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CONSTRUCTION ENGINEERING AND INSPECTION (CE&I) COSTS IN THE TEXAS DEPARTMENT OF TRANSPORTATION

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Abstract: Construction engineering and inspection (CE&I) costs not only constitute a large portion of a project's engineering and procurements costs, but also reliably consume a measure of project construction costs for state transportation agencies in the United States. In Texas specifically, CE&I costs comprised between 3.2% and 4.4% of total construction costs every year between 2005 and 2015. Discussions with subject matter experts from the Texas Department of Transportation (TxDOT) indicate that spending too little on CE&I can lead to quality issues, but spending too much could lead to inefficient use of limited public resources. This study provides an overview of CE&I costs TxDOT incurred between 2001 and 2017 to identify optimal allocation of resources (and consequently costs) for CE&I functions at the project level. Projects were aggregated at the contract level to reduce noise in the dataset, and trends based on project characteristics were identified, yielding analysis of project-level cost data for 6,577 construction projects. Our results indicate that CE&I costs (when expressed as a percentage of construction costs) have an inverse relationship with construction costs—i.e., as the construction contract size increases, the percentage CE&I costs decrease. In addition, CE&I costs vary based on the project type. Notably, project types with the highest percentage of construction costs devoted to CE&I are traffic signals (8.3%) and landscape and scenic enhancement (7.8%). This study additionally highlights a need for careful examination of costs for projects larger than $1 million whose classification contains the term "miscellaneous," as the use of such a generic category can result in misrepresentation of costs.

1 INTRODUCTION

Construction engineering and inspection (CE&I) costs not only constitute a large portion of a project's engineering and procurements costs, but also reliably consume a measure of project construction costs for state transportation agencies (STAs) in the United States. In Texas specifically, CE&I costs comprised between 3.2% and 4.4% of total construction costs every year between 2005 and 2015. Discussions with subject matter experts from the Texas Department of Transportation (TxDOT) indicate that spending too little on CE&I can lead to quality issues, but spending too much could lead to inefficient use of limited public resources. Existing literature about optimization of CE&I functions in STAs in the United States focuses on three major areas: (1) CE&I best practices during construction work, (2) personnel forecasting and allocation, and (3) the use of consulting companies to perform CE&I functions.

In exploring the first literature review topic, the researchers found that the CE&I best practices identified by existing literature include the provision of formations and technical certification programs (Tran et al., 2014; Marks and Teizer, 2016) as well as adequate testing equipment, assistance, and guidance (Hallowell et al., 2012). Additionally, having staff perform CE&I functions on a cluster of projects that are geographically close was highlighted as an efficient method to optimize resource allocation (Hallowell et al., 2012; Tran et al., 2014). More research about best practices in resource assignment to CE&I functions is still needed, as shown by a National Cooperative Highway Research Program (NCHRP) research project currently underway whose objective is to develop guidance for staffing transportation construction projects, with a focus on inspection and testing staffing (Taylor, 2018).

An investigation of the second topic area revealed that efficient personnel forecasting and allocation methods have been researched in the context of projects executed for STAs (e.g., Bell and Brandenburg, 2003 for the South Carolina Department of Transportation; Menches, Caldas et al., 2008 for TxDOT). STAs have developed metrics and tools to forecast staffing requirements. Existing tools include Excel-based forms, checklists, and calculation guidelines (Taylor and Maloney, 2013). Such forecasting methods need to be further developed and used by STAs according to Taylor and Maloney (2013), who showed that in 2013, "of the 40 STAs that responded to requests for information [for their study], only seven reported having some formal method or tool for estimating construction staffing needs for future projects."

Finally, the optimization of resource assignment for CE&I functions was studied in the context of decision-making procedures for outsourcing staff. Using CE&I consulting companies for construction projects provides to "STAs the improved ability to handle peak workloads, provide the flexibility of adding or reducing staff quickly, and bring special expertise that may not otherwise be available in-house" (Torres et al., 2015). Outsourcing can also be effective in the case of rural or remote areas (Tran et al., 2014). With the exception of studies completed by Tufte et al. (1988) and Radhakrishnan (2010), existing literature about decision-making procedure for outsourcing CE&I staff is scarce to the authors' knowledge. However, some STAs have been quickly transitioning to outsourced CE&I since 2010 (Torres et al., 2015). For instance, TxDOT, which has historically relied on a well-trained internal workforce for performing the CE&I functions on its construction projects, significantly increased its use of consultant contracting for select CE&I functions beginning in 2011. From one CE&I contract worth approximately $8 million in 2011, TxDOT has expanded CE&I outsourcing to over 71 contracts estimated at over $300 million in value in 2016. This increase occurred in a context of funding increases for TxDOT's projects: in 2017, the 10-year Unified Transportation Program plan increased to over $70 billion to meet the Texas's growing transportation demands (TxDOT, 2016). Such a shift in the use of consultants for CE&I functions requires further analyses to optimize resource assignment for CE&I functions. For instance, TxDOT currently uses a decentralized empirical process to determine CE&I outsourcing at the project level, but is developing a methodology for objectively assessing its CE&I needs and a decision support process for outsourcing the CE&I functions at the project level.

