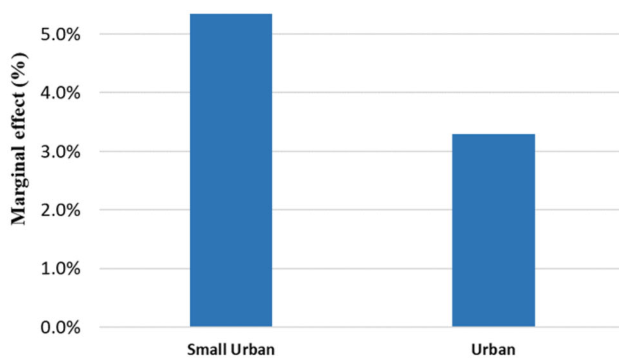


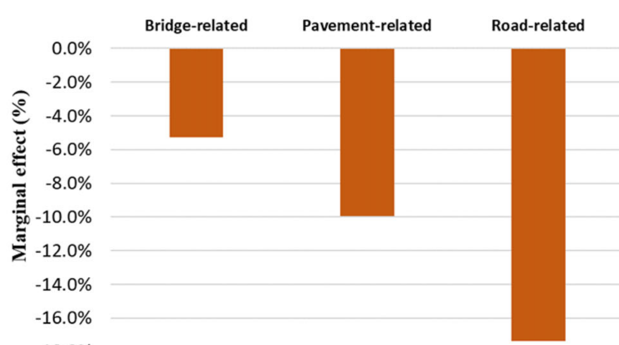

**Figure 5.4** Probability of change order vs. geographical area for the Crawfordsville District, bridge, design-build, and $2M.




(a) Sensitivity of change order probability to district (reference district is Greenfield).




(b) Sensitivity of change order probability to geographical area type (reference area type is "rural").




(c) Sensitivity of change probability to project type (reference is "demolition, maintenance, and traffic-related projects").

**Figure 5.5** Sensitivity of change order occurrence likelihood to different factors.

categorical (binary or multinary) variable, then the interpretation of marginal effect depends on the available levels. For example, regarding the design-build variable, the result shown in the table (0.2994) suggests that if the delivery approach for an impending contract is switched from traditional to a design-build contract, it will incur a 29.94% reduction in the probability that it will incur a change order.

**5.2.1.3 Odds ratios**. An odds ratio (OR) assesses the degree of association between an exposure variable (for example, contract award amount) and an outcome (in the context of this chapter, CO likelihood). The OR represents the chances that an outcome will occur given a specific exposure variable, compared to the chances that the outcome will occur in the absence of that exposure variable. With regard to a logistic regression (as used in this chapter), the regression coefficient of the exposure variable *i*, $b_i$, is the estimated increase in the log odds of the outcome (CO likelihood) per unit increase in the value of the exposure. In other words, the exponential function of the regression coefficient ($e^{bi}$) is the odds ratio associated with a one-unit increase in the exposure variable *i*. The OR is helpful not only to ascertain if a particular exposure variable is a risk factor for the outcome, but also to compare the magnitudes of various risk factors for that outcome (Szumilas, 2010). In this section, we use the terms exposure variable, independent variable, and factor interchangeably.

Figure 5.6 presents the odds of a contract encountering a CO based on the exposure factors considered in this study—the district of the contract location, rural/urban area location, project type, contracting method used for the project delivery (design-build or otherwise), and the contract award amount. The interpretation is made in the context of how the variable is defined. For example, regarding rural/urban area location, "rural" serves as the reference variable as defined in the list of variables earlier in this report. The result for urban (1.2 OR, in Figure 5.6) suggests that the odds of an urban contract encountering a CO is 1.2 times higher compared to a rural contract similar in all other exposure variables. In other words, contracts in rural areas are generally less likely to experience COs. The red bar refers to exposure variables whose odds exceed the odds of the reference exposure variable, and the green bar refer to exposure variables whose odds are lower than the odds of the reference exposure variable.

Figure 5.7 examines the CO severity (positive magnitude) of in terms of the total CO dollar amount. The figure suggests, for example, that the odds of a Seymour contract encountering a severe CO is 0.78 of the odds of a Greenfield contract encountering a severe CO, all other exposure variable remaining the same. (It may be noted that Greenfield District location is the reference level for this exposure variable). This indicates a 22% lower probability, generally, that a Seymour contract will experience a CO of the same severity compared to the Greenfield District.

## 5.3 Predicting the Change Order Direction and Magnitude

### *5.3.1 The Models*

This section discusses the development of the change order severity models. A binary logit model was developed to predict whether the value of a change order is positive or negative. Next, two MNL models are developed to predict the probability that a change order will have a positive value or negative values. Finally, a binary logit model was developed to predict the frequency category for change orders in a contract. For the MNL and binary logit model for the severity and category frequency outcomes of change orders, Table 5.3 presents the categories that were considered.


**Figure 5.6** Odds ratios—change orders likelihood and exposure (explanatory) factors.

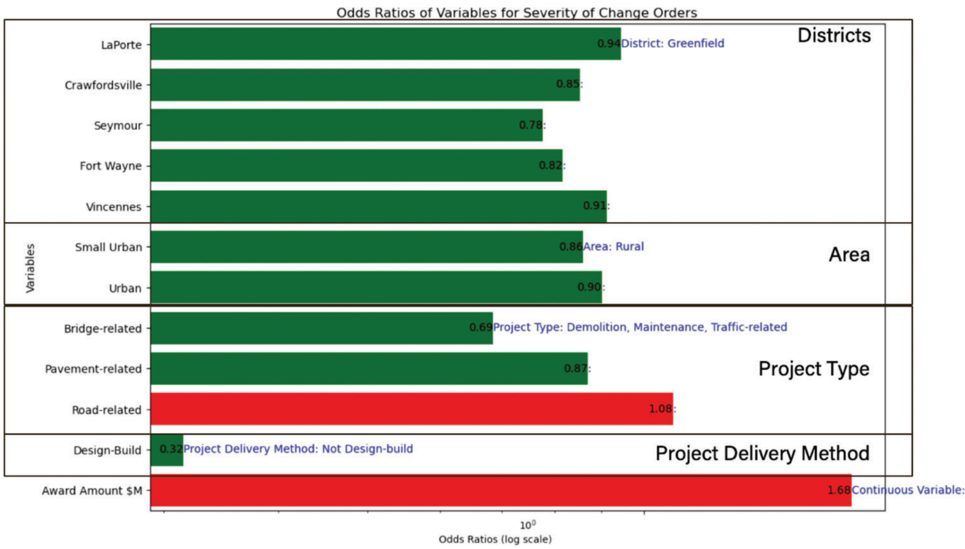



**Figure 5.7** Odds ratios—change orders magnitude and exposure (explanatory) factors.

TABLE 5.3
**Choice Sets for Severity and Frequency Models**

| | Number of Choices in the Choice Set | Choices |
|---|---|---|
| Severity | Positive-value: 3 | Value of COs:<br>($0 to $50K);<br>[$50K to $750K); and<br>[>$750K]. |
| | Negative-value: 3 | Value of COs:<br>[< -$750K];<br>(-$750K to -$50K]; and<br>(-$50K, $0). |
| Frequency | 2 | Number of COs:<br>(0, 10);<br>[10, Max]. |

Based on the table, three categories for CO severity and two categories for CO frequency are considered.

**5.3.1.1 Direction of the change order: Positive or negative?** A binary logit model is created to determine the likelihood whether a CO is positive or negative. The results have been summarized in Table C.4. The reference level for the dependent variable (i.e., positive or negative CO) is positive. Based on the data in Table C.4, pavement-related contracts are more prone to negative CO compared to demolition, maintenance, and traffic-related contracts. Figure 5.8 and Figure 5.9 present the probabilities of CO directions (positive or negative) for two project examples. It can be observed that generally, increasing the contract award amount increases the likelihood of positive change orders and decreases the likelihood of negative change orders.

**5.3.1.2 Magnitude of the positive-value change order.** To create an MNL model for positive COs, three categories were used (Table 5.2). An MNL was developed to predict the likelihood of a positive-value CO. The results are presented in Table C.6 in Appendix C. The reference level for the dependent variable is that the sum of a contract CO values is between 0 and $50K. The results suggest, for example, that the likelihood that for a design-build contract, the probability that the outcome (net magnitude of change orders) is $50K–$750K is lower than the probability that such outcome is $0–$50K. Figure 5.10 and Figure 5.11 demonstrate the likelihood of different CO levels over different contract award amounts, using two examples. In both examples, increasing the contract award increases the probability of severe positive change orders ($50K–$750K) and decreases the probability of light positive change orders ($0–$50K). Moreover, the probability of severe positive change orders ($50K–$750K) increases initially and then starts to decrease after a point.

**5.3.1.3 Magnitude of the positive-value change order.** Similar to their positive-value counterparts, three

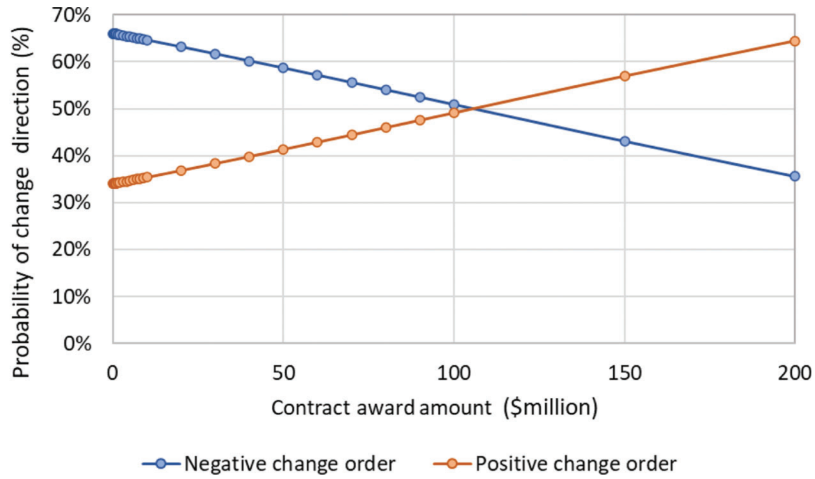



**Figure 5.8** Probability of change order direction (negative or positive) vs. contract award amount for the Vincennes District, small urban area, pavement, and not design-build.

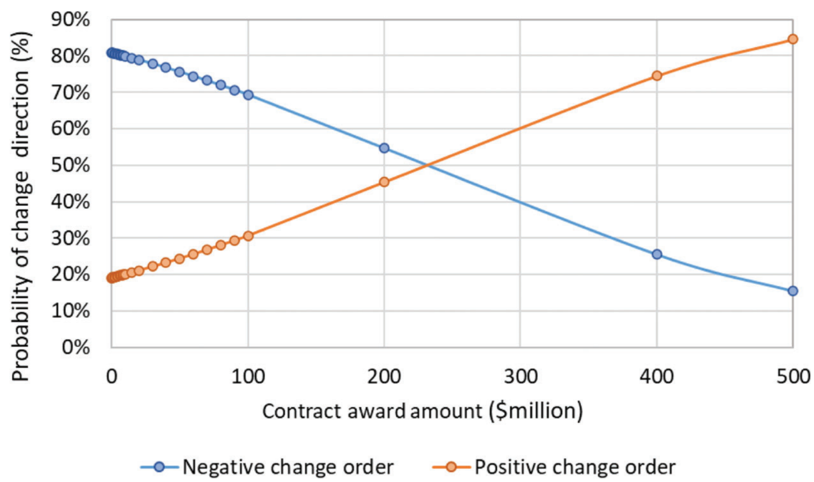



**Figure 5.9** Probability of change order direction (negative or positive) vs. contract award amount, for the Crawfordsville District, urban area, bridge, and design-build.

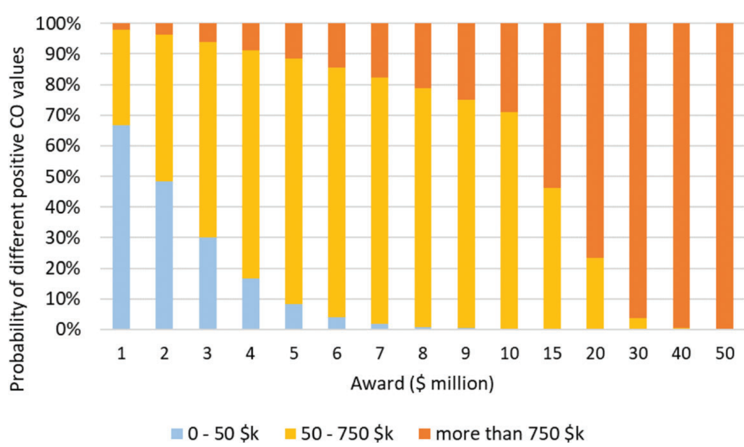



**Figure 5.10** Probability of different positive change order values vs. contract award amount for the Vincennes District, small urban area, pavement, and not design-build.

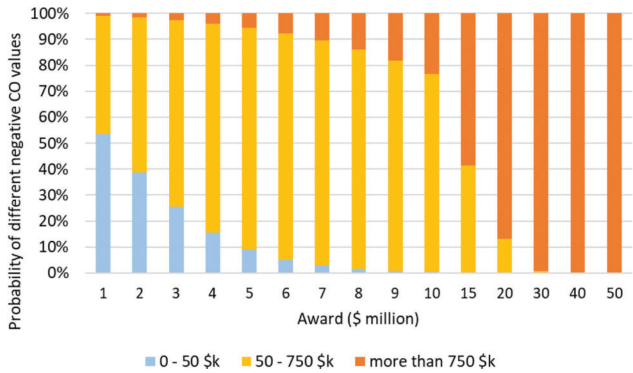
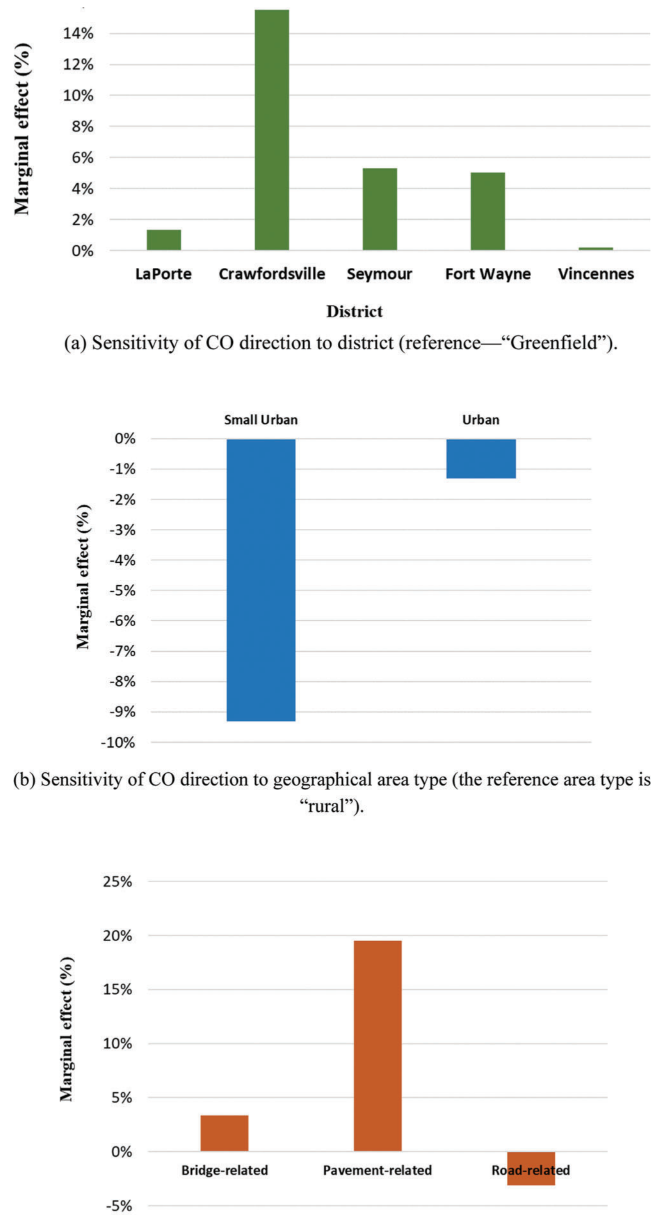



**Figure 5.11** Probability of different negative change order values vs. contract award amount for the Vincennes District, urban area, pavement, and not design-build.

categories were used, and an MNL was developed. The results are summarized in Table C.7 in Appendix C.

### *5.3.2 Sensitivity of CO Severity to the Influential Factors*

In this subsection, the result of the sensitivity analysis for the COS models are presented. There are three sensitivity analyses: (a) sensitivity analysis on whether a CO is positive or negative; (b) sensitivity analysis on positive CO values; and (c) sensitivity analysis on negative CO values. The sensitivities are done via calculating marginal effects and elasticities (when possible). The definition of marginal effects has been discussed before. In general, elasticity means how many percentages the dependent variable will change by 1% change in the independent variable. In the context of logit models, elasticity means how many percentages the probability of the dependent variable will change by a 1% change in the value of the independent variable. Obviously, the interpretation of the elasticity is more straight forward when we have continuous variables. Both marginal effects for the nominal variables and the elasticity values for the continuous independent variable are reported here. As an example, the results of marginal effect analysis for positive or negative CO are shown in Figure 5.12. In Table C.8, the marginal effect of -0.19356 for the design-build variable can be interpreted as a 0.19356 decrease in the probability that a negative CO occurs compared to traditionally delivered contracts. Note that this interpretation is statistically significant at 99% level of confidence. In Table C.8, when the dependent variable is [750, max $K], the elasticity is 1.1833 with respect to the award amount. This means that if a contract award amount increases by 1% (i.e., $10,000), high change order amounts (≥$750K) be 11.83% more likely to occur compared to low change order amount (<$750K). As Table C.8 suggests, neither the marginal effects nor the elasticities are statistically significant. This can be attributed to the small sample size of the dataset for contracts with negative-value change orders.




(a) Sensitivity of CO direction to district (reference—"Greenfield").



(b) Sensitivity of CO direction to geographical area type (the reference area type is "rural").



(c) Sensitivity of CO direction to project type (the reference project type is "demolition, maintenance, and traffic-related projects").

**Figure 5.12** Sensitivity of CO direction (positive vs. negative) to several factors.

### *5.3.3 Predicting the Category of Change Order Frequency*

The models developed in this subsection can be used to determine the likelihood that a contract will face 0–10 change orders or more than 10 change orders. A binary logit model is used. Table C.9 presents the results. The reference level for the dependent variable is that a contract experiences less than 10 change orders. Figure 5.13 and Figure 5.14 show changes in likelihood of each level of change order over different contract awards. Overall, increasing the contract award increases the probability of more than 10 change orders

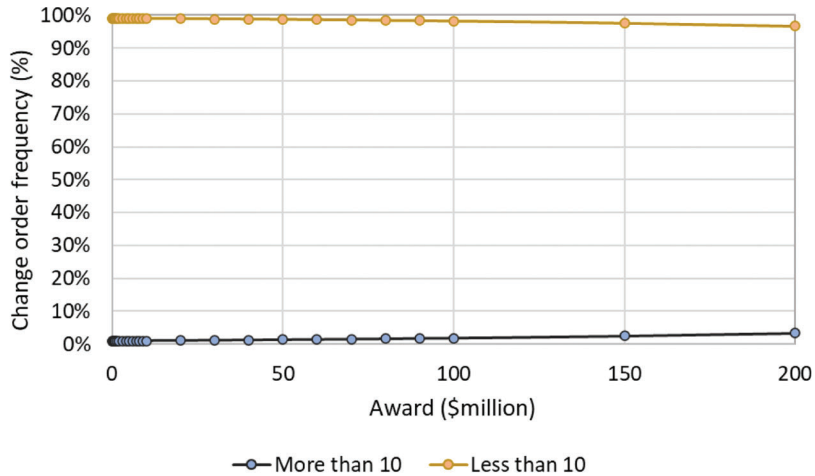



**Figure 5.13** Change order frequency vs. contract award amount for the Vincennes District, small urban area, pavement, and not design-build.

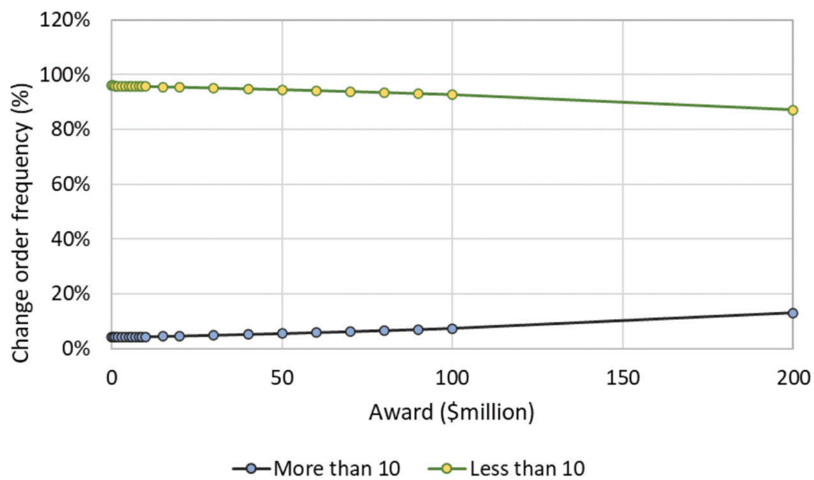


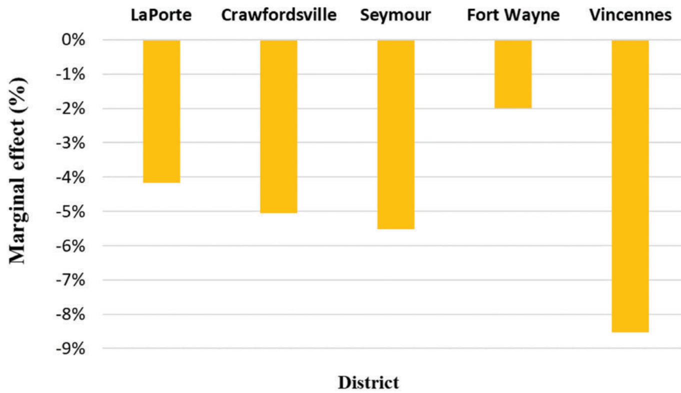

**Figure 5.14** Change order frequency vs. contract award amount for the Crawfordsville District, small urban area, road project, and not design-build.

in a project. In contrast, the probability of less than 10 change orders decreases. Table C.10 presents the marginal effects of COF model. According to the data in Table C.12, all INDOT districts have a lower likelihood of high COF compared to Greenfield. Also, the likelihood of COF increases with an increase in contract award amount. Figure 5.15 shows the results of marginal effects of different factors on the CO frequency.