This study seeks to identify trends in project characteristics that correspond to significant CE&I reduction or increase in costs. Project characteristics investigated are project classification (i.e., type of work performed) and total construction costs. This study is based on an analysis of project-level cost data for 6,577 construction projects conducted during the studied period. This dataset was prepared for analysis by excluding select projects and aggregating projects at the contract level. This study can help STAs in their decision-making when allocating resources to CE&I functions: based on the results of this study, they could identify potential ways to optimize expenditures and staff allocations. Additionally, the trends in project characteristics identified in this study could help STAs plan CE&I budgets based on their portfolio of future projects.

2 RESEARCH METHODS

2.1 Original dataset used

An Excel-based dataset of financial information for 7,094 projects was provided by TxDOT's Finance Division in November 2016. The projects' letting dates range from 2001 to 2017, with a majority letting between 2013 to 2015. These attributes were available for each project:

- Control Section Jobs (CSJ)—a unique contract identification number,
- Life-to-date construction (LTD) costs without administration costs,
- LTD administration costs,
- LTD construction engineering and inspection: (1) in-house without administration and (2) consultant costs without administration,
- LTD construction engineering and inspection administration costs,
- Project classification, such as Widen Freeway or Rehabilitation of Existing Road,
- Estimated total construction costs,
- Completion date estimated before the end of the project, and
- Project work: (1) short description and (2) complete description.

2.2 Data preparation

Projects excluded from the study had the following characteristics: (1) the project classification does not typically require CE&I, (2) the project description indicates that the construction project was likely managed by a different public entity, or (3) the project attributes indicate that the project is not significant (e.g., project is old or has an uncharacteristically low total LTD construction cost).

Projects that are not typical highway, roadway, or bridge construction types were excluded from this study. For instance, Bicycle Facility, Feasibility Studies, Outdoor Advertising Control, Preliminary Engineering, Right of Way, and Safety Rest Area were excluded from this study. The project classifications included in the study are shown in Table 1. In addition, the project classifications Emergency Response, Miscellaneous, and Exempt from Sealing – Transportation Enhancement Project were reviewed individually to determine applicability to the study. Eight hundred and thirty-two (832) of those projects were reviewed individually. The *type of work* and *project descriptions* were used to classify projects into these subcategories: road paint, pavement marking, major road/ bridge repair or reconstruction, guardrails, paving, intersection and lane improvements, landscape improvements, detention ponds, and repairs. Other project categories such as feasibility studies, money transfer, railroads, sidewalks, trails, bike lanes, traffic signs, lighting facilities, and emergency repairs were excluded from this study, as the CE&I work for those projects can be nonexistent, non-site-specific, or not performed by TxDOT. Note that TxDOT has stopped using the project classification Miscellaneous for projects that let in February 2018 or later. “Miscellaneous” represented a catchall classification and presented difficulties for research and analyses purposes, as this paper will expand upon in the Discussion section.

Based on the projects’ attributes, potentially atypical projects were identified. These projects were then reviewed individually and excluded from this study if necessary. For instance, all projects with let dates prior to January 1, 2001, were excluded.

Overall, the initial data preparation yielded the following groupings:

- 6,577 projects ($13,706,399,882 total construction costs) out of 7,094 ($14,752,213,626 total construction costs) were selected for the main analysis.
- 517 projects ($1,051,230,317 total construction costs) were not included in this analysis.

2.3 Project aggregation at the Contract CSJ level

The projects listed in the dataset were first screened at the CSJ level. However, a construction contract may contain several CSJs. Projects in the dataset were aggregated at the *Contract CSJ* level, with 2,370 unique Contract CSJ IDs (aggregated from 6,577 projects). This aggregation ensures that the analysis was performed at the construction-project level. Attributes for this aggregated dataset were populated as follows: total costs were calculated for all cost-related attributes, and project classifications were populated only if all the projects with a unique CSJ have identical project classifications (left blank otherwise).