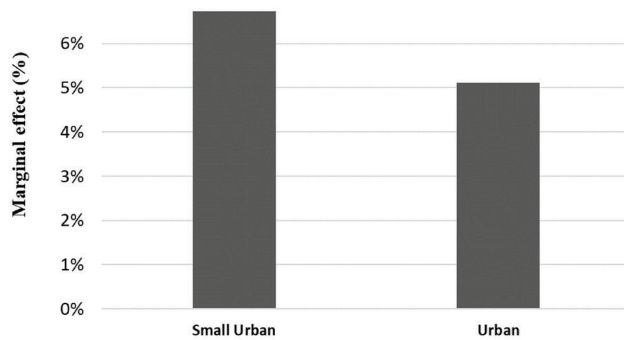
### *5.3.4 Predicting the CO Severity (Regression Models)*

This section presents three linear regression models for COS. The first model was developed using contract data with positive-value and negative-value change orders. The second model was created only for positive-value change orders. The third model was developed only for negative-value change orders. In Table C.11, Table C.12, and Table C.13, standardized coefficients are the regression coefficients assuming all the independent variables converted to z-scores before running the model. Therefore, one can simply compare the absolute value of standardized coefficients to measure the relative contribution of each independent variable on the dependent variable.

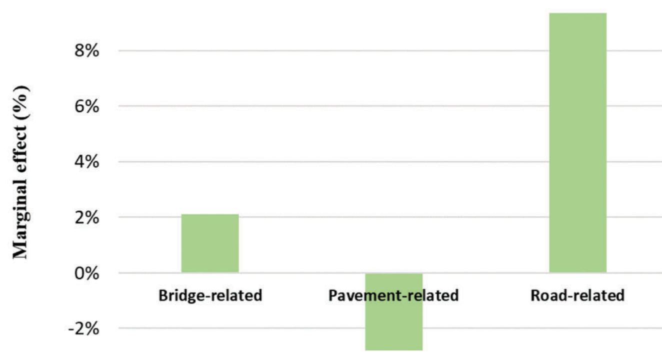
Based on the results in Table C.11, Table C.12, and Table C.13, it can be observed the two most important independent variables for COS are: Whether the contract is design-build or otherwise, and the contract award amount. The findings in Table C.11, Table C.12, and Table C.13 are compatible with the results of logit model presented earlier in this chapter. Figures 5.16, 5.17, 5.18 show cost overrun severity over different contract award amount for positive-and-negative change order model, only positive change order, and only negative change order, respectively. Generally, the higher the contract award, the higher the CO severity.




(a) Effect of district (Greenfield is considered the reference).




(b) Effect of area (rural area is considered the reference).




(c) Effect of project type (reference is demolition, maintenance, and traffic-related projects.

**Figure 5.15** Sensitivity of frequency of CO to different factors.

## 5.4 Modeling Schedule Delay Caused by Change Orders

Here the schedule delay (SD) of the contracts caused by COs are investigated using logit and linear regression models.

### *5.4.1 Logit Model*

- *Schedule Delay Occurring Likelihood*
  The result of the constructed binary logit model for predicting the likelihood whether an SD will happen or not, has been brought in Table C.14. According to the data in Table C.14, the likelihood of SD occurring increases with an increase in the contract award amount. Figure 5.17 shows the changes in schedule delay occurring likelihood over different contract award amounts, as an example. Increasing the contract award increases the likelihood schedule delay occurrence.

- *MNL Model for Positive Schedule Delay*
  The levels considered for the dependent variable (i.e., SD) are 1–90 days, 9–180 days, and more than 180 days. The results are summarized in Table C.15. The interpretation of the results is similar to that of the previous model. It was not possible to create binary logit model to predict the likelihood whether an SD is positive or negative, probably due to the small sample size of

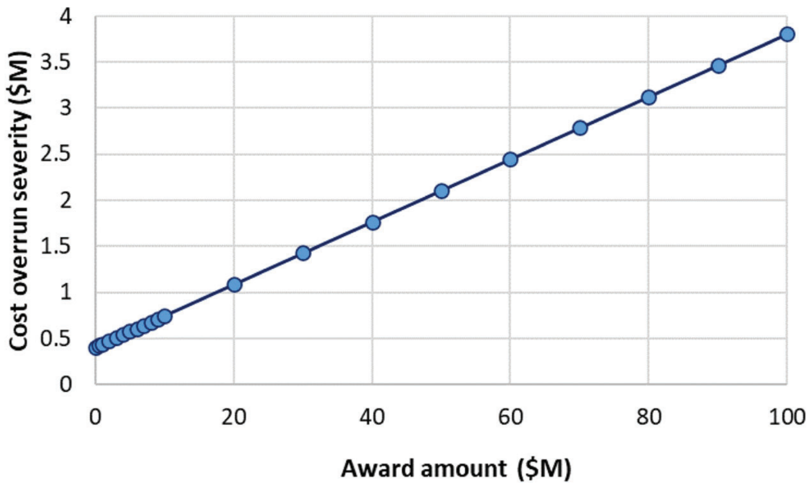



**Figure 5.16** CO severity ($M) vs. award amount ($M) for the Vincennes District, urban area, pavement project, and non-design-build.

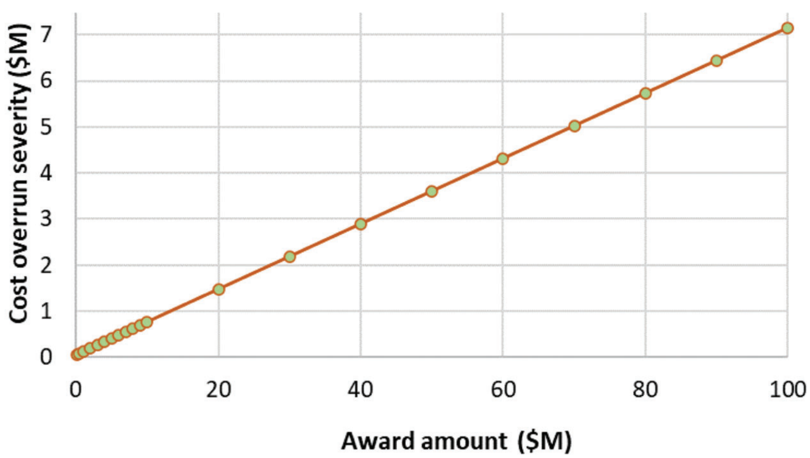



**Figure 5.17** Positive CO severity ($M) vs. award amount ($M) for the Vincennes District, urban area, pavement project, and non-design-build.

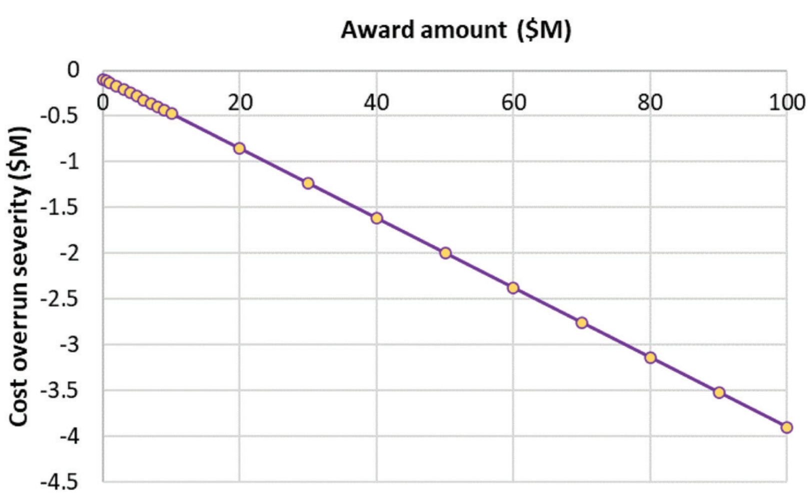



**Figure 5.18** Negative CO severity ($M) vs. award amount ($M) for the Vincennes District, urban area, pavement project, and non-design-build.

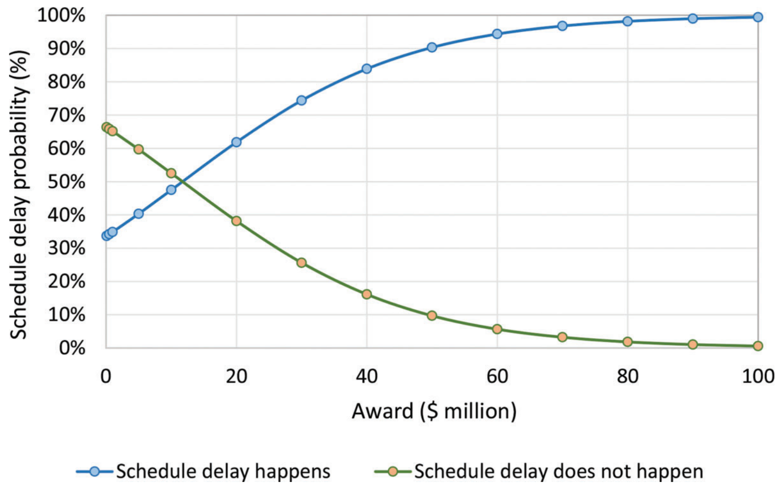



**Figure 5.19** Schedule delay occurring likelihood vs. contract award amount for the Vincennes District, urban area, pavement, and not design-build.

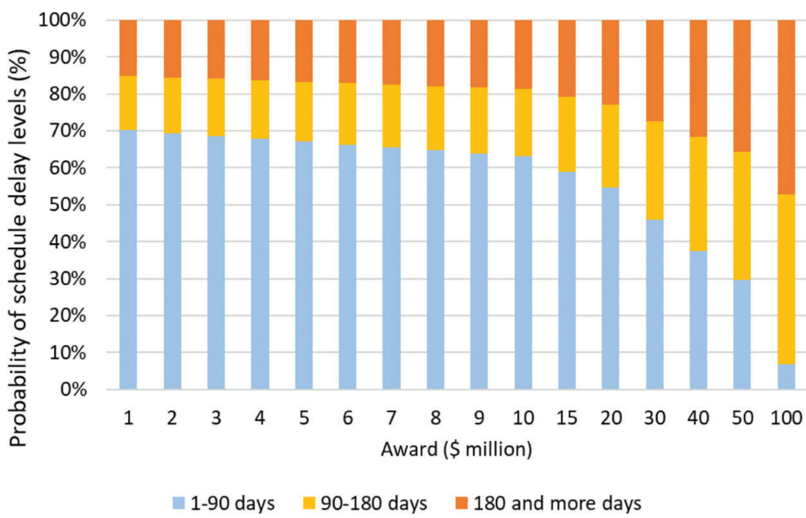



**Figure 5.20** Probability of schedule delay severity levels vs. contract award amount for the Vincennes District, urban area, pavement, and not design-build.

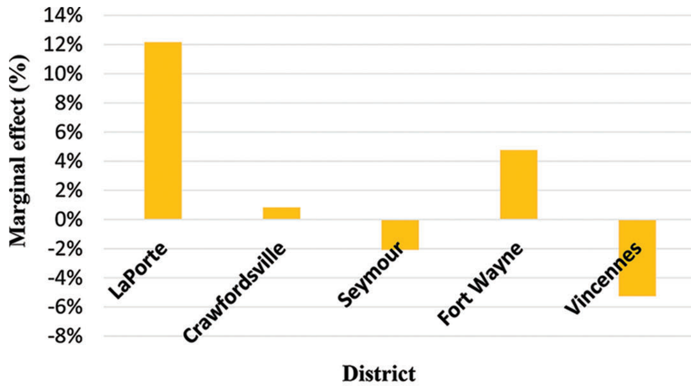
contracts with negative SDs. Figure 5.19 shows the probabilities of different levels of schedule delays over different contract award amounts, in a hypothetical project. In projects with higher contract awards, 90–180 days and more than 180 days delay are more probable (Figure 5.20).

### *5.4.2 Sensitivity of SD to the Influential Factors*

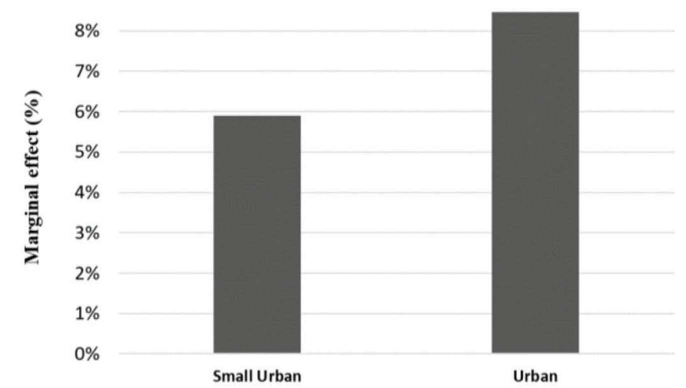
The results of sensitivity analysis via calculating marginal effects and elasticities for SD occurring and positive SD models are reported in Table C.16 and Table C.17, respectively. From the results, it can be observed that contracts with bridge- and pavement-dominant projects are less prone to face SD compared to contracts dominated by demolition, maintenance, and traffic-related project types. Referring to the data in Table C.16 and Table C.17, with a 1% increase in a contract award amount (i.e., $10,000), the probability that SD is between 1 to 90 days decreases (i.e., -0.00813) while the probability for SD to be between 90 to 180 days and more than 180 days increases, respectively (i.e., 0.00251 and 0.00563). These findings are statistically significant at 99% level of confidence. Figure 5.21 shows the results of sensitivity of schedule delay to different factors.

### *5.4.3 Regression Models for Schedule Delay*

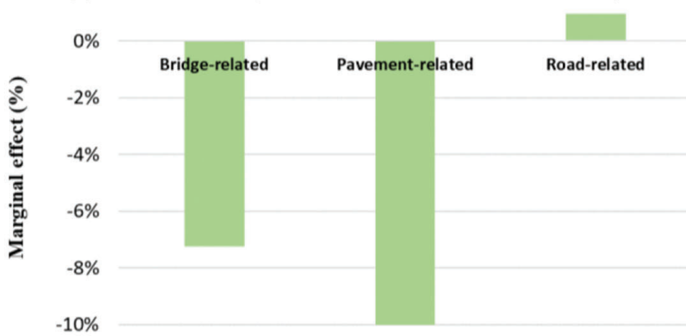
To predict positive SD in number of days, a regression model was developed. The results are summarized in Table C.18. Based on the results, the three most influential variables in predicting a contract SD are: geographical area, dominant project type, and contract award amount. In Figure 5.22, the schedule




(a) Effects of district (Greenfield is considered the reference).




(b) Effects of area (rural area is considered the reference).




(c) Effects of project type (reference project is demolition, maintenance, and traffic-related).

**Figure 5.21** Sensitivity of schedule delay to different factors.

delay over different contract award is shown under a hypothetical sample.

## 5.5 The Developed Models

The developed models are presented below. Please refer to Appendix C for the model details.

### Model for the Change Order Occurrence Likelihood (Table C.1)

The developed model for the probability that a change order occurs can be re-stated here as a horizontal string as follows.

$$CO\ Probability = 1/(1+exp(-f(x)))$$

Where: $f(x) = 0.79268 - 0.00553 \times LP - 0.05211 \times CV - 0.52208 \times SM - 0.26762 \times FW - 0.81635 \times VC + 0.45447 \times SU + 0.26177 \times UR - 0.39544 \times BR - 0.70344 \times PR - 1.15561 \times RR - 1.86902 \times DB + 1.50032 \times CA$

Where:
$CO\ Probability$ = probability that a given contract will incur a change order
$LP$ = Location in LaPorte District
$CV$ = Location in Crawfordsville District

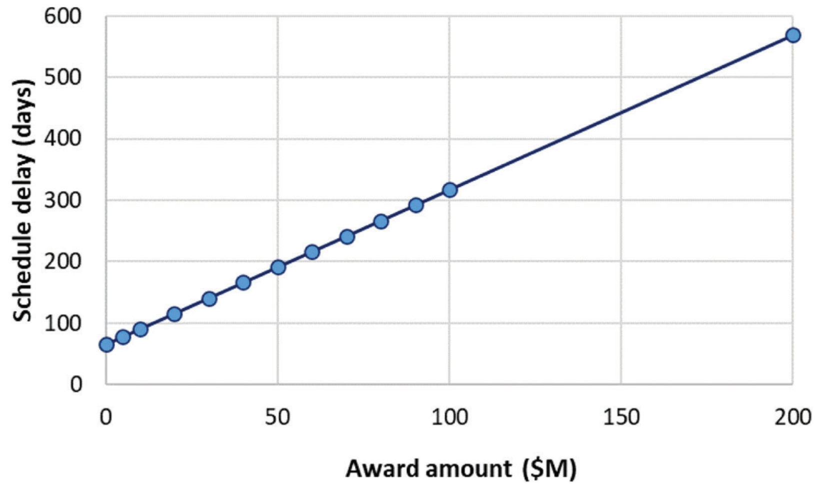



**Figure 5.22** Schedule delay (days) vs. contract award amount ($M) for the Vincennes District, urban area, pavement, and not design-build.

*SM* = Location in Seymour District
*FW* = Location in Fort Wayne District
*VC* = Location in Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
*SU* = Small urban area
*UR* = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
*BR* = Dominant project is a bridge work type
*PR* = Dominant project is a pavement work type
*RR* = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
*DB* = Design-build project (use 0 if the contract is not a design-build project)
*CA* = Contract award amount ($M)

**Model for Assessing the Sensitivity of CO Likelihood to the Influential Factors (Table C.2)**

Table C.2 assesses the marginal effects of the variables, and the sensitivity of change order propensity to the influential factors. If the contract award amount increases by $1M, there is a 0.19246 increase in the probability that a change order will occur.

**Model for Predicting the CO Magnitude: Positive- or Negative-Value Change Order (Table C.3)**

The developed model for the probability that a contract will face a positive change order can be re-stated here as a horizontal string as follows.

$Probability = 1/(1+exp(-f(x)))$

Where: $f(x) = -1.04794 + 0.0624 \times LP + 0.68784 \times CV + 0.24561 \times SM + 0.23279 \times FW + 0.00918 \times VC - 0.47510 \times SU - 0.06199 \times UR + 0.15762 \times BR + 0.84941 \times PR - 0.14972 \times RR - 1.18073 \times DB + 0.00629 \times CA$

Where:
*Probability* = probability that a given contract will incur a positive change order
*LP* = Location is LaPorte District
*CV* = Location is Crawfordsville District
*SM* = Location is Seymour District
*FW* = Location is Fort Wayne District
*VC* = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
*SU* = Small urban area
*UR* = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
*BR* = Dominant project is a bridge work type
*PR* = Dominant project is a pavement work type
*RR* = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
*DB* = Design-build project (use 0 if the contract is not a design-build project)
*CA* = Contract award amount ($M)

**Model for Predicting the Probability of a Positive-Value Change Order Table C.4**

The developed model for the probability that a change order will have a positive value can be re-stated here as a horizontal string.

$$(Probability)_1 = \frac{e^{f(x_1)}}{1 + e^{f(x_1)} + e^{f(x_2)}}$$

$$(Probability)_2 = \frac{e^{f(x_2)}}{1 + e^{f(x_1)} + e^{f(x_2)}}$$

Where: $f(x_1) = -1.02437 - 0.08168 \times LP - 0.23035 \times CV - 0.36562 \times SM - 0.29326 \times FW - 0.13275 \times VC - 0.21983 \times SU - 0.15145 \times UR -$

$0.54465 \times BR - 0.20176 \times PR + 0.10685 \times RR - 1.66571 \times DB + 0.75204 \times CA$

$f(x_2) = -3.40787 - 0.02589 \times LP - 0.54977 \times CV - 0.99733 \times SM - 0.72402 \times FW - 0.48215 \times VC - 3.21151 \times SU - 0.61037 \times UR - 0.69785 \times BR + 0.01004 \times PR - 0.23006 \times RR - 0.8691 \times DB + 0.9607 \times CA$

Where:
$(Probability)_1$ = probability that a given contract will incur a positive change order between \$50K–\$750K
$(Probability)_2$ = probability that a given contract will incur a positive change order greater than \$750K
$LP$ = Location in LaPorte District
$CV$ = Location in Crawfordsville District
$SM$ = Location in Seymour District
$FW$ = Location in Fort Wayne District
$VC$ = Location in Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount (\$M)

### Model for Predicting the Magnitude of a Negative-value Change Order (Table C.5)

The developed model for the probability that a change order will have a negative value can be re-stated here as a horizontal string as follows.

$$(CO\ Probability)_1 = \frac{e^{f(x_1)}}{1 + e^{f(x_1)} + e^{f(x_2)}}$$

$$(CO\ Probability)_2 = \frac{e^{f(x_2)}}{1 + e^{f(x_1)} + e^{f(x_2)}}$$

Where: $f(x_1) = -1.39459 + 0.10794 \times LP + 0.34812 \times CV + 0.24942 \times SM - 0.03671 \times FW - 0.14982 \times VC + 0.01765 \times SU + 0.1059 \times UR + 0.11526 \times BR + 0.67463 \times PR - 0.01983 \times RR + 1.2023 \times DB + 0.59936 \times CA$

$f(x_2) = -5.80640 + 0.29045 \times LP + 0.17904 \times CV - 0.69374 \times SM + 0.19377 \times FW - 0.23207 \times VC + 0.35045 \times UR - 0.08918 \times BR + 0.66846 \times PR - 2.99997 \times RR - 10.8252 \times DB + 0.90602 \times CA$

Where:
$(CO\ Probability)_1$ = probability that a given contract will incur a negative change order between \$50K–\$750K
$(CO\ Probability)_2$ = probability that a given contract will incur a negative change order greater than \$750K
$LP$ = Location in LaPorte District
$CV$ = Location in Crawfordsville District
$SM$ = Location in Seymour District
$FW$ = Location in Fort Wayne District
$VC$ = Location in Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount (\$M)

### Model for Predicting the Change Order Frequency (Table C.9)

The developed model for the probability that a contract will face more than 10 change orders can be re-stated here as a horizontal string.

$Probability = 1/(1+exp(-f(x)))$

Where: $f(x) = -3.33219 - 0.63688 \times LP - 0.80759 \times CV - 0.88228 \times SM - 0.28782 \times FW - 1.65248 \times VC + 0.78198 \times SU + 0.67874 \times UR + 0.28068 \times BR - 0.41511 \times PR + 1.04015 \times RR - 1.11928 \times DB + 0.53287 \times CA$

Where:
$Probability$ = Likelihood of contracts facing more than 10 change orders
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type

(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
*DB* = Design-build project (use 0 if the contract is not a design-build project)
*CA* = Contract award amount ($M)

**Model for Predicting the Change Order Frequency with Marginal Effects (Table C.10)**

$Probability = 1/(1+exp(-f(x)))$

Where: $f(x) = -0.04162 \times LP - 0.05063 \times CV - 0.05511 \times SM - 0.01995 \times FW - 0.08537 \times VC + 0.06735 \times SU + 0.05114 \times UR + 0.02116 \times BR - 0.02801 \times PR + 0.09357 \times RR - 0.06064 \times DB + 0.03865 \times CA$

Where:
*Probability* = Likelihood of contracts facing at least 10 change orders
*LP* = Location is LaPorte District
*CV* = Location is Crawfordsville District
*SM* = Location is Seymour District
*FW* = Location is Fort Wayne District
*VC* = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
*SU* = Small urban area
*UR* = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
*BR* = Dominant project is a bridge work type
*PR* = Dominant project is a pavement work type
*RR* = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
*DB* = Design-build project (use 0 if the contract is not a design-build project)
*CA* = Contract award amount ($M)

**Model for Predicting the CO Magnitude ($M) Using Linear Regression (Table C.11)**

$CO\ Severity = 0.497 - 0.036 \times LP - 0.073 \times CV - 0.033 \times SM - 0.054 \times FW - 0.004 \times VC - 0.028 \times SU - 0.036 \times UR - 0.047 \times BR - 0.05 \times PR + 0.033 \times RR - 0.429 \times DB + 0.034 \times CA$

*The above equation is with consideration only to both positive and negative change orders.*

Where:
*CO Severity* = Severity of change order (considering both positive ang negative change orders)
*LP* = Location is LaPorte District
*CV* = Location is Crawfordsville District
*SM* = Location is Seymour District
*FW* = Location is Fort Wayne District
*VC* = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
*SU* = Small urban area
*UR* = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
*BR* = Dominant project is a bridge work type
*PR* = Dominant project is a pavement work type
*RR* = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
*DB* = Design-build project (use 0 if the contract is not a design-build project)
*CA* = Contract award amount ($M)

**Model for Predicting the CO Magnitude ($M) for Positive-Value COs, Using Linear Regression (Table C.12)**

$CO\ Severity = 0.141 - 0.042 \times LP - 0.071 \times CV - 0.037 \times SM - 0.07 \times FW - 0.063 \times VC - 0.106 \times SU - 0.085 \times UR - 0.074 \times BR + 0.062 \times PR - 0.039 \times RR + 0.317 \times DB + 0.071 \times CA$

The above equation is with consideration only to positive change orders.

Where:
*CO Severity* = Severity of change order
*LP* = Location is LaPorte District
*CV* = Location is Crawfordsville District
*SM* = Location is Seymour District
*FW* = Location is Fort Wayne District
*VC* = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
*SU* = Small urban area
*UR* = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
*BR* = Dominant project is a bridge work type
*PR* = Dominant project is a pavement work type
*RR* = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
*DB* = Design-build project (use 0 if the contract is not a design-build project)
*CA* = Contract award amount ($M)

**Model for Predicting the CO Magnitude ($M) for Negative-Value COs, Using Linear Regression (Table C.13)**

$CO\ Severity = -0.025 - 0.006 \times LP - 0.02 \times CV + 0.017 \times SM - 0.001 \times FW - 0.002 \times VC + 0.038 \times SU - 0.019 \times UR + 0.004 \times BR - 0.049 \times PR + 0.045 \times RR + 0.529 \times DB - 0.038 \times CA$

The above equation is with consideration only to negative change orders.

Where:
$CO\ Severity$ = Severity of change order
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

**Model for Predicting the SD Occurrence Likelihood Using Binary Logit Model (Table C.14)**

$SD\ Probability = 1/(1+exp(-f(x)))$

Where: $f(x) = -0.38499 + 0.50580 \times LP + 0.03465 \times CV - 0.08791 \times SM + 0.19990 \times FW - 0.22299 \times VC + 0.24733 \times SU + 0.35222 \times UR - .30741 \times BR - 0.42817 \times PR + 0.03987 \times RR - 0.46506 \times DB + 0.05834 \times CA$

Where:
$SD\ Probability$ = Probability that the change order will lead to a schedule delay
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the 5 variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

**Model for Predicting the SD Magnitude Positive-value SD (Table C.15)**

$$(Probability)_1 = \frac{e^{f(x_1)}}{1 + e^{f(x_1)} + e^{f(x_2)}}$$

$$(Probability)_2 = \frac{e^{f(x_2)}}{1 + e^{f(x_1)} + e^{f(x_2)}}$$

$f(x_1) = -1.65288 - 0.28753 \times LP + 0.13514 \times CV + 0.32723 \times SM - 0.21919 \times FW + 0.64052 \times VC + 0.30531 \times SU + 0.17284 \times UR - 0.89206 \times BR - 0.75793 \times PR - 0.2262 \times RR + 0.43977 \times DB + 0.03515 \times CA$

$f(x_2) = -0.13652 - 0.33010 \times LP - 0.41829 \times CV - 0.40973 \times SM - 0.71581 \times FW - 0.2162 \times VC - 0.47172 \times SU - 0.39055 \times UR - 0.78952 \times BR - 0.82233 \times PR - 0.52655 \times RR + 0.88617 \times DB + 0.03507 \times CA$

$(Probability)_1$ = Probability that the change order will lead to a positive schedule delay of 90–180 days
$(Probability)_2$ = Probability that the change order will lead to a positive schedule delay of more than 180 days
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

**Model for the Marginal Effects for Contracts with CO (Table C.16)**

$SD\ Probability = 1/(1+exp(-f(x)))$

*Where* $f(x) = 0.12165 \times LP + 0.00824 \times CV - 0.02085 \times SM + 0.04764 \times FW - 0.05263 \times VC + 0.05903 \times SU + 0.08460 \times UR - 0.07260 \times BR - 0.09999 \times PR + 0.00949 \times RR - 0.1068 \times DB + 0.01386 \times CA$

Where:
$SD\ Probability$ = Probability that schedule delay will occur considering that a change order will happen
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

**Model for Marginal Effects for Contracts with Positive-Value SD (Table C.17)**

$$(Probability)_1 = \frac{e^{f(x_1)}}{1+e^{f(x_1)}+e^{f(x_2)}+e^{f(x_3)}}$$

$$(Probability)_2 = \frac{e^{f(x_2)}}{1+e^{f(x_1)}+e^{f(x_2)}+e^{f(x_3)}}$$

$$(Probability)_3 = \frac{e^{f(x_3)}}{1+e^{f(x_1)}+e^{f(x_2)}+e^{f(x_3)}}$$

$$f(x_1) = 0.07347 \times LP + 0.05751 \times CV + 0.04244 \times SM + 0.13051 \times FW - 0.01094 \times VC + 0.05396 \times SU + 0.05037 \times UR + 0.19029 \times BR + 0.18600 \times PR + 0.10063 \times RR - 0.17357 \times DB - 0.00813 \times CA$$

$$f(x_2) = -0.01928 \times LP + 0.02533 \times CV + 0.0442 \times SM - 0.00154 \times FW + 0.06994 \times VC + 0.04379 \times SU + 0.02829 \times UR - 0.06648 \times BR - 0.05218 \times PR - 0.0076 \times RR + 0.01868 \times DB + 0.00251 \times CA$$

$$f(x_3) = -0.05419 \times LP - 0.08283 \times CV - 0.08666 \times SM - 0.12897 \times FW - 0.059 \times VC - 0.09775 \times SU - 0.07866 \times UR - 0.12381 \times BR - 0.13381 \times PR - 0.09303 \times RR + 0.15489 \times DB + 0.00563 \times CA$$

$(Probability)_1$ = Probability that the CO will lead to a positive schedule delay of 1–90 days based on marginal effects.

$(Probability)_2$ = Probability that the CO will lead to a positive schedule delay of 90–180 days based on marginal effects.

$(Probability)_3$ = Probability that the CO will lead to a positive schedule delay of more than 180 days based on marginal effects.
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

**Model (Linear Regression) for Predicting the Magnitude of Positive-Value SD (days) (Table C.18)**

$$SD = 243.965 - 40.324 \times LP - 35.358 \times CV - 65.049 \times SM - 76.407 \times FW - 18.62 \times VC - 67.89 \times SU - 59.667 \times UR - 96.989 \times BR - 99.909 \times PR - 55.268 \times RR + 43.62 \times DB + 2.514 \times CA$$

The above equation is with consideration only to negative change orders.

Where:
$SD$ = Predicted schedule delay
$LP$ = Location is LaPorte District
$CV$ = Location is Crawfordsville District
$SM$ = Location is Seymour District
$FW$ = Location is Fort Wayne District
$VC$ = Location is Vincennes District
(For contracts located in Greenfield District, use zeros for all the five variables above.)
$SU$ = Small urban area
$UR$ = Urban area
(For contracts located in rural areas, use zeros for all the two variables above.)
$BR$ = Dominant project is a bridge work type
$PR$ = Dominant project is a pavement work type
$RR$ = Dominant project is a road work type
(For contracts that are dominated by demolition, maintenance, and traffic-related projects, use zeros for all the three variables above.)
$DB$ = Design-build project (use 0 if the contract is not a design-build project)
$CA$ = Contract award amount ($M)

TABLE 5.4
**Summary of Results**

| Independent Variables | Conclusions | Notes |
|---|---|---|
| **(a) Dependent Variable: The Propensity of Change Order (CO Occurs or Does Not Occur)** | | |
| District | In Seymour, Fort Wayne, and Vincennes districts, the odds that a contract will experience a CO is generally lower compared to Greenfield District (the district with the least likelihood of CO is Vincennes). | This conclusion is statistically significant at 95% degree of confidence. |
| Geographical Area | The odds that a contract in a small urban or urban area will experience a CO is generally greater compared to a contract in a rural area. | This conclusion is statistically significant at 99% degree of confidence. |
| Project Type | The odds that a bridge, pavement, or road contract, will experience a CO is generally lower compared to demolition, maintenance, or traffic contract (road contracts have the least odds of CO occurrence). | This conclusion is statistically significant at 99% degree of confidence. |
| Design-Build or Not | The odds that a design-build contract will experience a CO is generally lower compared to contracts that are not design-build. | This conclusion is statistically significant at 99% degree of confidence. |
| Contract Award Amount | Contracts with greater award amount are generally more likely to experience COs. | This conclusion is statistically significant at 99% degree of confidence. |
| **(b) Dependent Variable: Direction of the Change Order (Does the Change Order Lead to a Cost Increase (Positive-Value CO) or Cost Reduction (Negative Value CO))** | | |
| District | It is generally more likely that a contract in Seymour, Fort Wayne, and Crawfordsville districts will experience a negative CO compared to a Greenfield contract. | This conclusion is statistically significant at 95% degree of confidence. |
| Geographical Area | The odds of a negative-value CO are generally lower for small urban contracts compared to rural area contracts. | This conclusion is statistically significant at 99% degree of confidence. |
| Project Type | It is more generally likely that pavement contracts will face negative-value COs compared to demolition, maintenance, and traffic-related contracts. | This conclusion is statistically significant at 99% degree of confidence. |
| Design-Build or Not | Design-build contracts generally have lower odds of negative-value COs compared to contracts that are not design-build. | This conclusion is statistically significant at 95% degree of confidence. |
| Contract Award Amount | – | No significant conclusions at 90% confidence. |
| **(c) Dependent Variable: A Positive CO Value is More Likely to Fall in Which Severity Category?** | | |
| District | Contracts in Seymour and Fort Wayne districts that experience positive-value CO, are generally less likely to exceed $50K compared to those in Greenfield district. | This conclusion is statistically significant at 95% degree of confidence. |
| Geographical Area | Contracts in small urban and urban areas that experience positive-value CO, are generally less likely to exceed $750K compared to those in rural areas. | This conclusion is statistically significant at 99% degree of confidence. |
| Project Type | Bridge contracts that experience positive-value CO, are generally less likely to exceed $50K compared to contracts dominated by demolition, maintenance, and traffic contracts. | This conclusion is statistically significant at 95% degree of confidence. |
| Design-Build or Not | A design-build contract is generally less likely to experience CO worth $50K–$750K compared to contracts that are not design-build. | This conclusion is statistically significant at 95% degree of confidence. |
| Contract Award Amount | Generally, the higher the contract award amount, the greater the odds that the CO severity will be over $50K. | This conclusion is statistically significant at 99% degree of confidence. |

*(Continued)*

TABLE 5.4
*(Continued)*

| | | |
|---|---|---|
| **(d) Dependent Variable: Magnitude of a Negative-Value CO** | | |
| District | Contracts in Crawfordsville District that have negative-value CO are generally more likely to be of very large value (i.e., -\$50K to \$750K) compared to their counterparts in Greenfield District. | This conclusion is statistically significant at 90% degree of confidence. |
| Geographical Area | – | No significant conclusions at 90% confidence. |
| Project Type | Pavement contracts that have negative-value CO are generally more likely to be of very large value (i.e., -50K to -\$750K) compared to demolition, maintenance, and traffic contracts. Road contracts that have negative-value CO are generally more likely to extremely have value (i.e., over \$750K) compared to demolition, maintenance, and traffic-related contracts. | This conclusion is statistically significant at 99% degree of confidence. |
| Design-Build or Otherwise | – | No statistically significant conclusions with degree of confidence above 90% can be drawn. |
| Contract Award Amount | For contracts that experience negative-value CO, generally, the greater the contract award amount, the greater the odds that its CO magnitude will exceed \$50K. | This conclusion is statistically significant at 99% degree of confidence. |
| **(e) Dependent Variable: Likelihood That a Contract Experiences Few (<10 COs) or Several (≥10 COs)** | | |
| District | Contracts in LaPorte, Crawfordsville, Seymour, or Vincennes generally have a lower likelihood of several COs compared to Greenfield. Vincennes contracts have the least odds. | This conclusion is statistically significant at 99% degree of confidence. |
| Geographical Area | Contracts in small urban and urban areas are generally more likely to have several COs compared to their rural counterparts. | This conclusion is statistically significant at 99% degree of confidence. |
| Project Type | Pavement contracts are generally less likely to have several COs compared to demolition, maintenance, or traffic contracts. Road and bridge contracts are more likely to have several compared to demolition, maintenance, and traffic contracts. | The drawn conclusion for pavement-related contracts is statistically significant at 95% C.I; the degree of confidence for bridge-related and Road-related contracts are 90% and 99%, respectively. |
| Design-Build or Not | – | No statistically significant conclusions with degree of confidence above 90% can be drawn. |
| Contract Award Amount | Generally, the higher the contract award amount, the greater the odds that contract will experience several COs. | This conclusion is statistically significant at 99% degree of confidence. |
| **(f) Dependent Variable: What is the Propensity of a Contract to Experience SD?** | | |
| District | Generally, contracts in LaPorte and Fort Wayne have a greater chance of encountering SD compared to their counterparts in Greenfield (in Vincennes, such probability is lower compared to Greenfield. | This conclusion is statistically significant at 90% degree of confidence. |
| Geographical Area | Small urban and urban contracts are generally more likely to encounter SD compared to their rural counterparts. | This conclusion is statistically significant at 95% degree of confidence. |
| Project Type | Pavement and bridge contracts are generally less likely to encounter SD compared to demolition, maintenance, and traffic contracts. | This conclusion is statistically significant at 99% degree of confidence. |
| Design-Build or Not | – | No significant conclusions at 90% confidence. |
| Contract Award Amount | Generally, the greater the contract award amount, the greater the likelihood that the contract will encounter SD. | This conclusion is statistically significant at 99% degree of confidence. |

*(Continued)*

TABLE 5.4
*(Continued)*

| | (g) Dependent Variable: The Probability that a Contract Encounters Light (0–90 Days), Moderate (90–180 days) or Severe (>180 days) SD | |
|---|---|---|
| District | Contracts in Vincennes District are generally more likely to encounter moderate SD compared to Greenfield contracts. | This conclusion is statistically significant at 95% degree of confidence. |
| | LaPorte, Crawfordsville, Seymour, and Fort Wayne contracts are generally less likely to have severe SD compared to Greenfield District. | |
| Geographical Area | Small urban and urban contracts are generally less likely to encounter severe SD compared to rural contracts. | This conclusion is statistically significant at 99% degree of confidence. |
| Project Type | Pavement, bridge, and road contracts are generally less likely to encounter severe SD compared to demolition, maintenance, and traffic contracts. | This conclusion is statistically significant at 99% degree of confidence. |
| Design-Build or Not | – | No statistically significant conclusions with degree of confidence above 90% can be drawn. |
| Contract Award Amount | Generally, the higher the contract award amount, the greater the odds of the contract will have moderate or severe SD. | This conclusion is statistically significant at 99% degree of confidence. |

## 5.6 Chapter Summary

This chapter developed three broad categories of models: (a) CO propensity, direction, and magnitude, (b) CO frequency or count, and (c) contract schedule delay (SD) (Table 5.4).

*Discussion*

- Regarding CO severity, logit and linear regression models were developed. The results suggest that the contract type (design-build or otherwise) and contract award amount are the two most influential variables of CO propensity and monetary value.
- Regarding CO frequency, the results of logit model revealed that district, geographical area, and contract class are the three most influential variables.
- Regarding SD, the results of logit and linear regression models suggest that the geographical area, contract class and contract awards amount are the three most influential variables.
- It was not possible to create models for negative SD probably because the sample size of negative contract SD is small.

# CHAPTER 6. RECOMMENDATIONS AND GUIDELINES TO REDUCE THE INCIDENCE AND MAGNITUDE OF CHANGE ORDERS

## 6.1 Summary of Causes of Change Orders

Drawing from a comprehensive analysis of historical data concerning change orders analyzed in this paper, it becomes evident that certain key factors consistently contribute to the incidence of change orders. These factors primarily include changed conditions (ranging from constructability and construction-related challenges to soil and environmental factors), design-related errors and omissions, alterations in project scope (encompassing changes in quantities and items, as well as central office-initiated modifications), and final quantity adjustments. The summary of root causes is presented in Table 6.1. The table is referenced from various statistics provided in Chapter 3 on descriptive statistics. From the table, it is evident that more than 90% of CO's are caused due to the mentioned six sub-factors. The right actions taken against these items could yield positive results in reducing the number of change orders, schedule delays and cost overrun.

In this chapter, we explore these factors, offering specific recommendations tailored to mitigate the associated risks and enhance project management practices. By addressing these critical areas proactively, we hope that project stakeholders can significantly reduce the likelihood of occurrence of change orders thereby reducing cost overruns, schedule delays, and disputes, ultimately fostering more successful and efficient project outcomes. The measures mentioned in this section are referenced to Section 3.5 of this report on remedies for change orders.

TABLE 6.1
**Summary of the Top Root Causes of Change Orders**

| Critical Reasons | Cost Overrun Amount ($M) | Cost Overrun (as % of total) | No. of CO's | Rate of CO's (as % of total) |
|---|---|---|---|---|
| *Changed Conditions* | *265.88* | *42* | *9,544* | *42* |
| Constructability Related | 117.46 | 19 | 5,463 | 24 |
| Soils | 39.07 | 6 | 677 | 3 |
| Environmental | 25.36 | 4 | 469 | 2 |
| *Errors and Omissions* | *138.98* | *22* | *6,507* | *29* |
| Design Related | 75.49 | 12 | 3,410 | 15 |
| *Scope* | *109.36* | *17* | *2,371* | *10* |
| Quantities and Items | 59.94 | 9 | 739 | 3 |
| *Final Quantity Adjustments* | *-192.99* | | *2,268* | *10* |
| Total (above categories) | 514.22 + (-192.99) | 81 | 20,690 | 91 |
| Grand Total (including all categories) | 631.24 + (-192.99) | – | 22,681 | – |

## 6.2 Recommendations and Proposed Actions

The proposed actions are classified into four categories: changed condition, errors and omissions, scope, and final quantity adjustments. This section outlines the actions that should be undertaken by consultants, owners, and contractors. The suggestions below outline the suggested remedial actions within the category of "Changed Conditions," specifically addressing concerns related to constructability, soils, and environmental factors.

### *6.2.1 Constructability-Related*

*Consultant Actions*

- Place strong emphasis on creating clear and comprehensive plans and designs.
- Conduct detailed constructability reviews before the tender process.
- Ensure that project specifications align with design requirements.

*Owner Actions*

- Utilize computer-based project management software and Building Information Modeling (BIM) models to identify and resolve constructability clashes.
- Maintain a well-organized log of past change orders, allowing for pre-checking potential causes for each new project/bid.
- Create a checklist for contract conditions and project specifications.

*Contractor Actions*

- Ensure that work breakdown structures are prepared to identify clashes and prevent issues related to constructability.

### *6.2.2 Soils and Environmental*

*Consultant Actions*

- Conduct thorough site investigations to minimize unexpected conditions.

*Owner Actions*

- Consider alternative contract methods such as design-build and integrated project delivery to involve the contractor in the design phase, reducing the likelihood of soil and environmental surprises during construction.

### *6.2.3 Errors and Omissions*

The suggestions below outline the suggested remedial actions within the category of "Errors and Omissions," specifically addressing the concerns related to design related factors.

*Consultant Actions*

- Exercise caution regarding potential contract omissions and item overruns.
- Ensure coordination with owners for project specifications.

*Owner Actions*

- Mandate professional licensing for design engineers.
- Consider alternative contract methods like DB, lump sum contracts, etc.

### *6.2.4 Scope and Final Quantity Adjustments*

The suggestions below outline the suggested remedial actions within the category of "scope and final quantity adjustments," specifically addressing the concerns related to quantities.

*Consultant Actions*

- Ensure complete detailed engineering is ready prior to bidding.
- Ensure completeness of estimates (quantity and cost) prior to bidding.

*Owner Actions*

- Engage a third-party peer review for design and project estimates.

# CHAPTER 7. CONCLUDING REMARKS

## 7.1 Summary of Findings and Conclusion

The research has highlighted the trends and patterns of change orders associated with INDOT contracts from 2010 to 2020. Furthermore, this research also highlights the cost overruns and schedule delays across INDOT's six administrative districts and across project types.