Table 1: Dataset before and after project selection, and after aggregation at the Contract CSJ level

Classification	No. of projects in original dataset	Total LTD construction costs (including admin) before selection ($)	No. of unique contract CSJs selected after aggregation	Total LTD construction costs (including admin) after selection ($)	Total CE&I costs (% total LTD construction costs) after selection
Widen Freeway	46	2,058,198,359	24	1,916,914,984	3.70%
Widen Non-Freeway	187	1,931,582,145	64	1,876,402,374	4.40%
Rehabilitation of Existing Road	502	1,823,830,068	320	1,813,564,112	3.50%
Miscellaneous Construction	794	1,405,070,430	278	689,447,782	4.70%
Interchange	59	1,380,544,807	35	1,380,394,929	4.00%
Overlay	634	1,334,004,791	357	1,334,004,289	2.70%
Pavement Markings and Texturizing	1,369	714,448,603	345	713,900,101	4.10%
New Location Freeway	17	643,727,818	9	643,727,817	3.80%
New Location Non-Freeway	65	643,579,399	49	642,790,542	3.80%
Bridge Replacement	589	635,080,787	361	635,080,787	6.00%
Seal Coat	2,066	564,942,702	94	564,773,731	1.10%
Restoration	124	309,607,330	78	309,607,329	2.70%
Upgrade to Standards Freeway	22	233,577,632	17	233,577,631	3.70%
Convert Non-Freeway To Freeway	12	203,438,787	8	189,732,270	3.50%
Bridge Widening Or Rehabilitation	62	179,628,044	43	179,628,044	4.30%
Upgrade to Standards Non-Freeway	27	124,574,546	16	124,574,546	5.10%
Rehabilitate Roads	23	104,440,947	13	104,440,947	2.90%
Corridor Traffic Management	39	74,235,070	28	71,372,826	1.80%
Hazard Elimination & Safety	54	64,076,588	23	64,076,587	4.40%
Traffic Signal	93	62,758,407	62	62,758,406	8.30%
Landscape and Scenic Enhancement	131	61,199,378	98	61,198,577	7.80%
Exempt from Sealing - Transportation Enhancement	16	33,153,902	1	15,071,099	2.30%
Bridge Maintenance	56	22,111,153	24	22,111,153	3.40%
Railroad Relocation	3	17,743,881	3	17,743,880	0.10%
Provide Additional Surface	5	14,738,223	4	14,738,222	1.10%
Traffic Protection Devices	7	12,817,562	6	12,817,561	4.00%
Bridge Structure Repair	2	6,091,914	2	6,091,913	3.00%
Emergency Response	22	5,675,357	2	662,953	0.0.%

Classification	No. of projects in original dataset	Total LTD construction costs (including admin) before selection ($)	No. of unique contract CSJs selected after aggregation	Total LTD construction costs (including admin) after selection ($)	Total CE&I costs (% total LTD construction costs) after selection
Infrastructure Rehabilitation	4	2,757,317	1	2,757,317	0.10%
Grade Crossing Protection	23	2,558,421	5	2,437,173	1.20%
Total	7,094	14,752,213,626	2,370	13,706,399,882	3.8%

After aggregation, five outlier projects (out of 2,375) were identified and removed from the dataset. Those projects have CE&I costs higher than 50% of the total LTD construction costs and have a total construction cost of less than $0.5 million. The threshold of 50% was chosen to allow visually discernible scaling of the box and whisker plot along the vertical axis. As the number and absolute cost of the outlier projects is small, the effect on the analysis is minimal.

2.4 Summary of final contract CSJ data selected

Table 1 provides a summary of the dataset used for this study before and after processing the data and aggregation; project classifications were ranked from highest to lowest total LTD construction costs. Project classifications that were excluded from this study were also excluded from Table 1.

2.5 2.5. Study limitations

Limitations to this study include the fact that the dataset used is specific to TxDOT. Additionally, the let dates of the projects used in this study range various dates but are not equally distributed throughout these years since a majority of the projects have let dates ranging between 2013 to 2015. This study thus does not include a temporal analysis.

3 RESULTS

3.1 General data characterization after data preparation

Figures 1 and 2 show the CE&I costs versus LTD construction costs. The box and whisker format used in Figure 2 graphically displays the range of observed CE&I costs, providing a view of the historical variability for CE&I costs for different project sizes.