Based on the review of INDOT's Change Order Policy, the literature review, Chapter 3, indicated that change orders can have consequences beyond the conventional cost and schedule metrics. For example, metrics related to construction productivity, workers' morale, claims and disputes, and work quality. The research team analyzed the data collected from the SPMS system to derive the results and recommendations for this study. A variety of preprocessing steps, as described in Chapter 4, were performed to ensure the relevancy and the reliability of the data. The results reveal that change orders lead to a significant impact on the as-built cost of the project. However, due to data limitations this research could not accurately analyze the impact of change orders on schedule delays.

The study showed that between the years 2010 to 2020, 65% of all the INDOT contracts faced cost overruns due to change orders, and the average cost overrun was about 8.3% of the award amount. Similarly, almost 40% of the contracts face schedule delays. As illustrated in Table 7.1, this is a significant increase from the statistics calculated for 1996–2001. Cost overrun rates in bridge-related projects have almost halved over the past three decades and have remained almost similar for road-related projects. However, maintenance and traffic-related projects that include demolition, resurfacing, roadside work, traffic signals, and safety improvements have faced significant cost overruns. This may not be a major concern since the research team observed that the majority of these change orders are related to contract renewals. This suggests that INDOT renew, and processes annual contracts associated with these projects as change orders instead of processing them as new contracts.

The descriptive statistics also indicated that about 25% of the total contracts have faced at least 6 COs and 4% of the total contracts have faced more than 20 COs. INDOT approved change orders amounting to approxiamtely $415 million over 2010–2020. However, if we exclude the negative change orders (i.e., related to final quantity adjustments), the COs amount to approximately $615 million. Figure 7.1 describes the top 10 root causes that form a major chunk of these COs. Constructability and design-related issues have led to over $180 million of change orders. Soils, material, environmental conditions, and quantity-related issues also lead to over $100 million worth of change orders.

The district-wise top reasons and root causes of the change order are provided in Figure 7.2.

The project type-wise top reasons and root causes of the change order are provided in Figure 7.3.

Appendix B provides further details of the performance of each of the six INDOT administrative districts. One of the key observations was that the Vincennes and LaPorte districts faced severe change

TABLE 7.1
**Overview of Overruns and Delays**

| Description | 1996–2001 | 2010–2020 |
|---|---|---|
| Percent of Total Contracts Facing Cost Overruns | 55% | 65% |
| Percent of Total Contracts Facing Schedule Delays | 12% | 40.4% |
| Overall Avg. Cost Overrun | 4.5% | 8.3% |
| Bridge-Related | 8.1% | 3.54% |
| Road-Related | 4.1% | 3.77% |
| Maintenance/Traffic-Related | 6.6% | 14.02% (also includes COs related to contract renewals) |

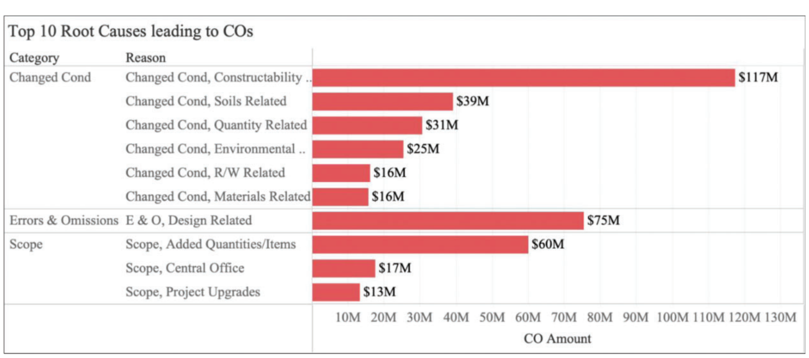



**Figure 7.1** Top ten root causes.

**Greenfield:**
1. Changed Cond, Constructability
2. Changed Cond, Quantities
3. Errors & Omission, Design
4. Changed Cond, Soils
5. Changed Cond, Utilities

**Vincennes:**
1. Changed Cond, Soils
2. Changed Cond, Constructability
3. Changed Cond, Environmental
4. Changed Cond, R/W
5. Errors & Omission, Design

**Seymour:**
1. Changed Cond, Constructability
2. Errors & Omission, Design
3. Emergency Work
4. Changed Cond, Permits
5. Changed Cond, Materials

**LaPorte:**
1. Changed Cond, Constructability
2. Errors & Omission, Design
3. Changed Cond, Soils
4. Changed Cond, Materials
5. MOT Safety Improvements

**Fort Wayne:**
1. Changed Cond, Constructability
2. Errors & Omission, Design
3. Changed Cond, Soils
4. Changed Cond, Materials
5. Errors & Omission, Quantity

**Crawfordsville:**
1. Errors & Omission, Design
2. Changed Cond, Constructability
3. Changed Cond, Soils
4. Changed Cond, Environmental
5. Errors & Omission, Permits

**Figure 7.2** District-wise top five root causes of change orders.

**Road-related:**
1. Changed Cond, Constructability
2. Errors & Omissions, Design
3. Changed Cond, Soils
4. Changed Cond, Environmental
5. Changed Cond, R/W

**Bridge-related:**
1. Changed Cond, Constructability
2. Errors & Omissions,, Design
3. Changed Cond, Soils
4. Emergency Work
5. Changed Cond, Materials

**Pavement-related:**
1. Changed Cond, Quantity
2. Changed Cond, Constructability
3. Errors & Omissions,, Design
4. MOT Safety Improvement
5. Changed Cond, Materials

**Demolition, Maintenance, and Traffic-related:**
(except Contract Renewal)
1. Changed Cond, Constructability
2. Errors & Omissions,, Design
3. Changed Cond, Soils
4. Changed Cond, Utilities
5. Changed Cond, Environmental

**Figure 7.3** Project type-wise top five root causes of change orders.

orders related to soils-related changed conditions compared to other districts. Similarly, LaPorte faced higher design-related issues compared to others. Scope addition related change orders most likely come with a cost and/or schedule increase and therefore, may not be directly termed as "cost overruns and/or time delays," respectively. Based on the literature review, change orders can impair productivity and morale, and could add complexity to site safety management.

From the logit and linear regression models, it was identified that design-build (Y/N) and contract award amount are the two most significant factors that influence the likelihood of change order occurrence and the magnitude of the change order. All other factors remaining the same, design-build projects generally encountered fewer change orders compared to traditional (or, non-design-build) projects when other variables (such as the district, award amount, and type of the project). In predicting the expected count (frequency) of change orders associated with a given contract, the district, project type, and geographical area (urban/rural/semi-urban) were found to be more influential compared to the contract award amount and the design-build (Y/N) status. Furthermore, in predicting schedule delay, geographical area, project type, and award amount were found to be statistically significant.

For the research Objective #2 (i.e., identify contract and project types that are more likely to experience change orders), the authors considered various factors such as the district, award amount, type of the project, type of the contract, and planned duration. However, the authors acknowledge that this is not an exhaustive list to build a robust prediction model. Potentially important factors, such as the level of bid competition, difference between the engineer's estimate and the award amount, contractor/sub-contractor characteristics, robustness of the bid package, also influence the contract outcomes. The authors could not include these factors in the developed models in this study, due to lack of such data. Sections 4.1.2 and 5.2 provide details and the full list of available/implemented variables in the present study.

## 7.2 Scope for Future Work

The current study had certain limitations considering the depth of data available and the absence of a detailed survey involving project stakeholders. Future research may consider the following directions.

- Comprehensive data—More parameters of the data could be retrieved from each change order to analyze the root causes of the change orders. The classification of the change order causes may be revisited.
- Future work could use different mathematical specifications for some of the models. For example, for binary outcomes, binary probit could be used instead of binary logit. In addition, for count data such as the number of

change orders, models like Poisson and negative binomial regression are preferable; alternatively, the number of change orders could be converted into a rate and then used as a continuous variable.

- The full impact of change orders on schedule delays needs to be analyzed and the current data provides only a limited information of the schedule delay due to specific change order.
- The geographical variations of change orders and their reasons may be reviewed. Analyzing local factors and regulations might unveil insights applicable to specific regions.
- Analysis may be done based on a wider range of contract types. The current data provided only whether the project was design-build or not.
- A more thorough investigation into the non-monetary impacts of change orders, such as productivity, work quality, and safety, could be explored.
- Refining the regression models by including additional variables (if data becomes available) and validating them against new data could improve their accuracy in predicting change order occurrences and their magnitudes.
- Interviews of all stakeholders—consultants, contractors, field supervision engineers and INDOT team could throw more light on the issue of change orders.
- The recommendations and corrections required in the existing INDOT change order manual could be performed.

By addressing these limitations and focusing on these areas for future research, a more comprehensive understanding of change orders and their effects on the projects can be achieved.

## REFERENCES


Ahmed, M. O., Assaad, R. H., El-adaway, I. H., Echele, E., Govro, K., & Watson, J. (2022). Administering change orders in highway projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *14*(2). https://doi.org/10.1061/(asce)la.1943-4170.0000528

Al-Dubaisi, A. H. (2000). *Change orders in construction projects in Saudi Arabia* [Doctoral Dissertation, King Fahd University of Petroleum and Minerals].

Al-Kofahi, Z. G., Mahdavian, A., & Oloufa, A. (2022). System dynamics modeling approach to quantify change orders impact on labor productivity 1: principles and model development comparative study. *International Journal of Construction Management*, *22*(7), 1355–1366. https://doi.org/10.1080/15623599.2020.1711494

Alleman, D., Antoine, A. L., Stanford, M. S., & Molenaar, K. R. (2020). Project delivery methods' change order types and magnitudes experienced in highway construction. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *12*(2), 04520006. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000661

Alnuaimi, A. S., Taha, R. A., Al Mohsin, M., & Al-Harthi, A. S. (2010). Causes, effects, benefits, and remedies of change orders on public construction projects in Oman. *Journal of Construction Engineering and Management*, *136*(5), 615–622. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000154

Alshdiefat, A., & Aziz, Z. (2018). Causes of change orders in the Jordanian construction industry. *Journal of Building Construction and Planning Research*, *06*(04), 234–250. https://doi.org/10.4236/jbcpr.2018.64016

Anastasopoulos, P. C., Labi, S., Bhargava, A., Bordat, C., & Mannering, F. L. (2010). Frequency of change orders in highway construction using alternate count-data modeling methods. *Journal of Construction Engineering and Management*, *136*(8), 886–893. https://doi.org/10.1061/ASCECO.1943-7862.0000198

Assaad, R. H., Ahmed, M. O., El-Adaway, I. H., & Shrestha, P. P. (2022). Management of change orders in infrastructure transportation projects. *Practice Periodical on Structural Design and Construction*, *27*(1), 05021006. https://doi.org/10.1061/(asce)sc.1943-5576.0000640

Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management*, *24*(4), 349–357. https://doi.org/10.1016/j.ijproman.2005.11.010

Bordat, C., McCullouch, B. G., Labi, S., & Sinha, K. C. (2004) *An analysis of cost overruns and time delays of INDOT* projects (Joint Transportation Research Program Publication FHWA/IN/JTRP-2004/07). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284313134

Catalão, F. P., Cruz, C. O., & Sarmento, J. M. (2019). The determinants of cost deviations and overruns in transport projects, an endogenous models approach. *Transport Policy*, *74*(1), 224–238. https://doi.org/10.1016/j.tranpol.2018.12.008

Chen, M. T. (1992). Change control and tracking (Symposium U.2). *Transactions of the American Association of Cost Engineers*, *2*, 10.

Choi, K., Yin, Y., Goehl, D., & Jeong, H. D. (2021). Alternative contracting methods: Modeling and assessing the effects of contract type on time-cost-change performance. *Journal of Management in Engineering*, *37*(1). https://doi.org/10.1061/(asce)me.1943-5479.0000863

Duvvuru Mohan, V. K., Prezzi, M., & McCullouch, B. (2011). *Analysis of change orders in geotechnical engineering work at INDOT* (Joint Transportation Research Program Publication FHWA/IN/JTRP-2011/10). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284314623

Fisk, E. R., & Reynolds, W. D. (1997). *Construction project administration*. Wiley.

Gkritza, K., & Labi, S. (2008). Estimating cost discrepancies in highway contracts: Multistep econometric approach. *Journal of Construction Engineering and Management*, *134*(12), 953–962.

Goodrum, P., Taylor, T. R. B., Lester, W., McCoy, A., Uddin, M. M., & Shan, Y. (2010). *Change orders and lessons learned* (Report No. KTC-10-18/SPR 384-09-1F). University of Kentucky Transportation Center. https://uknowledge.uky.edu/ktc_researchreports/33

Halwatura, R. U., & Ranasinghe, N. P. N. P. (2013). *Causes of variation orders in road construction projects in Sri Lanka*. International Scholarly Research Notices. https://doi.org/10.1155/2013/381670

Hanna, A. S., & Iskandar, K. A. (2017). Quantifying and modeling the cumulative impact of change orders. *Journal of Construction Engineering and Management*, *143*(10). https://doi.org/10.1061/(asce)co.1943-7862.0001385

Hanna, A. S., Camlic, R., Pehr, P. A., & Nordheim, E. V. (2002). Quantitative definition of projects impacted by change orders. *Journal of Construction Engineering and Management*, *128*(1). https://doi.org/10.1061/ASCE0733-93642002128:157

Hansen, S., Rostiyanti, S. F., & Rif'at, A. (2020). Causes, effects, and mitigations framework of contract change orders: Lessons learned from GBK aquatic stadium project. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *12*(1). https://doi.org/10.1061/(asce)la.1943-4170.0000341

Hsieh, T. Y., Lu, S. T., & Wu, C. H. (2004). Statistical analysis of causes for change orders in metropolitan public works. *International Journal of Project Management*, *22*(8), 679–686. https://doi.org/10.1016/j.ijproman.2004.03.005

Ibbs, W. (2012). Construction change: Likelihood, severity, and impact on productivity. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *4*(3), 67–73. https://doi.org/10.1061/(asce)la.1943-4170.0000089

INDOT. (2014, April). *Change orders on construction contracts policy*. Indiana Department of Transportation. https://www.in.gov/indot/files/10-_Change_Order_Policy.pdf

Keane, P., Sertyesilisik, B., & Ross, A. D. (2010). Variations and change orders on construction projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *2*(2), 89–96.

Kermanshachi, S., Rouhanizadeh, B., & Govan, P. (2022). Developing management policies and analyzing impact of change orders on labor productivity in construction projects. *Journal of Engineering, Design and Technology*, *20*(5), 1257–1279. https://doi.org/10.1108/JEDT-10-2020-0428

Khalafallah, A., & Shalaby, Y. (2019). Change orders: automating comparative data analysis and controlling impacts in public projects. *Journal of Construction Engineering and Management*, *145*(11). https://doi.org/10.1061/(ASCE)CO.1943

Mahamid, I. (2017). Effect of change orders on rework in highway projects in Palestine. *Journal of Financial Management of Property and Construction*, *22*(1), 62–76. https://doi.org/10.1108/JFMPC-03-2016-0015

Manege, S. L., & Kennedy, C. J. (2022). Adoption of technological cost data management in the Tanzania building construction industry. *Journal of Advanced Management Science*, *10*(4), 88–93.

Moselhi, O., Assem, I., & El-Rayes, K. (2005). Change orders impact on labor productivity. *Journal of Construction Engineering and Management*, *131*(3), 354–359. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:3(354)

Moselhi, O., Leonard, C., & Fazio, P. (1991). Impact of change orders on construction productivity. *Canadian Journal of Civil Engineering*, *18*(3), 484–492.

Naji, K. K., Gunduz, M., & Naser, A. F. (2022). The effect of change order management factors on construction project success: A structural equation modeling approach. *Journal of Construction Engineering and Management*, *148*(9), 04022085. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002350

Padhye, S., & Hastak, M. (2024). A framework to evaluate information and source credibility: International construction decision-making. *Journal of Management in Engineering*, *40*(1), 04023046

Patil, S., Gupta, A., Desa, D., & Sajane, A. (2013). Causes of delay in Indian transportation infrastructure projects. *International Journal of Research in Engineering and Technology*, *2*(11), 71–80.

Ramos-Maldonado, D., González-Quevedo, A. A., & Molina-Bas, O. (2016). Study of change orders in design-build-maintain projects of the XXI Century Schools in Puerto Rico. *Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan* (pp. 579–587).

Randolph, D. A., Rajendra, K., & Campfield, J. J. (1987). Using risk management techniques to control contract costs. *Journal of Management in Engineering*, *3*(4), 314–324.

Sambasivan, M., & Soon, Y. W. (2007). Causes and effects of delays in Malaysian construction industry. *International Journal of Project Management*, *25*(5), 517–526. https://doi.org/10.1016/j.ijproman.2006.11.007

Senouci, A., Alsarraj, A., Gunduz, M., & Eldin, N. (2017). Analysis of change orders in Qatari construction projects. *International Journal of Construction Management*, *17*(4), 280–292. https://doi.org/10.1080/15623599.2016.1211973

Serag, E., & Oloufa, A. (2007, June). *Change orders impact on project cost* [Paper presentation]. In 2007 Annual Conference & Exposition, Trends in Construction Engineering II, ASEE, Honolulu, HI.

Serag, E., Oloufa, A., Malone, L., & Radwan, E. (2010). Model for quantifying the impact of change orders on project cost for U.S. roadwork construction. *Journal of Construction Engineering and Management*, *136*(9), 1015–1027.

Shrestha, B., Shrestha, P. P., Maharjan, R., & Gransberg, D. (2022). Cost, change order, and schedule performance of highway projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *14*(1). https://doi.org/10.1061/(asce)la.1943-4170.0000523

Shrestha, K. K. (2016). *Causes of change orders and its impact on road maintenance* [Doctoral Dissertation, University of Nevada]. Digital Scholarship@UNLV. https://doi.org/10.34917/9112187

Shrestha, P. P., & Maharjan, R. (2018). Effects of change orders on cost growth, schedule growth, and construction intensity of large highway projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *10*(3). https://doi.org/10.1061/(asce)la.1943-4170.0000264

Shrestha, P. P., Shrestha, K. K., & Kandie, T. K. (2017). Effects of change orders on the cost and schedule of rural road maintenance projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *9*(3), 04517010. https://doi.org/10.1061/(ASCE)LA.1943-4170.00002

Shrestha, P. P., Shrestha, K. K., & Zeleke, H. B. (2019). Probability of change orders and the effect on cost and schedule for new public-school buildings. *Engineering, Construction and Architectural Management*, *26*(6), 1087–1104. https://doi.org/10.1108/ECAM-01-2018-0017

Szumilas, M. (2010). Explaining odds ratios. *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, *19*(3), 227.

Tymvios, N., McCullouch, B. G., & Sinha, K. C. (2002). *An initial evaluation of design-build highway projects performed by the Indiana Department of Transportation* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2002/21). West Lafayette, Indiana: Purdue University. https://doi.org/10.5703/1288284313142

Yitmen, I., Sevay, H., Taneri, C., & Yalçıner, H. (2006, June 14–16). *An expert system for quantifying the impact of change orders on project performance* [Conference session]. Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montréal, Canada.

Zaneldin, E. K. (2020). Investigating the types, causes and severity of claims in construction projects in the UAE. *International Journal of Construction Management*, *20*(5), 385–401. https://doi.org/10.1080/15623599.2018.1484863

Zhao, X., Hwang, B. G., & Yu, G. S. (2013). Identifying the critical risks in underground rail international construction joint ventures: Case study of Singapore. *International Journal of Project Management*, *31*(4), 554–566. https://doi.org/10.1016/J.IJPROMAN.2012.10.014

# APPENDICES

**Appendix A. Number of Contracts by Project Class and Work Type**

**Appendix B. Contract Award Amounts and Change Orders by District**

**Appendix C. Detailed Results of the Statistical Modeling**

# APPENDIX A. NUMBER OF CONTRACTS BY PROJECT CLASS AND WORK TYPE

Project Classification (as created by the authors), Work Type, and Number of Contracts (2010 to 2020)

| Project Classification | Work Type | |
|---|---|---|
| Road-related | Added Travel Lanes | 48 |
| | Auxiliary Lanes | 12 |
| | Interchange Modification | 14 |
| | Interchange Work | 7 |
| | Intersection Improvement | 209 |
| | New Interchange Construction | 2 |
| | New Road Construction | 77 |
| | New Road, Grading Only | 1 |
| | New Road, Paving Only | 1 |
| | Null | 151 |
| | Railroad Work | 1 |
| | Road Construction | 44 |
| | Road Rehab (3R/4R Standards) | 128 |
| Pavement-related | Null | 135 |
| | Patch And Rehab Pavement | 76 |
| | Pavement Markings | 9 |
| | Pavement Rehabilitation Or Repair | 517 |
| | Pavement Replacement | 15 |
| | Pavement Replacement, Asphalt | 15 |
| | Pavement Replacement, Concrete | 14 |
| | Pavement Replacement, Small Town | 4 |
| | Pavement, Other | 25 |
| Bridge-related | Bridge Channel Correction | 8 |
| | Bridge Deck Reconstruction | 136 |
| | Bridge Maintenance/Repair | 61 |
| | Bridge Painting | 20 |
| | Bridge Rehabilitation Or Repair | 427 |
| | Bridge Replacement | 67 |
| | Bridge Replacement, Concrete | 130 |
| | Bridge Replacement, Other Const | 35 |
| | Bridge Replacement, Special | 2 |
| | Bridge Replacement, Steel | 13 |
| | Bridge Widening | 7 |
| | New Bridge Construction | 16 |
| | New Bridge, Concrete Construction | 14 |
| | New Bridge, Other Construction | 8 |
| | New Bridge, Special | 1 |
| | New Bridge, Steel Construction | 2 |
| | Null | 230 |
| | Raise Bridge/Lower Pavement | 1 |
| Demolition, Maintenance, and Traffic-related | Barrier Wall | 2 |
| | Demolition | 31 |
| | Drainage Ditch Correction | 9 |
| | Guardrail Atten., New Or Modernize | 4 |
| | Guardrail Work | 26 |
| | Guardrail, Maintenance Or Repair | 23 |
| | Install New Cable Rail Barriers | 3 |
| | Install New Guardrail | 11 |
| | Intelligent Transportaton Sys (Its) | 8 |
| | Lighting | 30 |
| | Null | 427 |
| | Other Project Type | 24 |
| | Other Type Project (Miscellaneous) | 79 |
| | Replace Superstructure | 26 |
| | Resurface | 479 |
| | Roadside Facilities | 39 |
| | Roadside Maintenance | 65 |
| | Roadside Work | 170 |
| | Roadside Work, Other | 166 |
| | Safety Improvements | 149 |
| | Sewer/Curb/Gutter Construction | 4 |
| | Sight Distance Improvement | 14 |
| | Signing | 45 |
| | Slide Correction | 26 |
| | Small Structure | 137 |
| | Small Structure, Replacement | 177 |
| | Substructure Repair And Rehab | 11 |
| | Traffic Hardware Modernization | 9 |
| | Traffic Signals | 102 |
| | Traffic, Other | 10 |
| | Wedge And Level | 9 |
| Grand Total | | 4,998 |

Figure A.1 Number of contracts by project class and work type.

# APPENDIX B. CONTRACT AWARD AMOUNTS AND CHANGE ORDERS BY DISTRICT

## B.1 Greenfield

Of the INDOT districts, Greenfield had the largest share of the number and award amount of contracts during the analysis period (2010 to 2020): 1,092 contracts of combined value $2.42 billion, with breakdown provided in Figure B.1.

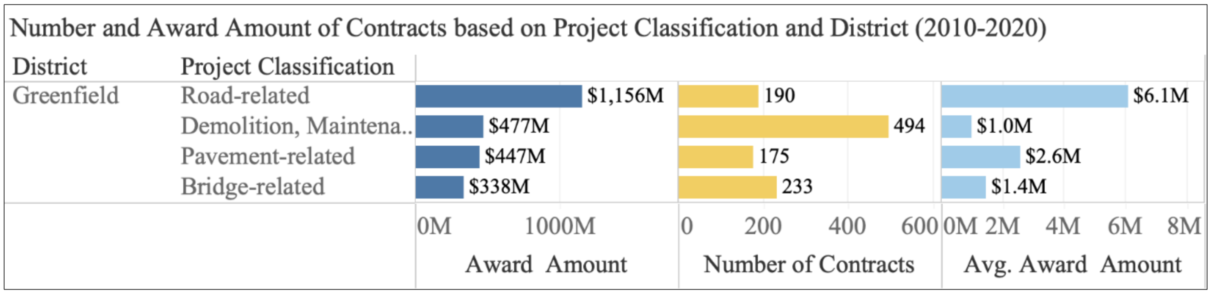



Figure B.1 Greenfield contracts.

As shown in Figure B.1, most of these contracts ($1.16 billion) are road related. This section addresses the trends and patterns associated with the magnitude and causes of change orders (COS), across the project types, in the Greenfield District. This district approved 6,456 COs worth $122M between 2010 and 2020. Figure B.2 presents the CO distribution across the project types.

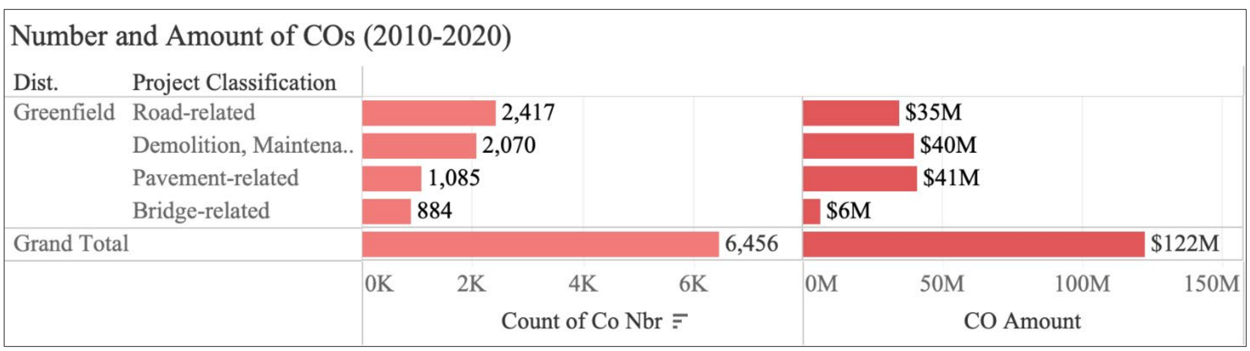



Figure B.2 Greenfield change orders.

Figure B.2 suggests that road-related projects (2,417 COs) in Greenfield District are more "susceptible," compared to other project types, to the incidence of COs compared to pavement-related projects (1,085 COs). Surprisingly, despite the fewer pavement-related COs, the total CO amount for this project type is $41 million, exceeding the $35 million total for road-related projects. This implies that, on average, each CO in pavement-related project in the Greenfield District is associated with significantly higher financial risk compared to road-related projects in that district.

Also, it can be noted that demolition, maintenance, and traffic-related projects contribute to approximately 30% of the total CO amount. Further analysis shows that, between 2010 and 2020, a substantial portion of COs in this project types are associated with the following root causes: emergency work, scope changes, and standards and specification changes.

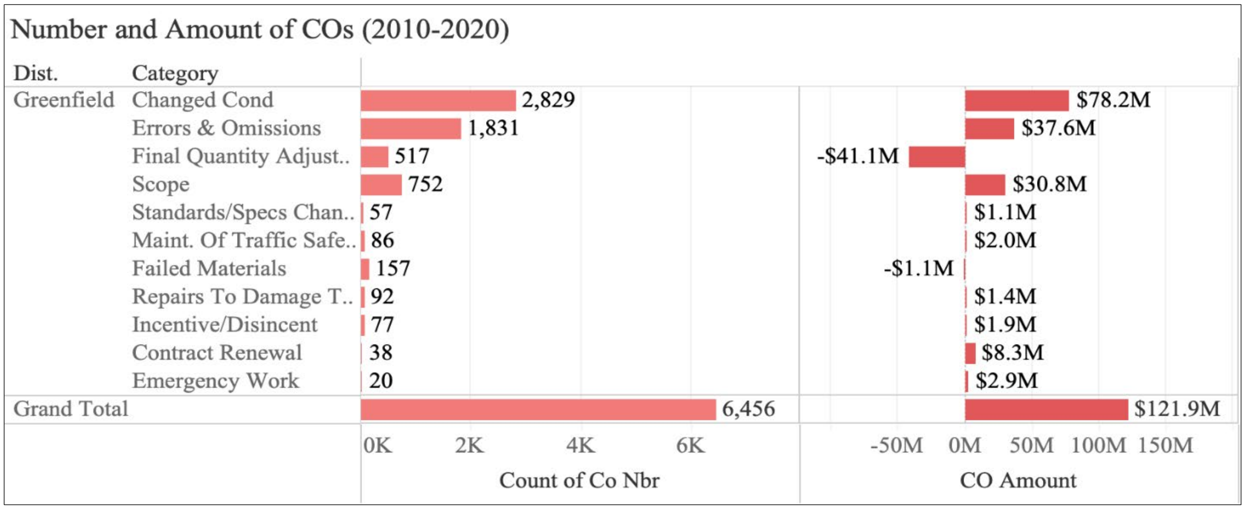



Figure B.3 Greenfield CO categories.

Figure B.3 provides a detailed breakdown of the magnitude of various CO categories within the Greenfield District, shedding light on the most frequent and severe categories that lead to COs in projects of that district. Changed conditions, errors and omissions, and scope changes are CO root-cause categories for projects awarded by the district. Figure B.4 provides further understanding into the root causes of these root cause categories.

CO Range of Root Causes (2010 to 2020)

| Dist. | Category | Reason | CO Range: 0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | > 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| Greenfield | Changed Cond | Changed Cond, Constructability .. | 580 | 131 | 104 | 12 | | 1 | 828 |
| | | Changed Cond, Construction Rel.. | 509 | 78 | 62 | 6 | 2 | | 657 |
| | | Changed Cond, Utilities Related | 207 | 36 | 15 | 3 | | | 261 |
| | | Changed Cond, Materials Related | 152 | 31 | 18 | 3 | | | 204 |
| | | Changed Cond, Soils Related | 76 | 43 | 29 | 3 | | | 151 |
| | | Changed Cond, Quantity Related | 65 | 29 | 37 | 7 | 4 | 5 | 147 |
| | | Changed Cond, Environmental R.. | 67 | 13 | 15 | 1 | 1 | | 97 |
| | Errors & Omissions | E & O, Design Related | 667 | 146 | 87 | 15 | | | 915 |
| | | E & O, Contract Related | 106 | 20 | 15 | | | | 141 |
| | | E & O, Item Related | 106 | 18 | 5 | | | | 129 |
| | | E & O, Quantity Related | 71 | 28 | 16 | 3 | | | 118 |
| | | E & O, Traffic Control | 82 | 9 | 3 | | | | 94 |
| | Scope | Scope, Added Quantities/Items | 122 | 30 | 45 | 10 | | 2 | 209 |
| | | Scope, Local Agency Request | 104 | 13 | 14 | 3 | | 1 | 135 |
| | | Scope, Project Upgrades | 51 | 16 | 12 | 3 | | | 82 |
| Grand Total | | | 2,965 | 641 | 477 | 69 | 7 | 9 | 4,168 |

Figure B.4 Greenfield CO ranges by root cause.

Figure B.4 indicates that in Greenfield District, out of the total of 4,168 COs, 1,485 stem from constructability-related and construction-related changed conditions, with design-related errors and omissions accounting for 915 COs. These factors are associated with COs whose monetary amount are less than $250,000. In contrast, COs exceeding $250,000 are associated primarily with changed conditions related to constructability, design, utility, soils, and materials.

## B.2 Crawfordsville

Notably, Crawfordsville District stands out among INDOT administrative districts as the district with the smallest total CO amount despite sharing a similar distribution of contract count and total amount with other districts. Figure B.5 presents an overview of the award amounts and the number of contracts across various project categories in the Crawfordsville District.

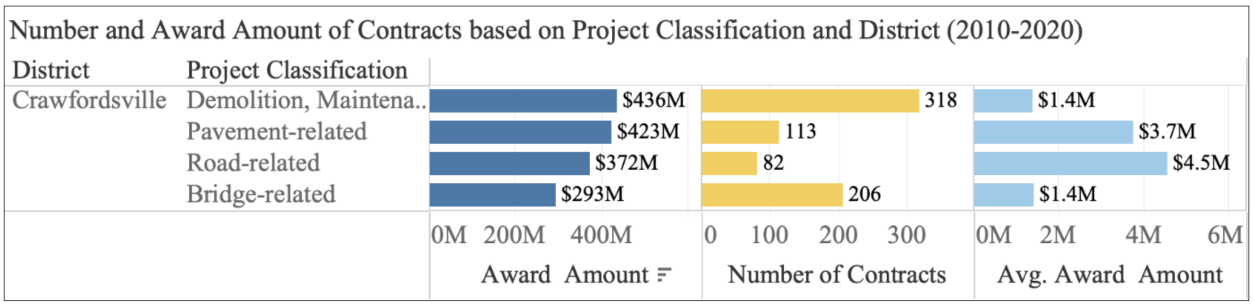



Figure B.5 Crawfordsville contracts.

The Crawfordsville District awarded 719 contracts worth $1.53B from 2010 to 2020. The number of road contracts were approximately one-half of that of Greenfield District, but the number of bridge contracts were comparable. The district's contract awards were dominated (in terms of award amount) by demolition, maintenance, and traffic contracts, followed closely by pavement, road, and bridge-related contracts. Figure B.6 presents some details of the COs encountered by these contracts across the project types. Crawfordsville approved a total number of 3,418 COs from 2010 to 2020 with a total amount of $29M.

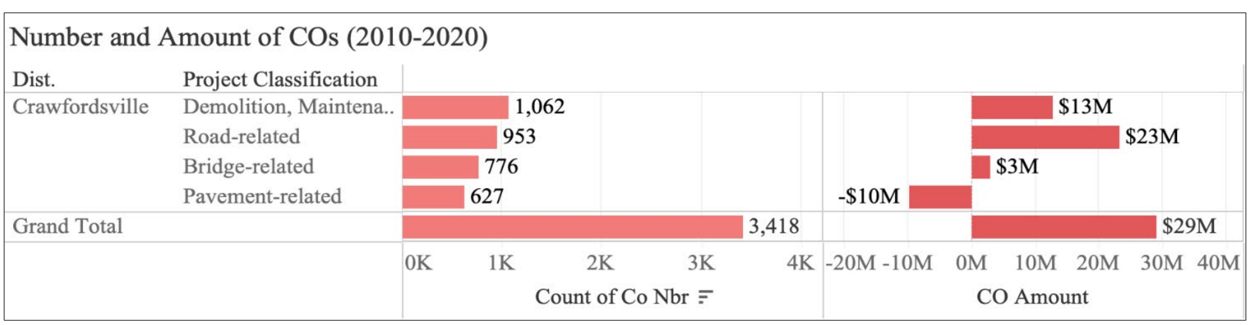



Figure B.6 Crawfordsville change orders.

It can be observed that, statewide, road-related and bridge-related contracts have experienced more COs compared to other project types. In the Crawfordsville District, road contracts have experienced COs worth $23 million, significantly exceeding that of $3 million for bridge contracts. However, it is worth noting that in this district, the pavement-related COs are in the negative (savings worth $10 million). The total CO amount for Crawfordsville is $29 million, the lowest of the six districts. Figure B.7 breaks down of the CO root cause categories in Crawfordsville.

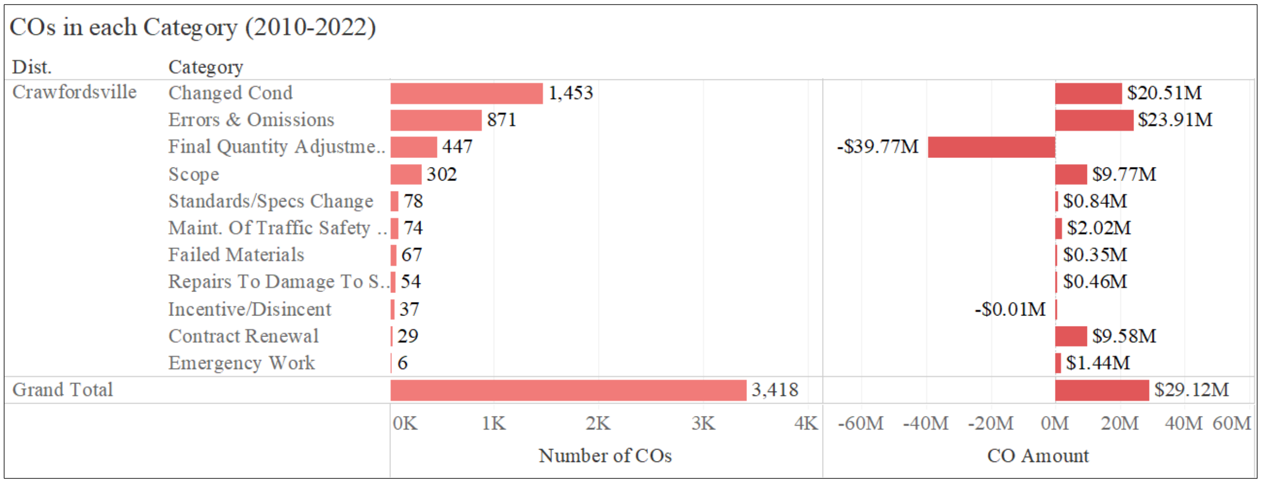



Figure B.7 Crawfordsville CO categories.

In alignment with the broader INDOT-level trends, the Crawfordsville District encountered a substantial number of COs primarily attributed to changed conditions and errors and omissions, collectively accounting for more than 50% of the total COs. These two CO root cause categories incurred an overall cost of $44 million. Interestingly, Crawfordsville also saw a significant offset in CO-related costs due to Final Quantity Adjustments, with a negative amount (savings) of $40 million. This was influential in reducing CO-related cost overruns in the Crawfordsville District. Figure B.8 further expands on these change order categories to highlight the root causes and their corresponding CO ranges.

CO Range of Root Causes (2010 to 2020)

| Dist. | Category | Reason | 0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | > 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | CO Range | | | | | | |
| Crawfordsville | Changed Cond | Changed Cond, Constructability .. | 332 | 51 | 33 | 1 | 1 | | 418 |
| | | Changed Cond, Construction Rel.. | 195 | 26 | 26 | 3 | | | 250 |
| | | Changed Cond, Materials Related | 95 | 18 | 14 | 1 | 1 | | 129 |
| | | Changed Cond, Soils Related | 60 | 17 | 23 | 4 | | | 104 |
| | | Changed Cond, Utilities Related | 77 | 11 | 9 | | | | 97 |
| | | Changed Cond, Environmental R.. | 54 | 15 | 16 | 4 | | | 89 |
| | | Changed Cond, Quantity Related | 24 | 14 | 10 | 2 | | | 50 |
| | Errors & Omissions | E & O, Design Related | 321 | 66 | 34 | 7 | | 1 | 429 |
| | | E & O, Item Related | 85 | 10 | 5 | | | | 100 |
| | | E & O, Contract Related | 48 | 11 | 9 | | 1 | | 69 |
| | | E & O, Traffic Control | 34 | 2 | 1 | | | | 37 |
| | | E & O, Quantity Related | 17 | 8 | 4 | | | | 29 |
| | Scope | Scope, Added Quantities/Items | 45 | 14 | 9 | 3 | | | 71 |
| | | Scope, Project Upgrades | 15 | 7 | 8 | | | | 30 |
| | | Scope, Local Agency Request | 15 | 6 | 5 | | | | 26 |
| Grand Total | | | 1,417 | 276 | 206 | 25 | 3 | 1 | 1,928 |

Figure B.8 Crawfordsville CO range.

Similar to the other districts, 668 of the 1,928 COs are related to changed conditions, constructability-related COs. Further research is required to investigate the root causes associated with such a high number of constructability-related COs at all of INDOT's administrative districts. Crawfordsville also had one (1) errors and omissions contract-related CO in the range of $750K to $2M and one (1) design-related CO that resulted in a cost increase of over $2M. Moreover, materials-related and soils-related COs also contribute to 6 COs that led to a cost increase of over $250K.

## B.3 Vincennes

Vincennes generally had fewer contracts and smaller contract sizes compared to other districts in the 2010-2020 period. Also, the district had the fewest number of COs but the second highest share of the total district-wide CO amount. This indicates that, on average, COs in the Vincennes District is more severe compared to other districts. Figure B.9 provides details on contract counts and award amounts at the Vincennes District within the study period.

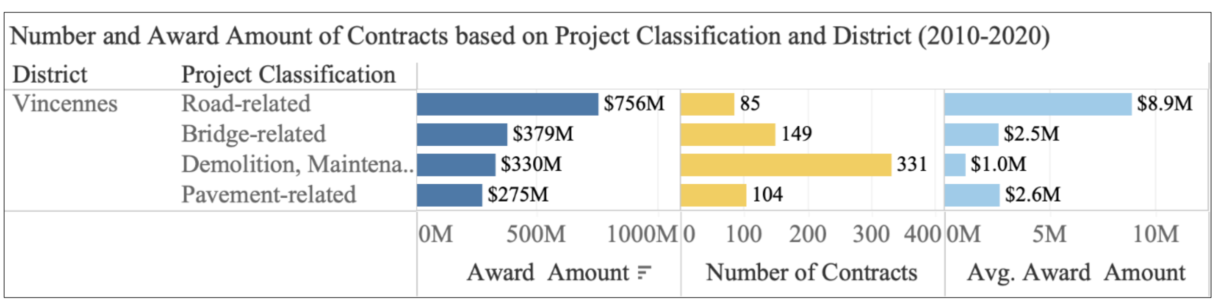



Figure B.9 Vincennes contracts.

It was observed that road-related projects in Vincennes have an average award amount of approximately $9M. This suggests that executing road-related contracts in Vincennes has been historically more expensive compared to any other districts. Furthermore, as illustrated in Figure B.10, road projects also contribute over 50% of the total CO amount in this district. Figure B.11 illustrates the magnitude of the CO root-cause categories in this district. Similar to the situation at other districts, changed conditions and errors and omissions are the two topmost categories that lead to COs.

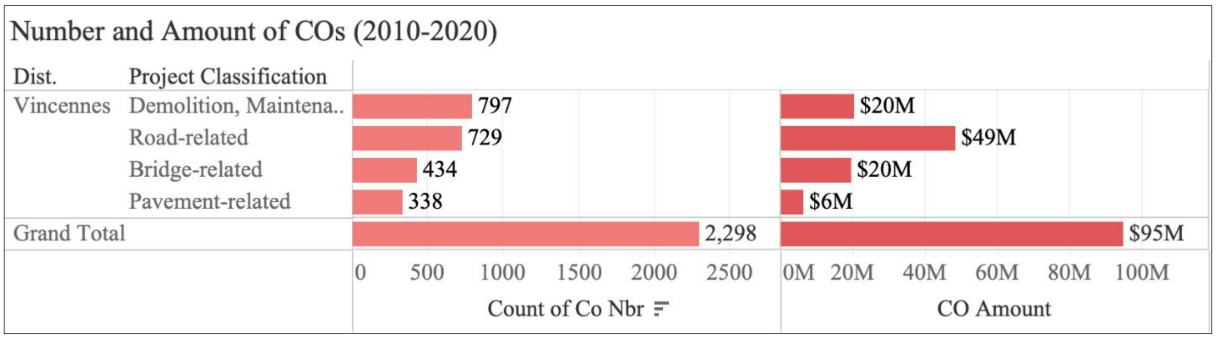



Figure B.10 Vincennes change orders.

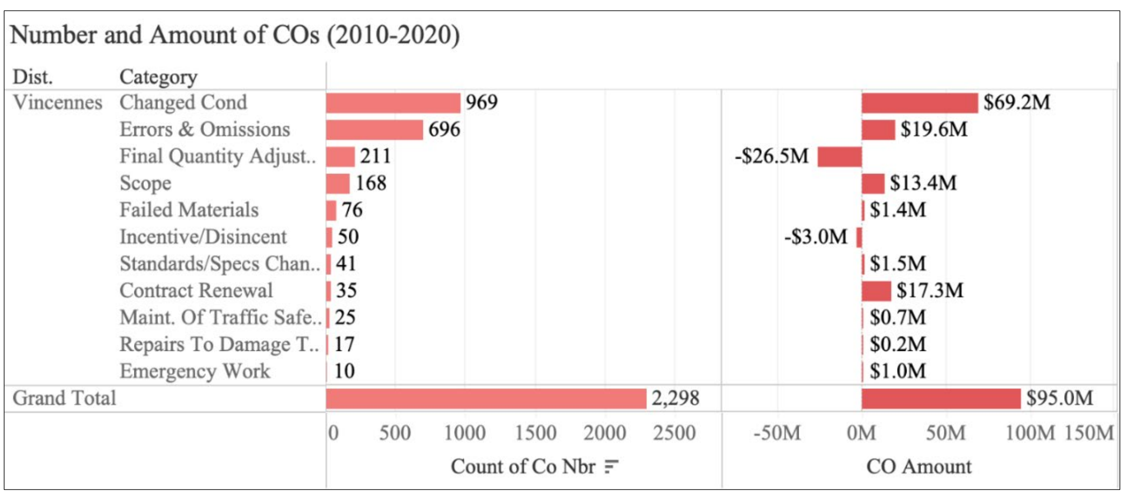



Figure B.11 Vincennes CO categories.