3.2 Results by project classification

The total CE&I costs (as a percentage of the total construction costs) for each project classification varies between 0.0% and 8.3%, depending on the project classifications (see Table 1). Additionally, the CE&I costs of all projects selected for this study represent 3.8% of total LTD construction costs. Project classifications with total CE&I costs greater than 4.6% of total LTD construction costs are Miscellaneous Construction, Upgrade to Standards Non-Freeway, Bridge Replacement, Landscape and Scenic Enhancement, and Traffic Signal (as Table 1 indicates). Costs associated with Miscellaneous Construction and Bridge Replacement are particularly critical since they are in the top 10 of project classifications that correspond to the highest total LTD construction costs in the selected data. Additionally, the total LTD construction costs of projects whose classifications are Miscellaneous Construction or Bridge Replacement represent 9.7% of the total LTD construction costs of all projects. Figures 3 and 4 show CE&I costs versus total construction costs for those two project classifications. Charts showing CE&I costs versus total construction costs are provided in Figures 5 and 6 for the two project classifications that correspond to the highest total LTD construction costs after aggregation (see Table 1). Those project classifications are, respectively, Widen Freeway and Widen Non-Freeway.

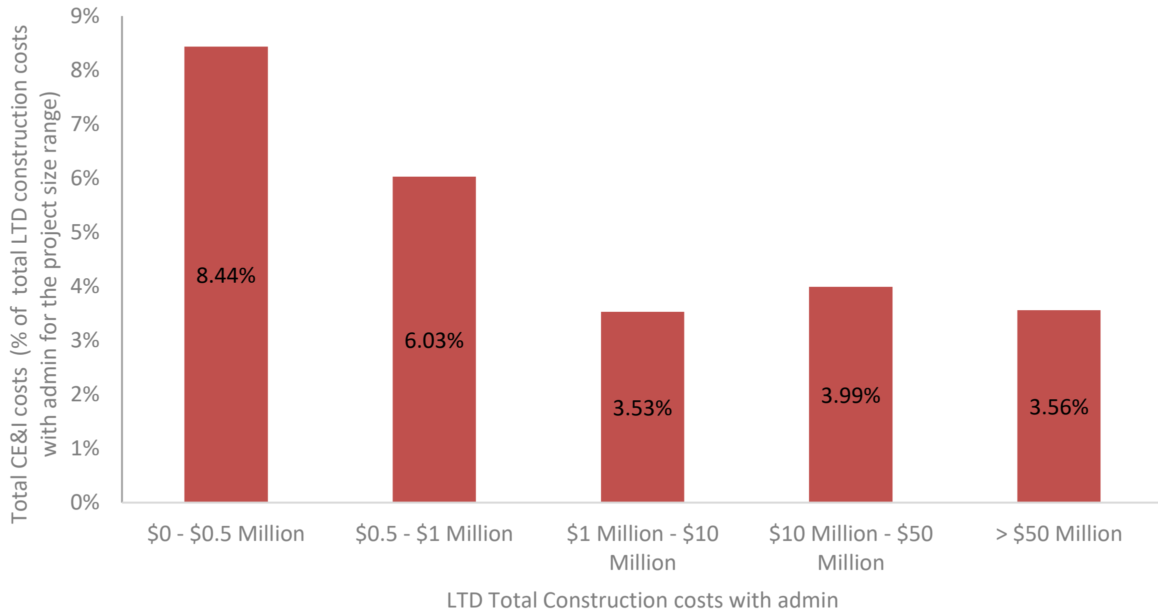

Figure 1: Total CE&I costs per project size range (% of total construction cost) versus project size