Failed materials, maintenance of traffic safety improvements, repairs to damage to state property, and emergency work constituted a relatively small (in magnitude) CO amount compared to other CO root-cause categories. However, they to cost overruns exceeding $3M between the 2010–2020 period. The CO savings (negative CO amount) associated with Final Quantity Adjustments helped to lower the total deficit associated with CO in the district. Figure B.12 presents the monetary impact associated with the CO root causes. Similar to the other districts, constructability, design, and soils-related CO are the top three root causes of COs in terms of adverse financial impact.

However, it can be observed that the root cause that stands out in Vincennes District, is environmental-related changed conditions: seven (7) COs related to environmental-related root causes led to over $250K in the study period, with two (2) of them causing over $2M in cost overruns. Moreover, one (1) soils-related root cause also led to a cost overrun exceeding $2M.

CO Range of Root Causes (2010 to 2020)

| Dist. | Category | Reason | CO Range<br>0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | > 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| Vincennes | Changed Cond | Changed Cond, Constructability .. | 179 | 32 | 43 | 4 | 2 | | 260 |
| | | Changed Cond, Construction Rel.. | 80 | 33 | 27 | 6 | | | 146 |
| | | Changed Cond, Soils Related | 42 | 19 | 28 | 7 | 4 | 1 | 101 |
| | | Changed Cond, Environmental R.. | 42 | 15 | 29 | 5 | 1 | 2 | 94 |
| | | Changed Cond, Materials Related | 53 | 18 | 12 | | | | 83 |
| | | Changed Cond, Quantity Related | 37 | 13 | 17 | 3 | 2 | | 72 |
| | | Changed Cond, Utilities Related | 31 | 6 | 4 | 2 | | | 43 |
| | Errors & Omissions | E & O, Design Related | 202 | 56 | 50 | 7 | | | 315 |
| | | E & O, Item Related | 55 | 7 | 4 | | | | 66 |
| | | E & O, Quantity Related | 26 | 8 | 8 | 1 | | | 43 |
| | | E & O, Contract Related | 21 | 4 | 6 | 1 | | | 32 |
| | | E & O, Traffic Control | 22 | 2 | 4 | | | | 28 |
| | Scope | Scope, Added Quantities/Items | 37 | 8 | 4 | 1 | | 1 | 51 |
| | | Scope, Project Upgrades | 8 | 2 | 1 | 1 | | | 12 |
| | | Scope, Local Agency Request | 7 | 1 | | | | | 8 |
| Grand Total | | | 842 | 224 | 237 | 38 | 9 | 4 | 1,354 |

Figure B.12 Vincennes CO range.

## B.4 Fort Wayne

Figure B.13 and Figure B.14. present the number of contracts, award amount, number of COs, and CO amount at Fort Wayne District.

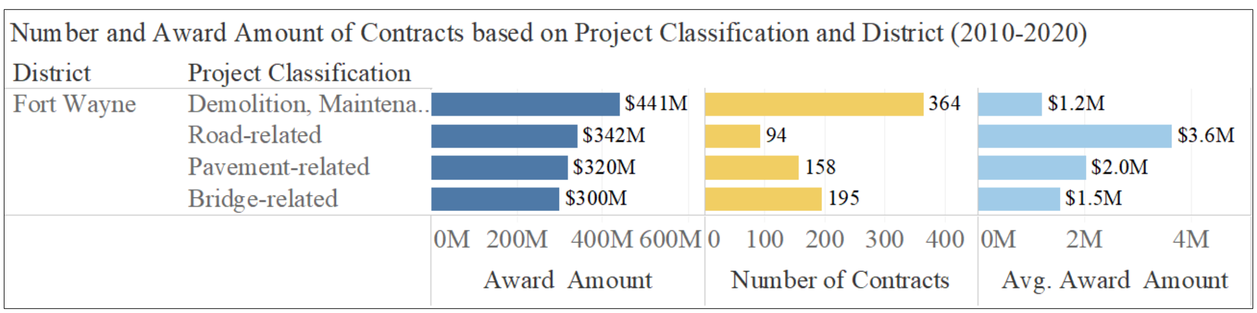



Figure B.13 Fort Wayne contracts.

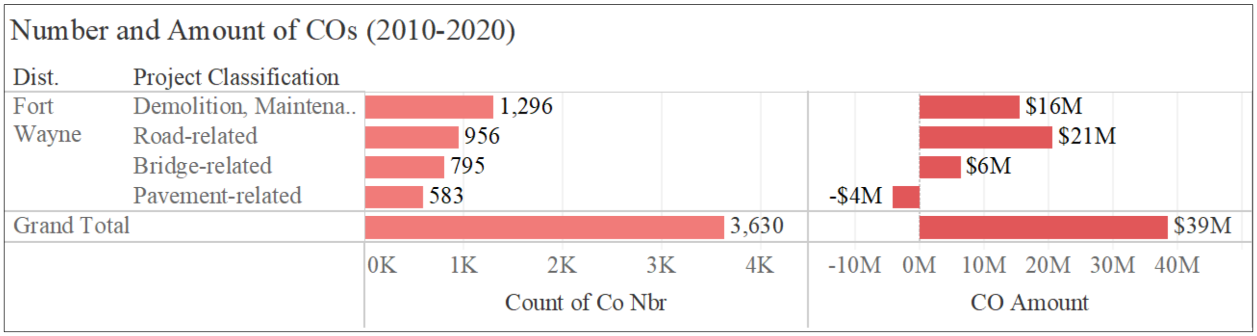


Figure B.14 Fort Wayne change orders.

It is observed that in this district, road-related projects have faced significantly higher CO amounts compared to bridge-related projects despite having a similar CO count. The impacts of repairs to damage to state property, MOT safety improvements, standards/specification changes, are not as high in magnitude as those of other CO categories, but consistently contributed $4M in cost overruns. Changed conditions and errors and omissions are the top two categories of the CO root cause categories. However, further investigation is required to make more confident conclusions regarding the impacts of these root causes. Within the analysis period, there was no contract in Fort Wayne with CO exceeding $250K.

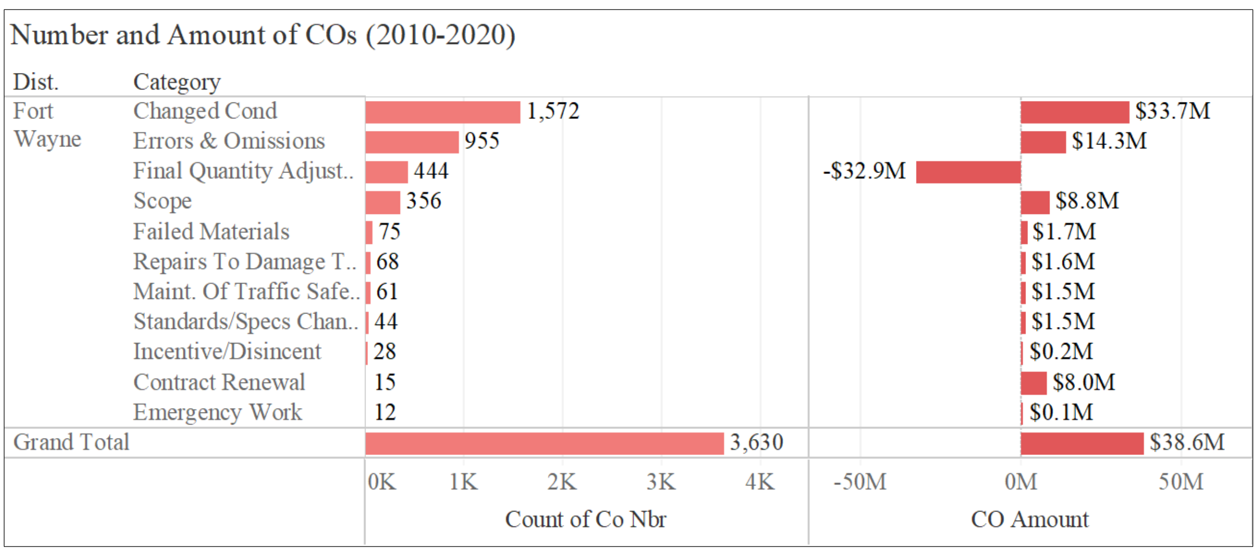


Figure B.15 Fort Wayne CO categories.

CO Range of Root Causes (2010 to 2020)

| Dist. | Category | Reason | CO Range<br>0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | > 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| Fort Wayne | Changed Cond | Changed Cond, Constructability .. | 701 | 113 | 76 | 7 | 1 | 1 | 899 |
| | | Changed Cond, Soils Related | 40 | 12 | 19 | 3 | | | 74 |
| | | Changed Cond, Environmental R.. | 32 | 6 | 2 | | | | 40 |
| | | Changed Cond, Materials Related | 85 | 18 | 14 | 3 | | | 120 |
| | | Changed Cond, Quantity Related | 31 | 9 | 15 | | 1 | | 56 |
| | | Changed Cond, Utilities Related | 100 | 9 | 6 | | | | 115 |
| | Errors & Omissions | E & O, Design Related | 373 | 54 | 40 | | 1 | | 468 |
| | | E & O, Item Related | 94 | 10 | 9 | | | | 113 |
| | | E & O, Quantity Related | 30 | 13 | 8 | 1 | | | 52 |
| | | E & O, Contract Related | 38 | 5 | 7 | | | | 50 |
| | | E & O, Traffic Control | 58 | 7 | | | | | 65 |
| | | E & O, Construct Related | 26 | 8 | 3 | | | | 37 |
| | Scope | Scope, Added Quantities/Items | 72 | 15 | 23 | 7 | | | 117 |
| | | Scope, Project Upgrades | 19 | 2 | 8 | | | | 29 |
| | | Scope, Local Agency Request | 58 | 3 | 4 | | | | 65 |
| Grand Total | | | 1,757 | 284 | 234 | 21 | 3 | 1 | 2,300 |

Figure B.16 Fort Wayne CO range.

## B.5 LaPorte

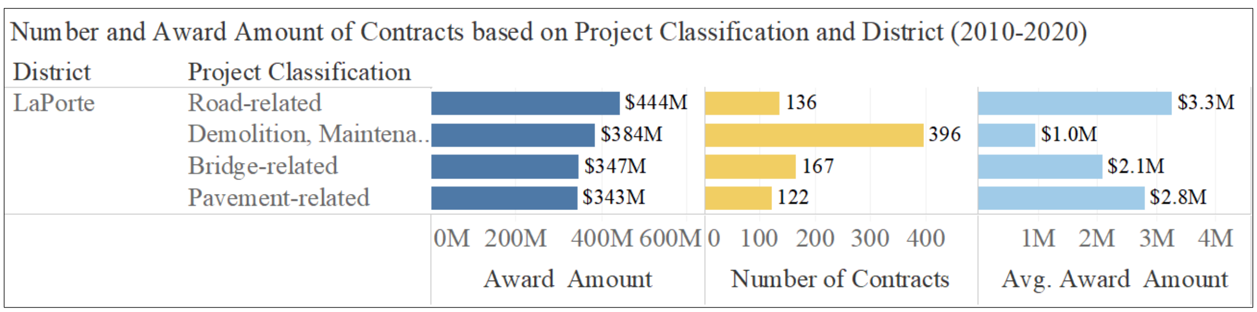



Figure B.17 LaPorte contracts.

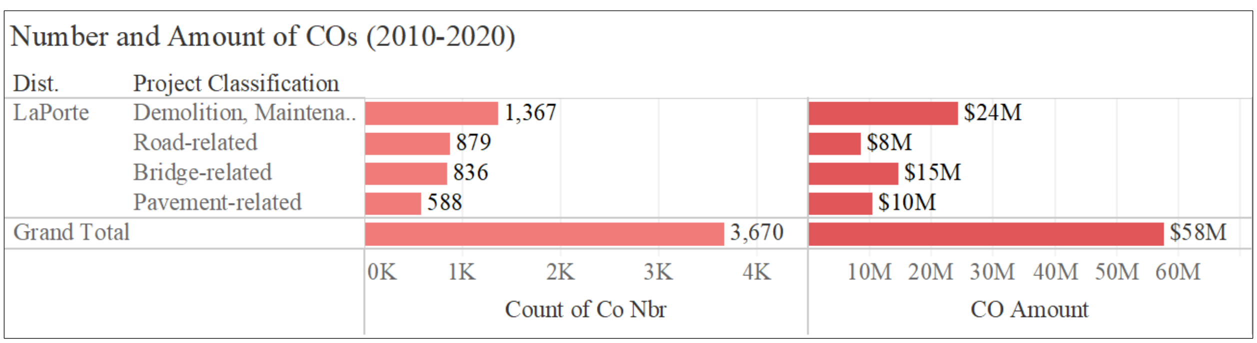



Figure B.18 LaPorte change orders.

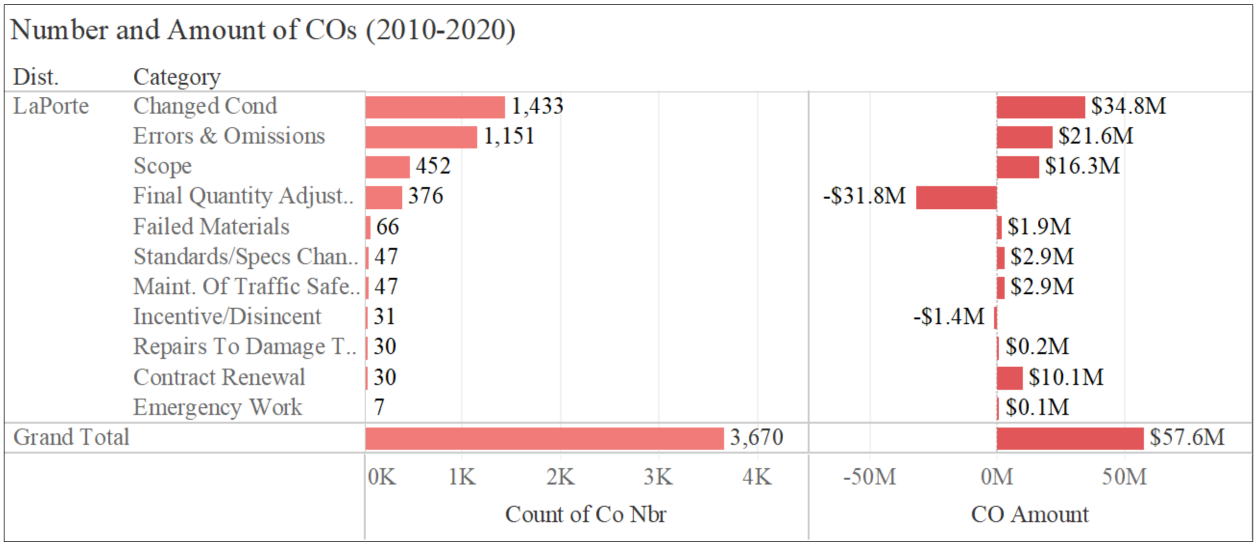



Figure B.19 LaPorte CO categories.

CO Range of Root Causes (2010 to 2020)

| Dist. | Category | Reason | CO Range: 0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|
| LaPorte | Changed Cond | Changed Cond, Constructability .. | 525 | 111 | 68 | 8 | 3 | 715 |
| | | Changed Cond, Soils Related | 49 | 29 | 26 | 3 | 1 | 108 |
| | | Changed Cond, Environmental R.. | 32 | 8 | 5 | | | 45 |
| | | Changed Cond, Materials Related | 122 | 27 | 14 | 2 | 1 | 166 |
| | | Changed Cond, Quantity Related | 19 | 16 | 17 | 3 | | 55 |
| | | Changed Cond, Utilities Related | 101 | 17 | 12 | 1 | | 131 |
| | Errors & Omissions | E & O, Design Related | 416 | 67 | 49 | 7 | | 539 |
| | | E & O, Item Related | 109 | 13 | 10 | 2 | | 134 |
| | | E & O, Quantity Related | 67 | 17 | 13 | | | 97 |
| | | E & O, Contract Related | 47 | 7 | 4 | 1 | | 59 |
| | | E & O, Traffic Control | 47 | 5 | 1 | | | 53 |
| | | E & O, Construct Related | 42 | 10 | 4 | 1 | | 57 |
| | Scope | Scope, Added Quantities/Items | 91 | 21 | 14 | 1 | 3 | 130 |
| | | Scope, Project Upgrades | 49 | 18 | 16 | 4 | 1 | 88 |
| | | Scope, Local Agency Request | 36 | 18 | 9 | 2 | | 65 |
| Grand Total | | | 1,752 | 384 | 262 | 35 | 9 | 2,442 |

Figure B.20 LaPorte CO range.

## B.6 Seymour

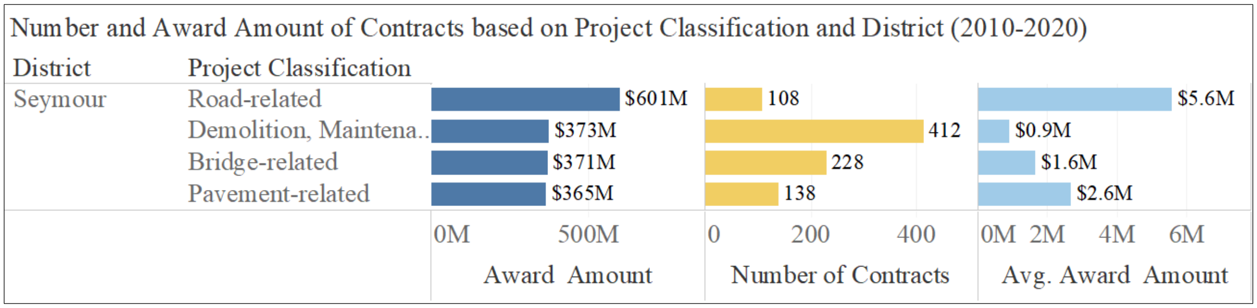



Figure B.21 Seymour contracts.

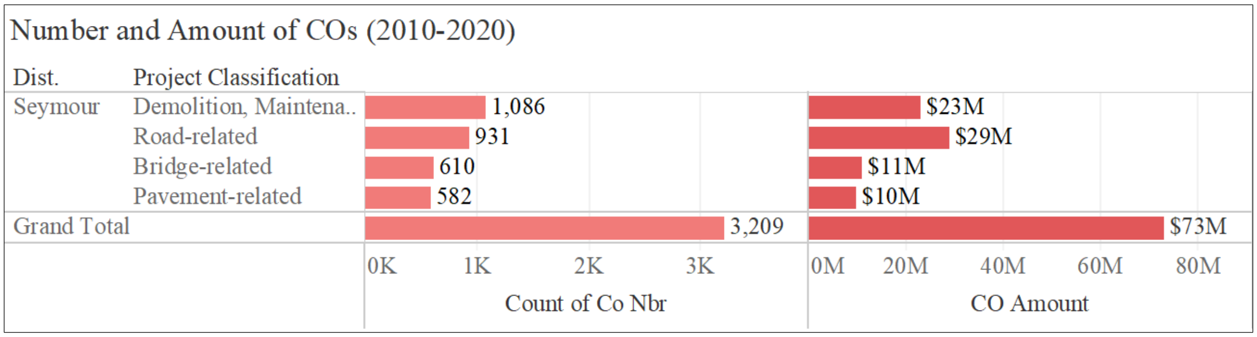



Figure B.22 Seymour change orders.

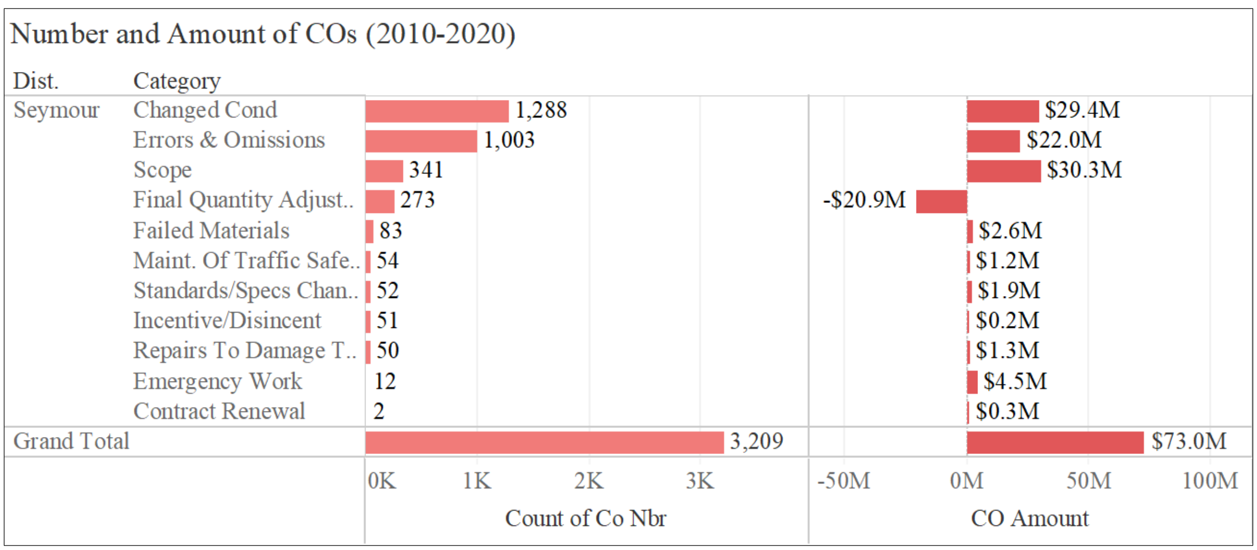



Figure B.23 Seymour CO categories.

CO Range of Root Causes (2010 to 2020)

| Dist. | Category | Reason | 0 - 20k | 20.1k - 50k | 50.1k - 250k | 250.1k - 750k | 750.1k - 2M | > 2M | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | CO Range | | | | | | |
| Seymour | Changed Cond | Changed Cond, Constructability .. | 450 | 90 | 55 | 12 | 4 | 1 | 612 |
| | | Changed Cond, Soils Related | 52 | 26 | 21 | 3 | | | 102 |
| | | Changed Cond, Environmental R.. | 65 | 11 | 7 | 1 | | | 84 |
| | | Changed Cond, Materials Related | 77 | 11 | 5 | | 1 | | 94 |
| | | Changed Cond, Quantity Related | 38 | 15 | 11 | 1 | | | 65 |
| | | Changed Cond, Utilities Related | 78 | 14 | 8 | | | | 100 |
| | Errors & Omissions | E & O, Design Related | 400 | 69 | 57 | 8 | 4 | | 538 |
| | | E & O, Item Related | 91 | 5 | 3 | | | | 99 |
| | | E & O, Quantity Related | 21 | 9 | 10 | 1 | | | 41 |
| | | E & O, Contract Related | 46 | 5 | 5 | | | | 56 |
| | | E & O, Traffic Control | 32 | 1 | 1 | | | | 34 |
| | | E & O, Construct Related | 26 | 2 | 1 | | | | 29 |
| | Scope | Scope, Added Quantities/Items | 69 | 22 | 22 | 14 | 4 | 4 | 135 |
| | | Scope, Project Upgrades | 20 | 9 | 6 | | 1 | | 36 |
| | | Scope, Local Agency Request | 16 | 3 | 6 | 1 | | | 26 |
| Grand Total | | | 1,481 | 292 | 218 | 41 | 14 | 5 | 2,051 |

Figure B.24 Seymour CO range.

# APPENDIX C. DETAILED RESULTS OF THE STATISTICAL MODELING

## C.1 Modelling Change Order Occurrence Likelihood

Table C.1 Result of Binary Logit for CO Occurrence Likelihood

| Variables | Coefficient | Standard Error | z | P-value | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Constant | 0.79268*** | 0.11218 | 7.07000 | 0.00000 | 0.57281 | 1.01255 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | -0.00553 | 0.13890 | -0.04000 | 0.96820 | -0.27777 | 0.26670 |
| Crawfordsville | -0.05211 | 0.14427 | -0.36000 | 0.71800 | -0.33488 | 0.23067 |
| Seymour | -0.52208*** | 0.12424 | -4.20000 | 0.00000 | -0.76560 | -0.27857 |
| Fort Wayne | -0.26762** | 0.13503 | -1.98000 | 0.04750 | -0.53228 | -0.00296 |
| Vincennes | -0.81635*** | 0.13711 | -5.95000 | 0.00000 | -1.08509 | -0.54762 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | 0.45447*** | 0.16622 | 2.73000 | 0.00630 | 0.12868 | 0.78027 |
| Urban | 0.26177*** | 0.09278 | 2.82000 | 0.00480 | 0.07993 | 0.44361 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | -0.39544*** | 0.10190 | -3.88000 | 0.00010 | -0.59517 | -0.19571 |
| Pavement-Related | -0.70344*** | 0.12404 | -5.67000 | 0.00000 | -0.94656 | -0.46032 |
| Road-Related | -1.15561*** | 0.12695 | -9.10000 | 0.00000 | -1.40444 | -0.90678 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -1.86902*** | 0.39856 | -4.69000 | 0.00000 | -2.65019 | -1.08785 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 1.50032*** | 0.08424 | 17.81000 | 0.00000 | 1.33522 | 1.66543 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.2 Sensitivity of CO Likelihood to the Influential Factors

Table C.2 Marginal Effects of the Variables for CO Occurrence Likelihood

| **Variables** | **Marginal Effect** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | -0.00071 | 0.01785 | -0.04000 | 0.96830 | -0.03569 | 0.03427 |
| Crawfordsville | -0.00673 | 0.01879 | -0.36000 | 0.72000 | -0.04356 | 0.03009 |
| Seymour | -0.07152*** | 0.01793 | -3.99000 | 0.00010 | -0.10666 | -0.03639 |
| Fort Wayne | -0.03554* | 0.01850 | -1.92000 | 0.05470 | -0.07181 | 0.00072 |
| Vincennes | -0.11755*** | 0.02133 | -5.51000 | 0.00000 | -0.15936 | -0.07574 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | 0.05340*** | 0.01767 | 3.02000 | 0.00250 | 0.01877 | 0.08803 |
| Urban | 0.03296*** | 0.01143 | 2.88000 | 0.00390 | 0.01056 | 0.05535 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | -0.05273*** | 0.01401 | -3.76000 | 0.00020 | -0.08019 | -0.02528 |
| Pavement-Related | -0.09947*** | 0.01874 | -5.31000 | 0.00000 | -0.13621 | -0.06274 |
| Road-Related | -0.17346*** | 0.02045 | -8.48000 | 0.00000 | -0.21354 | -0.13338 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -0.29944*** | 0.06585 | -4.55000 | 0.00000 | -0.42850 | -0.17038 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.19246*** | 0.01060 | 18.15000 | 0.00000 | 0.17168 | 0.21324 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.3 CO Magnitude Model: Positive- or Negative-Value Change Order

Table C.3 Positive- or Negative-Value Change Order

| **Variables** | **Coefficient** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Constant | -1.04794*** | 0.09558 | -10.96000 | 0.00000 | -1.23528 | -0.86060 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | 0.0624 | 0.11302 | 0.55000 | 0.58090 | -0.15911 | 0.28391 |
| Crawfordsville | 0.68784*** | 0.11244 | 6.12000 | 0.00000 | 0.46747 | 0.90821 |
| Seymour | 0.24561** | 0.11323 | 2.17000 | 0.03010 | 0.02369 | 0.46754 |
| Fort Wayne | 0.23279** | 0.11430 | 2.04000 | 0.04170 | 0.00876 | 0.45681 |
| Vincennes | 0.00918 | 0.12959 | 0.07000 | 0.94350 | -0.24481 | 0.26318 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | -0.47510*** | 0.14382 | -3.30000 | 0.00100 | -0.75698 | -0.19322 |
| Urban | -0.06199 | 0.07745 | -0.80000 | 0.42350 | -0.21380 | 0.08981 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | 0.15762* | 0.08777 | 1.80000 | 0.07250 | -0.01441 | 0.32964 |
| Pavement-Related | 0.84941*** | 0.09391 | 9.05000 | 0.00000 | 0.66536 | 1.03346 |
| Road-Related | -0.14972 | 0.11829 | -1.27000 | 0.20560 | -0.38155 | 0.08212 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -1.18073** | 0.49860 | -2.37000 | 0.01790 | -2.15796 | -0.20350 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.00629 | 0.00618 | 1.02000 | 0.30890 | -0.00582 | 0.01839 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.4 Positive-Value Change Order Magnitude

Table C.4 Multinomial Logit Results for Positive-Value CO Amounts

| **Variables** | **Coefficient** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Reference level of the dependent variable is 0–$50 K) | | | | | | |
| **Model For Dependent Variable Level: [$50K–$750K)** | | | | | | |
| Constant | -1.02437*** | 0.12076 | -8.4800 | 0.0000 | -1.2611 | -0.7877 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | -0.08168 | 0.14086 | -0.5800 | 0.5620 | -0.3578 | 0.1944 |
| Crawfordsville | -0.23035 | 0.16024 | -1.4400 | 0.1506 | -0.5444 | 0.0837 |
| Seymour | -0.36562** | 0.14845 | -2.4600 | 0.0138 | -0.6566 | -0.0747 |
| Fort Wayne | -0.29326** | 0.14795 | -1.9800 | 0.0475 | -0.5833 | -0.0033 |
| Vincennes | -0.13275 | 0.16186 | -0.8200 | 0.4121 | -0.4500 | 0.1845 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | -0.21983 | 0.16473 | -1.3300 | 0.1820 | -0.5427 | 0.1030 |
| Urban | -0.15145 | 0.10544 | -1.4400 | 0.1509 | -0.3581 | 0.0552 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | -0.54465*** | 0.11952 | -4.5600 | 0.0000 | -0.7789 | -0.3104 |
| Pavement-Related | -0.20176 | 0.15155 | -1.3300 | 0.1831 | -0.4988 | 0.0953 |
| Road-Related | 0.10685 | 0.1476 | 0.7200 | 0.4691 | -0.1824 | 0.3961 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -1.66571** | 0.71176 | -2.3400 | 0.0193 | -3.0607 | -0.2707 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.75204*** | 0.04483 | 16.7700 | 0.0000 | 0.6642 | 0.8399 |
| **Model For Dependent Variable Level: [>$750K]** | | | | | | |
| Constant | -3.40787*** | 0.26963 | -12.6400 | 0.0000 | -3.9363 | -2.8794 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | -0.02589 | 0.29426 | -0.0900 | 0.9299 | -0.6026 | 0.5508 |
| Crawfordsville | -0.54977 | 0.35925 | -1.5300 | 0.1259 | -1.2539 | 0.1543 |
| Seymour | -0.99733*** | 0.38316 | -2.6000 | 0.0092 | -1.7483 | -0.2464 |
| Fort Wayne | -0.72402** | 0.34914 | -2.0700 | 0.0381 | -1.4083 | -0.0397 |
| Vincennes | -0.48215 | 0.35325 | -1.3600 | 0.1723 | -1.1745 | 0.2102 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | -3.21151*** | 1.11282 | -2.8900 | 0.0039 | -5.3926 | -1.0304 |
| Urban | -0.61037*** | 0.2322 | -2.6300 | 0.0086 | -1.0655 | -0.1553 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | -0.69785** | 0.2886 | -2.4200 | 0.0156 | -1.2635 | -0.1322 |
| Pavement-Related | 0.01004 | 0.28931 | 0.0300 | 0.9723 | -0.5570 | 0.5771 |
| Road-Related | -0.23006 | 0.32445 | -0.7100 | 0.4783 | -0.8660 | 0.4059 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -0.8691 | 1.15953 | -0.7500 | 0.4535 | -3.1417 | 1.4035 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.96070*** | 0.04906 | 19.5800 | 0.0000 | 0.8646 | 1.0569 |

***, **, * *indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.5 Negative-Value Change Order Magnitude

Table C.5 Multinomial Logit Results for Negative-Value CO Amounts

| Variables | Coefficient | Standard Error | z | P-value | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Reference level of the dependent variable is ($-50K, $0K) | | | | | | |
| **Dependent Variable Level: ($-750K, $-50K]** | | | | | | |
| Constant | -1.39459*** | 0.18697 | -7.46 | 0 | -1.76104 | -1.02815 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | 0.10794 | 0.21299 | 0.51 | 0.6123 | -0.3095 | 0.52539 |
| Crawfordsville | 0.34812* | 0.19743 | 1.76 | 0.0779 | -0.03884 | 0.73507 |
| Seymour | 0.24942 | 0.20926 | 1.19 | 0.2333 | -0.16073 | 0.65956 |
| Fort Wayne | -0.03671 | 0.2135 | -0.17 | 0.8635 | -0.45515 | 0.38174 |
| Vincennes | -0.14982 | 0.24716 | -0.61 | 0.5444 | -0.63425 | 0.33461 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | 0.01765 | 0.26681 | 0.07 | 0.9473 | -0.50529 | 0.54058 |
| Urban | 0.1059 | 0.13992 | 0.76 | 0.4491 | -0.16835 | 0.38015 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | 0.11526 | 0.15898 | 0.72 | 0.4685 | -0.19634 | 0.42686 |
| Pavement-Related | 0.67463*** | 0.16556 | 4.07 | 0 | 0.35014 | 0.99912 |
| Road-Related | -0.01983 | 0.23001 | -0.09 | 0.9313 | -0.47064 | 0.43097 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | 1.2023 | 1.23918 | 0.97 | 0.3319 | -1.22646 | 3.63106 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.59936*** | 0.05259 | 11.4 | 0 | 0.49629 | 0.70244 |
| **Dependent Variable Level: [Min, $-750K]** | | | | | | |
| Constant | -5.80640*** | 0.74424 | -7.8 | 0 | -7.26509 | -4.34771 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | 0.29045 | 0.72519 | 0.4 | 0.6888 | -1.13089 | 1.71179 |
| Crawfordsville | 0.17904 | 0.72649 | 0.25 | 0.8053 | -1.24486 | 1.60294 |
| Seymour | -0.69374 | 0.91165 | -0.76 | 0.4467 | -2.48054 | 1.09306 |
| Fort Wayne | 0.19377 | 0.73055 | 0.27 | 0.7908 | -1.23809 | 1.62562 |
| Vincennes | -0.23207 | 0.84723 | -0.27 | 0.7841 | -1.8926 | 1.42846 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | – | – | – | – | – | – |
| Urban | 0.35045 | 0.47554 | 0.74 | 0.4611 | -0.58158 | 1.28249 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | -0.08918 | 0.65777 | -0.14 | 0.8922 | -1.37839 | 1.20003 |
| Pavement-Related | 0.66846 | 0.52954 | 1.26 | 0.2068 | -0.36943 | 1.70635 |
| Road-Related | -2.99997** | 1.16923 | -2.57 | 0.0103 | -5.29162 | -0.70833 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -10.8252 | 858.6443 | -0.01 | 0.9899 | -1693.74 | 1672.087 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.90602*** | 0.07421 | 12.21 | 0 | 0.76057 | 1.05147 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.6 Sensitivity of CO Magnitude to the Influential Factors

Table C.6 Marginal Effects for Positive-Value or Negative-Value COs

| **Variables** | **Marginal Effect** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | 0.01324 | 0.02411 | 0.55000 | 0.58300 | -0.03402 | 0.06049 |
| Crawfordsville | 0.15521*** | 0.02623 | 5.92000 | 0.00000 | 0.10380 | 0.20663 |
| Seymour | 0.05302** | 0.02492 | 2.13000 | 0.03340 | 0.00418 | 0.10187 |
| Fort Wayne | 0.05020** | 0.02511 | 2.00000 | 0.04560 | 0.00099 | 0.09940 |
| Vincennes | 0.00194 | 0.02739 | 0.07000 | 0.94360 | -0.05174 | 0.05562 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | -0.09310*** | 0.02578 | -3.61000 | 0.00030 | -0.14362 | -0.04258 |
| Urban | -0.01304 | 0.01626 | -0.80000 | 0.42230 | -0.04491 | 0.01882 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | 0.03363* | 0.01892 | 1.78000 | 0.07550 | -0.00345 | 0.07072 |
| Pavement-Related | 0.19502*** | 0.02223 | 8.77000 | 0.00000 | 0.15145 | 0.23859 |
| Road-Related | -0.03105 | 0.02408 | -1.29000 | 0.19730 | -0.07825 | 0.01615 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -0.19356*** | 0.05727 | -3.38000 | 0.00070 | -0.30581 | -0.08131 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.00133 | 0.00130 | 1.02000 | 0.30900 | -0.00123 | 0.00388 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.7 Sensitivity of CO Magnitude to the Influential Factors

Table C.7 Marginal Effects and Elasticities for Positive-Value CO Amounts

| **Variables** | **Marginal Effect** | **Elasticity** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| **Marginal Effects on Probability for Dependent Variable is ($K–$50K)** | | | | | | |
| LaPorte | 0.01848 | – | 0.56 | 0.5756 | -0.04622 | 0.08318 |
| Crawfordsville | 0.05985 | – | 1.59 | 0.1117 | -0.01389 | 0.1336 |
| Seymour | .09702*** | – | 2.78 | 0.0055 | 0.02857 | 0.16548 |
| Fort Wayne | .07659** | – | 2.2 | 0.0275 | 0.00849 | 0.14469 |
| Vincennes | 0.03717 | – | 0.98 | 0.3275 | -0.03723 | 0.11157 |
| Small Urban | .10068** | – | 2.45 | 0.0142 | 0.02024 | 0.18112 |
| Urban | .04339* | – | 1.75 | 0.0796 | -0.00512 | 0.09189 |
| Bridge-Related | .13176*** | – | 4.74 | 0 | 0.07723 | 0.18628 |
| Pavement-Related | 0.04445 | – | 1.25 | 0.2104 | -0.0251 | 0.11401 |
| Road-Related | -0.0199 | – | -0.57 | 0.5687 | -0.08832 | 0.04852 |
| Design-Build | .38244** | – | 2.31 | 0.0209 | 0.05804 | 0.70684 |
| Award Amount $M | -.18188*** | -1.13023 | -21.12 | 0 | -0.19875 | -0.165 |
| **Marginal Effects on Probability for Dependent Variable is [$50K, $750K)** | | | | | | |
| LaPorte | -0.01939 | – | -0.59 | 0.5554 | -0.08386 | 0.04507 |
| Crawfordsville | -0.04331 | – | -1.15 | 0.2483 | -0.11685 | 0.03022 |
| Seymour | -.06577* | – | -1.87 | 0.0617 | -0.13477 | 0.00323 |
| Fort Wayne | -0.05457 | – | -1.57 | 0.1165 | -0.12271 | 0.01357 |
| Vincennes | -0.02101 | – | -0.56 | 0.5783 | -0.09511 | 0.05309 |
| Small Urban | 0.0228 | – | 0.53 | 0.5981 | -0.06198 | 0.10759 |
| Urban | -0.02254 | – | -0.91 | 0.3609 | -0.07088 | 0.0258 |
| Bridge-Related | -.11679*** | – | -4.15 | 0 | -0.17197 | -0.0616 |
| Pavement-Related | -0.04967 | – | -1.42 | 0.1553 | -0.11819 | 0.01884 |
| Road-Related | 0.03167 | – | 0.93 | 0.3541 | -0.03531 | 0.09866 |
| Design-Build | -0.38737** | – | -2.33 | 0.0197 | -0.71304 | -0.06169 |
| Award Amount $M | .016132*** | 0.6808 | 19.46 | 0 | 0.14508 | 0.17757 |
| **Marginal Effects on Probability for Dependent Variable is [$750K, Max]** | | | | | | |
| LaPorte | 0.00091 | – | 0.08 | 0.9349 | -0.02096 | 0.02278 |
| Crawfordsville | -0.01654 | – | -1.2 | 0.2298 | -0.04353 | 0.01045 |
| Seymour | -.03125** | – | -2.12 | 0.0339 | -0.06011 | -0.00238 |
| Fort Wayne | -0.02202 | – | -1.64 | 0.1016 | -0.04838 | 0.00434 |
| Vincennes | -0.01616 | – | -1.2 | 0.2311 | -0.0426 | 0.01028 |
| Small Urban | -0.12348*** | – | -3.42 | 0.0006 | -0.19434 | -0.05262 |
| Urban | -0.02085** | – | -2.32 | 0.0203 | -0.03846 | -0.00324 |
| Bridge-Related | -0.01497 | – | -1.33 | 0.1842 | -0.03707 | 0.00713 |
| Pavement-Related | 0.00522 | – | 0.49 | 0.6242 | -0.01566 | 0.0261 |
| Road-Related | -0.01177 | – | -0.96 | 0.3381 | -0.03586 | 0.01231 |
| Design-Build | 0.00493 | – | 0.11 | 0.9091 | -0.07961 | 0.08946 |
| Award Amount $M | 0.02056*** | 1.1833 | 7.59 | 0 | 0.01525 | 0.02586 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.8 Sensitivity of CO Magnitude to the Influential Factors

Table C.8 Marginal Effects and Elasticities for Negative-Value CO Amounts

| Variables | Marginal Effect | Elasticity | z | P-value | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| **Marginal Effects on Probability for Dependent Variable is ($-50K, $0K)** | | | | | | |
| LaPorte | -0.02577 | – | 0 | 0.9996 | -102.273 | 102.2215 |
| Crawfordsville | -0.08262 | – | 0 | 0.9992 | -159.292 | 159.1263 |
| Seymour | -0.05869 | – | 0 | 0.9999 | -644.615 | 644.4974 |
| Fort Wayne | 0.00858 | – | 0 | 0.9999 | -154.008 | 154.0255 |
| Vincennes | 0.03566 | – | 0 | 0.9982 | -31.4843 | 31.55561 |
| Small Urban | 0.01573 | – | 0 | 1 | -9,471.24 | 9,471.271 |
| Urban | -0.02532 | – | 0 | 0.9997 | -142.605 | 142.5541 |
| Bridge-Related | -0.02726 | – | 0 | 0.9997 | -148.548 | 148.4932 |
| Pavement-Related | -0.16032 | – | 0 | 0.9975 | -101.225 | 100.9047 |
| Road-Related | 0.00656 | – | 0 | 1 | -1,920.37 | 1,920.38 |
| Design-Build | -0.27827 | – | 0 | 0.9999 | -7,935.24 | 7,934.681 |
| Award Amount $M | -0.14263 | -0.9181 | 0 | 0.998 | -111.788 | 111.5028 |
| **Marginal Effects on Probability for Dependent Variable is ($-750K, $-50K]** | | | | | | |
| LaPorte | 0.02541 | – | 0 | 0.9999 | -269.795 | 269.8461 |
| Crawfordsville | 0.08268 | – | 0 | 0.9988 | -103.634 | 103.7994 |
| Seymour | 0.06003 | – | 0 | 0.9999 | -757.182 | 757.3021 |
| Fort Wayne | -0.00892 | – | 0 | 0.9999 | -204.184 | 204.1664 |
| Vincennes | -0.03543 | – | 0 | 0.9997 | -201.487 | 201.4164 |
| Small Urban | 0.03541 | – | 0 | 1 | ********** | 14,828.55 |
| Urban | 0.02486 | – | 0 | 0.9999 | -330.945 | 330.9947 |
| Bridge-Related | 0.02752 | – | 0 | 0.9996 | -115.811 | 115.8663 |
| Pavement-Related | 0.15991 | – | 0 | 0.9995 | -526.054 | 526.3741 |
| Road-Related | -0.00181 | – | 0 | 1 | -3,030.36 | 3,030.357 |
| Design-Build | 0.29667 | – | 0 | 1 | ********** | 11,218.4 |
| Award Amount $M | 0.14177 | 0.58217 | 0 | 0.9997 | -783.121 | 783.4042 |
| **Marginal Effects on Probability for Dependent Variable is [min, $-750K]** | | | | | | |
| LaPorte | 0.00036 | – | 0 | 1 | -372.068 | 372.0682 |
| Crawfordsville | -.053304D-04 | – | 0 | 1 | -.55492D+02 | .55492D+02 |
| Seymour | -0.00135 | – | 0 | 1 | -1401.8 | 1,401.797 |
| Fort Wayne | 0.00034 | – | 0 | 1 | -358.192 | 358.1925 |
| Vincennes | -0.00022 | – | 0 | 1 | -232.972 | 232.9713 |
| Small Urban | -0.05114 | – | 0 | 1 | ********** | 24,299.72 |
| Urban | 0.00045 | – | 0 | 1 | -473.549 | 473.5497 |
| Bridge-Related | -0.00025 | – | 0 | 1 | -264.359 | 264.359 |
| Pavement-Related | 0.00041 | – | 0 | 1 | -425.149 | 425.1497 |
| Road-Related | -0.00476 | – | 0 | 1 | -4950.74 | 4,950.727 |
| Design-Build | -0.0184 | – | 0 | 1 | ********** | 19,153.05 |
| Award Amount $M | 0.00086 | 1.34976 | 0 | 1 | -894.907 | 894.9087 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.9 Change Order Frequency Models

Table C.9 Result of Binary Model for CO Frequency Model

| **Variables** | **Coefficient** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Constant | -3.33219*** | 0.16664 | -20 | 0 | -3.65881 | -3.00558 |
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | -0.63688*** | 0.17519 | -3.64 | 0.0003 | -0.98025 | -0.29352 |
| Crawfordsville | -0.80759*** | 0.19392 | -4.16 | 0 | -1.18766 | -0.42752 |
| Seymour | -0.88228*** | 0.19924 | -4.43 | 0 | -1.27279 | -0.49177 |
| Fort Wayne | -0.28782 | 0.17534 | -1.64 | 0.1007 | -0.63148 | 0.05583 |
| Vincennes | -1.65248*** | 0.27166 | -6.08 | 0 | -2.18492 | -1.12003 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | 0.78198*** | 0.21408 | 3.65 | 0.0003 | 0.36238 | 1.20158 |
| Urban | 0.67874*** | 0.13249 | 5.12 | 0 | 0.41906 | 0.93842 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | 0.28068* | 0.1595 | 1.76 | 0.0784 | -0.03192 | 0.59329 |
| Pavement-Related | -0.41511** | 0.18109 | -2.29 | 0.0219 | -0.77004 | -0.06018 |
| Road-Related | 1.04015*** | 0.15531 | 6.7 | 0 | 0.73575 | 1.34455 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -1.11928 | 1.01104 | -1.11 | 0.2683 | -3.10089 | 0.86232 |
| **Award Amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.53287*** | 0.02486 | 21.43 | 0 | 0.48414 | 0.5816 |

***, **, * *indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

Table C.10 Marginal Effects of the CO Frequency Model

| **Variables** | **Marginal Effect** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| **District (Greenfield as reference)** | | | | | | |
| LaPorte | -0.04162*** | 0.01028 | -4.05 | 0.0001 | -0.06177 | -0.02147 |
| Crawfordsville | -0.05063*** | 0.01043 | -4.86 | 0 | -0.07107 | -0.03019 |
| Seymour | -0.05511*** | 0.01059 | -5.2 | 0 | -0.07587 | -0.03435 |
| Fort Wayne | -0.01995* | 0.0116 | -1.72 | 0.0855 | -0.04268 | 0.00279 |
| Vincennes | -0.08537*** | 0.00956 | -8.93 | 0 | -0.10411 | -0.06663 |
| **Area (rural as reference)** | | | | | | |
| Small Urban | 0.06735*** | 0.02147 | 3.14 | 0.0017 | 0.02528 | 0.10942 |
| Urban | 0.05114*** | 0.01032 | 4.95 | 0 | 0.03091 | 0.07138 |
| **Project Type (demolition, maintenance, and traffic-related as reference)** | | | | | | |
| Bridge-Related | 0.02116* | 0.01248 | 1.7 | 0.09 | -0.0033 | 0.04563 |
| Pavement-Related | -.02801** | 0.01129 | -2.48 | 0.0131 | -0.05015 | -0.00588 |
| Road-Related | 0.09357*** | 0.01689 | 5.54 | 0 | 0.06046 | 0.12668 |
| **Not Design-Build as Reference** | | | | | | |
| Design-Build | -0.06064 | 0.03924 | -1.55 | 0.1223 | -0.13755 | 0.01628 |
| **Award amount as a Continuous Variable** | | | | | | |
| Award Amount $M | 0.03865*** | 0.00186 | 20.74 | 0 | 0.03499 | 0.0423 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

## C.10 Predicting the CO Magnitude ($M) Using Linear Regression

Table C.11 Linear Regression Result for CO Amounts ($M)

| | Unstandardized Coefficients | | Standardized Coefficients | | | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|
| **Variables** | **B** | **Std. Error** | **Beta** | ***t*** | **Sig.** | **Lower Bound** | **Upper Bound** |
| Constant | 0.497 | 0.083 | | 6.026 | 0.000 | 0.336 | 0.659 |
| LaPorte | -0.036 | 0.026 | -0.022 | -1.385 | 0.166 | -0.086 | 0.015 |
| Crawfordsville | -0.073 | 0.027 | -0.043 | -2.727 | 0.006 | -0.126 | -0.021 |
| Seymour | -0.033 | 0.025 | -0.021 | -1.285 | 0.199 | -0.082 | 0.017 |
| Fort Wayne | -0.054 | 0.026 | -0.034 | -2.061 | 0.039 | -0.105 | -0.003 |
| Vincennes | -0.004 | 0.028 | -0.003 | -0.156 | 0.876 | -0.059 | 0.051 |
| Small Urban | -0.028 | 0.031 | -0.012 | -0.893 | 0.372 | -0.088 | 0.033 |
| Urban | -0.036 | 0.018 | -0.029 | -2.046 | 0.041 | -0.071 | -0.002 |
| Bridge-Related | -0.047 | 0.020 | -0.034 | -2.332 | 0.020 | -0.087 | -0.007 |
| Pavement-Related | -0.050 | 0.023 | -0.031 | -2.196 | 0.028 | -0.094 | -0.005 |
| Road-Related | 0.033 | 0.025 | 0.020 | 1.338 | 0.181 | -0.015 | 0.082 |
| Design-Build | -0.429 | 0.079 | -0.074 | -5.445 | 0.000 | -0.583 | -0.274 |
| Award Amount $M | 0.034 | 0.001 | 0.328 | 23.453 | 0.000 | 0.031 | 0.037 |

Table C.12 Linear Regression Result for Positive-Value CO Amounts ($M)

| Variables | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Standardized Coefficients Beta | t-value | Sig. | 95.0% Confidence Interval for B Lower Bound | 95.0% Confidence Interval for B Upper Bound |
|---|---|---|---|---|---|---|---|
| Constant | 0.141 | 0.030 | | 4.635 | 0.000 | 0.081 | 0.201 |
| LaPorte | -0.042 | 0.036 | -0.022 | -1.175 | 0.240 | -0.112 | 0.028 |
| Crawfordsville | -0.071 | 0.040 | -0.032 | -1.777 | 0.076 | -0.149 | 0.007 |
| Seymour | -0.037 | 0.037 | -0.018 | -.992 | 0.321 | -0.110 | 0.036 |
| Fort Wayne | -0.070 | 0.037 | -0.035 | -1.866 | 0.062 | -0.143 | 0.004 |
| Vincennes | -0.063 | 0.041 | -0.029 | -1.538 | 0.124 | -0.143 | 0.017 |
| Small Urban | -0.106 | 0.042 | -0.041 | -2.511 | 0.012 | -0.190 | -0.023 |
| Urban | -0.085 | 0.026 | -0.056 | -3.269 | 0.001 | -0.137 | -0.034 |
| Bridge-Related | -0.074 | 0.029 | -0.042 | -2.536 | 0.011 | -0.131 | -0.017 |
| Pavement-Related | 0.062 | 0.036 | 0.028 | 1.710 | 0.087 | -0.009 | 0.132 |
| Road-Related | -0.039 | 0.036 | -0.019 | -1.071 | 0.284 | -0.109 | 0.032 |
| Design-Build | 0.317 | 0.112 | 0.045 | 2.828 | 0.005 | 0.097 | 0.536 |
| Award Amount $M | 0.071 | 0.002 | 0.588 | 34.938 | 0.000 | 0.067 | 0.075 |

Table C.13 Linear Regression Results for Negative-Value CO Amounts ($M)

| Variables | Unstandardized Coefficients | | Standardized Coefficients | t-value | Sig. | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| Constant | -0.025 | 0.018 | | -1.362 | 0.174 | -0.061 | 0.011 |
| LaPorte | -0.006 | 0.022 | -0.007 | -0.282 | 0.778 | -0.049 | 0.036 |
| Crawfordsville | -0.020 | 0.020 | -0.025 | -0.992 | 0.321 | -0.060 | 0.020 |
| Seymour | 0.017 | 0.021 | 0.021 | 0.818 | 0.413 | -0.024 | 0.059 |
| Fort Wayne | -0.001 | 0.022 | -0.001 | -0.029 | 0.977 | -0.043 | 0.042 |
| Vincennes | -0.002 | 0.025 | -0.002 | -0.097 | 0.923 | -0.051 | 0.046 |
| Small Urban | 0.038 | 0.028 | 0.027 | 1.345 | 0.179 | -0.017 | 0.093 |
| Urban | -0.019 | 0.014 | -0.029 | -1.362 | 0.174 | -0.047 | 0.008 |
| Bridge-Related | 0.004 | 0.017 | 0.005 | 0.223 | 0.824 | -0.029 | 0.036 |
| Pavement-Related | -0.049 | 0.016 | -0.067 | -3.031 | 0.002 | -0.081 | -0.017 |
| Road-Related | 0.045 | 0.023 | 0.043 | 1.967 | 0.049 | 0.000 | 0.090 |
| Design-Build | 0.529 | 0.107 | 0.102 | 4.922 | 0.000 | 0.318 | 0.739 |
| Award Amount $M | -0.038 | 0.001 | -0.703 | -33.507 | 0.000 | -0.041 | -0.036 |

Table C.14 Binary Logit Model Results for SD Occurrence Likelihood

| **Variables** | **Coefficient** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Constant | -0.38499*** | 0.08789 | -4.38 | 0 | -0.55726 | -0.21273 |
| LaPorte | 0.50580*** | 0.1035 | 4.89 | 0 | 0.30295 | 0.70865 |
| Crawfordsville | 0.03465 | 0.1079 | 0.32 | 0.7481 | -0.17683 | 0.24613 |
| Seymour | -0.08791 | 0.10637 | -0.83 | 0.4085 | -0.29638 | 0.12057 |
| Fort Wayne | 0.19990* | 0.10617 | 1.88 | 0.0597 | -0.00819 | 0.40799 |
| Vincennes | -0.22299* | 0.12059 | -1.85 | 0.0644 | -0.45934 | 0.01336 |
| Small Urban | 0.24733** | 0.12456 | 1.99 | 0.0471 | 0.00321 | 0.49146 |
| Urban | 0.35222*** | 0.07288 | 4.83 | 0 | 0.20937 | 0.49506 |
| Bridge-Related | -0.30741*** | 0.08339 | -3.69 | 0.0002 | -0.47086 | -0.14397 |
| Pavement-Related | -0.42817*** | 0.0944 | -4.54 | 0 | -0.61319 | -0.24315 |
| Road-Related | 0.03987 | 0.10641 | 0.37 | 0.7079 | -0.16869 | 0.24843 |
| Design-Build | -0.46506 | 0.39872 | -1.17 | 0.2435 | -1.24653 | 0.31641 |
| Award Amount $M | 0.05834*** | 0.00966 | 6.04 | 0 | 0.0394 | 0.07727 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

Table C.15 MNL Model Results for the Positive-Value SD Magnitude Model

| **Variables** | **Coefficient** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| Reference level of the dependent variable is [1, 90) days | | | | | | |
| **Dependent Variable Level: [90, 180) Days** | | | | | | |
| Constant | -1.65288*** | 0.21643 | -7.64 | 0 | -2.07707 | -1.22869 |
| LaPorte | -0.28753 | 0.24711 | -1.16 | 0.2446 | -0.77186 | 0.19679 |
| Crawfordsville | 0.13514 | 0.25534 | 0.53 | 0.5966 | -0.36532 | 0.6356 |
| Seymour | 0.32723 | 0.25024 | 1.31 | 0.191 | -0.16323 | 0.81769 |
| Fort Wayne | -0.21919 | 0.26106 | -0.84 | 0.4011 | -0.73086 | 0.29249 |
| Vincennes | 0.64052** | 0.27262 | 2.35 | 0.0188 | 0.1062 | 1.17483 |
| Small Urban | 0.30531 | 0.26976 | 1.13 | 0.2577 | -0.22342 | 0.83404 |
| Urban | 0.17284 | 0.17085 | 1.01 | 0.3117 | -0.16203 | 0.5077 |
| Bridge-Related | -0.89206*** | 0.23231 | -3.84 | 0.0001 | -1.34738 | -0.43674 |
| Pavement-Related | -0.75793*** | 0.24665 | -3.07 | 0.0021 | -1.24136 | -0.27451 |
| Road-Related | -0.2262 | 0.2128 | -1.06 | 0.2878 | -0.64328 | 0.19089 |
| Design-Build | 0.43977 | 0.80307 | 0.55 | 0.584 | -1.13422 | 2.01377 |
| Award Amount $M | 0.03515*** | 0.01073 | 3.28 | 0.0011 | 0.01412 | 0.05617 |
| **Dependent Variable Level: [180–Max] Days** | | | | | | |
| Constant | -0.13652 | 0.14576 | -0.94 | 0.349 | -0.42221 | 0.14917 |
| LaPorte | -0.33010** | 0.16384 | -2.01 | 0.0439 | -0.65122 | -0.00898 |
| Crawfordsville | -0.41829** | 0.19024 | -2.2 | 0.0279 | -0.79114 | -0.04544 |
| Seymour | -0.40973** | 0.19168 | -2.14 | 0.0326 | -0.78543 | -0.03404 |
| Fort Wayne | -0.71581*** | 0.18813 | -3.8 | 0.0001 | -1.08453 | -0.34709 |
| Vincennes | -0.2162 | 0.21532 | -1 | 0.3153 | -0.63822 | 0.20582 |
| Small Urban | -0.47172** | 0.23031 | -2.05 | 0.0405 | -0.92312 | -0.02033 |
| Urban | -0.39055*** | 0.12516 | -3.12 | 0.0018 | -0.63585 | -0.14524 |
| Bridge-Related | -0.78952*** | 0.15705 | -5.03 | 0 | -1.09733 | -0.4817 |
| Pavement-Related | -0.82233*** | 0.17829 | -4.61 | 0 | -1.17178 | -0.47289 |
| Road-Related | -0.52655*** | 0.17515 | -3.01 | 0.0026 | -0.86983 | -0.18326 |
| Design-Build | 0.88617 | 0.60516 | 1.46 | 0.1431 | -0.29992 | 2.07226 |
| Award Amount $M | 0.03507*** | 0.00985 | 3.56 | 0.0004 | 0.01577 | 0.05437 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

Table C.16 Marginal Effects for SD Probability for Contracts with CO

| **Variables** | **Marginal Effect** | **Standard Error** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| LaPorte | 0.12165*** | 0.02471 | 4.92 | 0 | 0.07322 | 0.17008 |
| Crawfordsville | 0.00824 | 0.02566 | 0.32 | 0.7483 | -0.04206 | 0.05853 |
| Seymour | -0.02085 | 0.02517 | -0.83 | 0.4076 | -0.07018 | 0.02849 |
| Fort Wayne | .04764* | 0.02531 | 1.88 | 0.0598 | -0.00197 | 0.09725 |
| Vincennes | -0.05263* | 0.02818 | -1.87 | 0.0618 | -0.10786 | 0.0026 |
| Small Urban | 0.05903** | 0.02974 | 1.99 | 0.0471 | 0.00075 | 0.11731 |
| Urban | 0.08460*** | 0.01753 | 4.83 | 0 | 0.05024 | 0.11896 |
| Bridge-Related | -0.07260*** | 0.01945 | -3.73 | 0.0002 | -0.11072 | -0.03449 |
| Pavement-Related | -0.09999*** | 0.02139 | -4.68 | 0 | -0.1419 | -0.05807 |
| Road-Related | 0.00949 | 0.02537 | 0.37 | 0.7084 | -0.04024 | 0.05922 |
| Design-Build | -0.1068 | 0.08711 | -1.23 | 0.2202 | -0.27754 | 0.06394 |
| Award Amount $M | 0.01386*** | 0.00229 | 6.04 | 0 | 0.00936 | 0.01835 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

Table C.17 Marginal Effects of the Positive-Value SD Magnitude Model

| **Variables** | **Marginal Effect** | **Elasticity** | **z** | **P-value** | **95% Confidence Interval** | |
|---|---|---|---|---|---|---|
| **Marginal Effects on Probability for Dependent Variable is [1, 90) Days of Delay** | | | | | | |
| LaPorte | 0.07347** | – | 2.12 | 0.0337 | 0.00565 | 0.14129 |
| Crawfordsville | 0.05751 | – | 1.48 | 0.1399 | -0.01884 | 0.13385 |
| Seymour | 0.04244 | – | 1.09 | 0.2767 | -0.03404 | 0.11893 |
| Fort Wayne | 0.13051*** | – | 3.4 | 0.0007 | 0.05531 | 0.2057 |
| Vincennes | -0.01094 | – | -0.25 | 0.8035 | -0.09713 | 0.07524 |
| Small Urban | 0.05396 | – | 1.2 | 0.2318 | -0.03448 | 0.14239 |
| Urban | 0.05037** | – | 1.96 | 0.0494 | 0.00013 | 0.10061 |
| Bridge-Related | 0.19029*** | – | 5.87 | 0 | 0.12679 | 0.25378 |
| Pavement-Related | 0.18600*** | – | 5.15 | 0 | 0.11521 | 0.25679 |
| Road-Related | 0.10063*** | – | 2.87 | 0.0041 | 0.03197 | 0.16929 |
| Design-Build | -0.17357 | – | -1.3 | 0.1948 | -0.43593 | 0.08879 |
| Award Amount $M | -0.00813*** | -0.04037 | -3.71 | 0.0002 | -0.01243 | -0.00383 |
| **Marginal Effects on Probability for Dependent Variable is [90, 180) Days of Delay** | | | | | | |
| LaPorte | -0.01928 | – | -0.8 | 0.4223 | -0.06638 | 0.02782 |
| Crawfordsville | 0.02533 | – | 1.03 | 0.3051 | -0.02308 | 0.07373 |
| Seymour | 0.04422* | – | 1.84 | 0.0664 | -0.00299 | 0.09143 |
| Fort Wayne | -0.00154 | – | -0.06 | 0.952 | -0.05149 | 0.04841 |
| Vincennes | 0.06994*** | – | 2.7 | 0.007 | 0.0191 | 0.12079 |
| Small Urban | 0.04379* | – | 1.68 | 0.0939 | -0.00744 | 0.09503 |
| Urban | 0.02829* | – | 1.72 | 0.0862 | -0.00403 | 0.06062 |
| Bridge-Related | -0.06648*** | – | -2.97 | 0.003 | -0.11036 | -0.02259 |
| Pavement-Related | -0.05218** | – | -2.17 | 0.0297 | -0.09922 | -0.00515 |
| Road-Related | -0.0076 | – | -0.37 | 0.7115 | -0.04788 | 0.03267 |
| Design-Build | 0.01868 | – | 0.25 | 0.7995 | -0.12546 | 0.16282 |
| Award Amount $M | 0.00251*** | 0.07043 | 2.78 | 0.0055 | 0.00074 | 0.00428 |
| **Marginal Effects on Probability for Dependent Variable is [180, Max] Days of Delay** | | | | | | |
| LaPorte | -0.05419* | – | -1.79 | 0.0729 | -0.1134 | 0.00503 |
| Crawfordsville | -0.08283** | – | -2.37 | 0.0176 | -0.15125 | -0.01442 |
| Seymour | -0.08666** | – | -2.47 | 0.0135 | -0.15544 | -0.01789 |
| Fort Wayne | -0.12897*** | – | -3.72 | 0.0002 | -0.19689 | -0.06105 |
| Vincennes | -0.059 | – | -1.51 | 0.1323 | -0.13582 | 0.01783 |
| Small Urban | -0.09775** | – | -2.31 | 0.0211 | -0.18081 | -0.01468 |
| Urban | -0.07866*** | – | -3.43 | 0.0006 | -0.12365 | -0.03367 |
| Bridge-Related | -0.12381*** | – | -4.27 | 0 | -0.18065 | -0.06697 |
| Pavement-Related | -0.13381*** | – | -4.06 | 0 | -0.19837 | -0.06925 |
| Road-Related | -0.09303*** | – | -2.9 | 0.0037 | -0.1559 | -0.03015 |
| Design-Build | 0.15489 | – | 1.47 | 0.1423 | -0.052 | 0.36178 |
| Award Amount $M | 0.00563*** | 0.07018 | 3.37 | 0.0007 | 0.00236 | 0.00889 |

****, **, * indicate that the variable is statistically significant at 1%, 5%, 10% level, respectively.*

Table C.18 Linear Regression Results for the Positive-Value SD Magnitude Model (days)

| Variables | Unstandardized Coefficients | | Standardized Coefficients | | | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | *t* | Sig. | Lower Bound | Upper Bound |
| Constant | 243.965 | 13.294 | | 18.352 | 0.000 | 217.893 | 270.038 |
| LaPorte | -40.324 | 14.618 | -0.077 | -2.759 | 0.006 | -68.994 | -11.654 |
| Crawfordsville | -35.358 | 16.537 | -0.057 | -2.138 | 0.033 | -67.793 | -2.924 |
| Seymour | -65.049 | 16.580 | -0.107 | -3.923 | 0.000 | -97.567 | -32.531 |
| Fort Wayne | -76.407 | 15.875 | -0.134 | -4.813 | 0.000 | -107.542 | -45.271 |
| Vincennes | -18.620 | 18.918 | -0.026 | -0.984 | 0.325 | -55.723 | 18.483 |
| Small Urban | -67.890 | 18.558 | -0.087 | -3.658 | 0.000 | -104.287 | -31.493 |
| Urban | -59.667 | 10.812 | -0.138 | -5.519 | 0.000 | -80.872 | -38.462 |
| Bridge-Related | -96.989 | 13.121 | -0.181 | -7.392 | 0.000 | -122.723 | -71.256 |
| Pavement-Related | -99.909 | 14.559 | -0.165 | -6.863 | 0.000 | -128.462 | -71.355 |
| Road-Related | -55.268 | 14.605 | -0.096 | -3.784 | 0.000 | -83.913 | -26.624 |
| Design-Build | 43.620 | 53.184 | 0.020 | 0.820 | 0.412 | -60.689 | 147.928 |
| Award Amount $M | 2.514 | 0.668 | 0.094 | 3.766 | 0.000 | 1.205 | 3.823 |

## About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

## About This Report

An open access version of this publication is available online. See the URL in the citation below.

Padhye, S., Sharma, A., Arefkhani, H., Benny, D., Gkritza, K., Labi, S., & Hastak, M. (2024). *INDOT project change orders: Root causes and recommendations* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2024/14). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317747