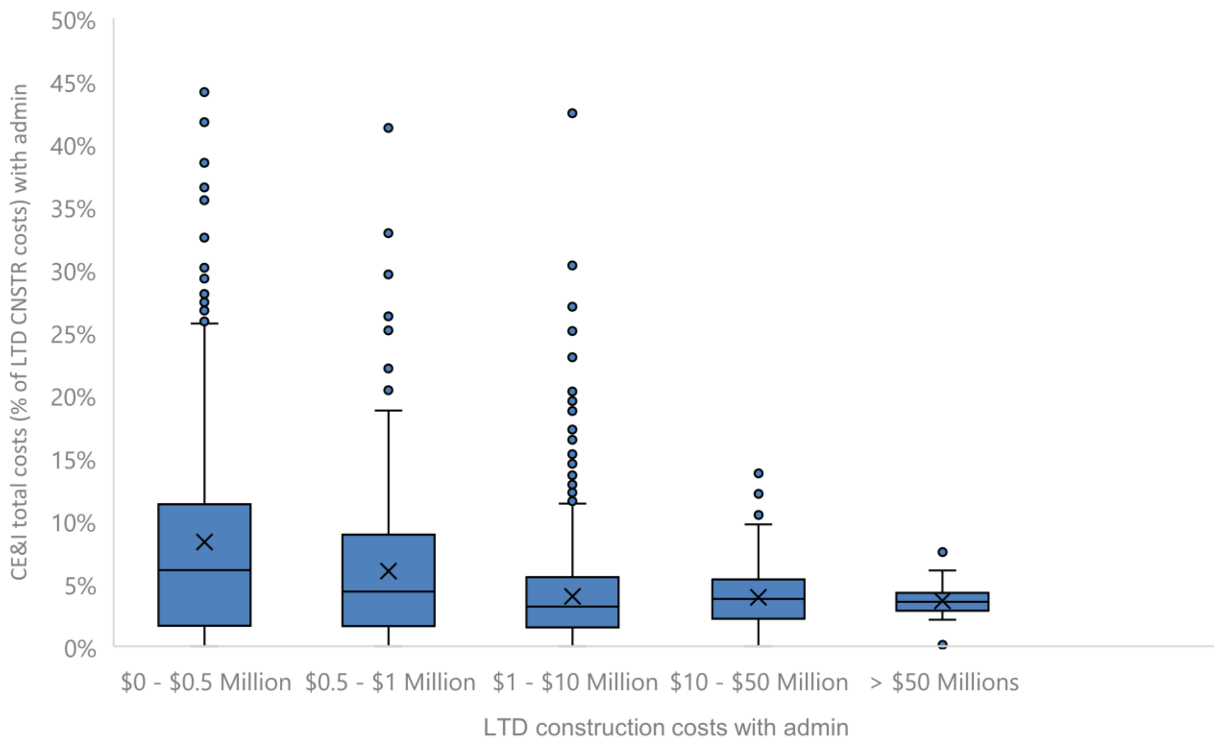

Figure 2: Total CE&I costs (% of total construction cost) versus project size

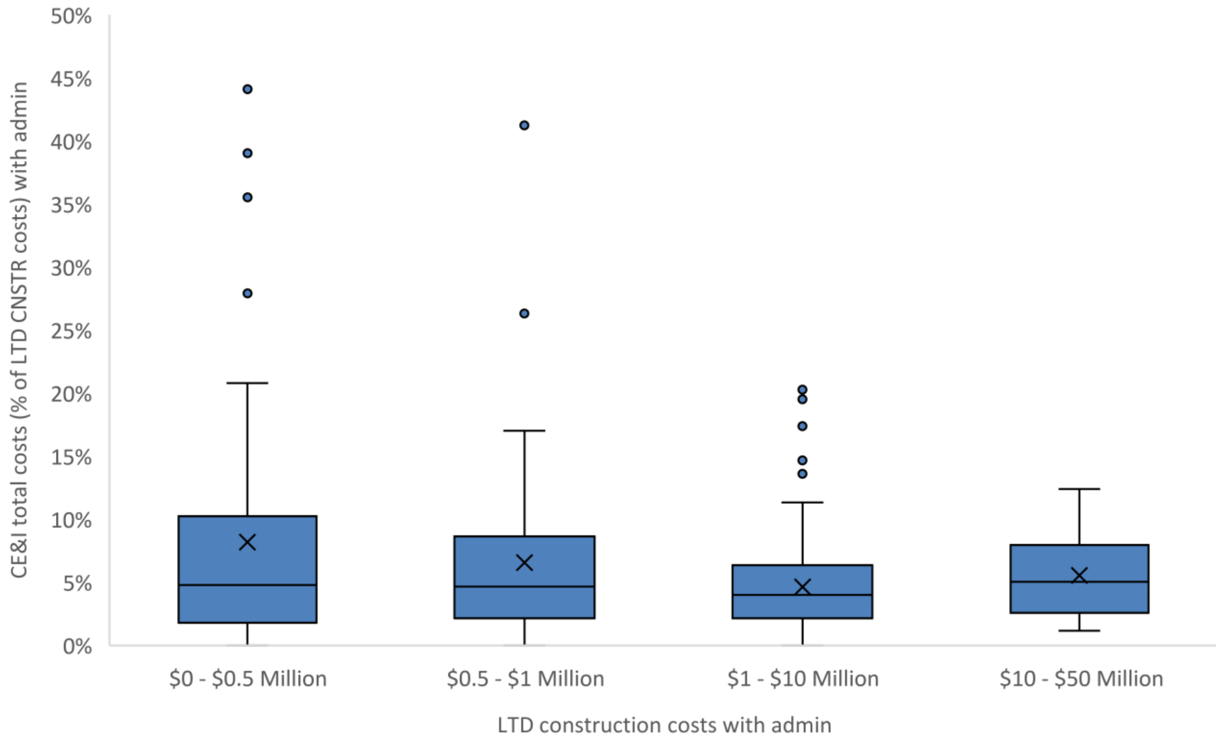

Figure 3: Miscellaneous Construction—total CE&I costs as a percentage of the total LTD construction costs

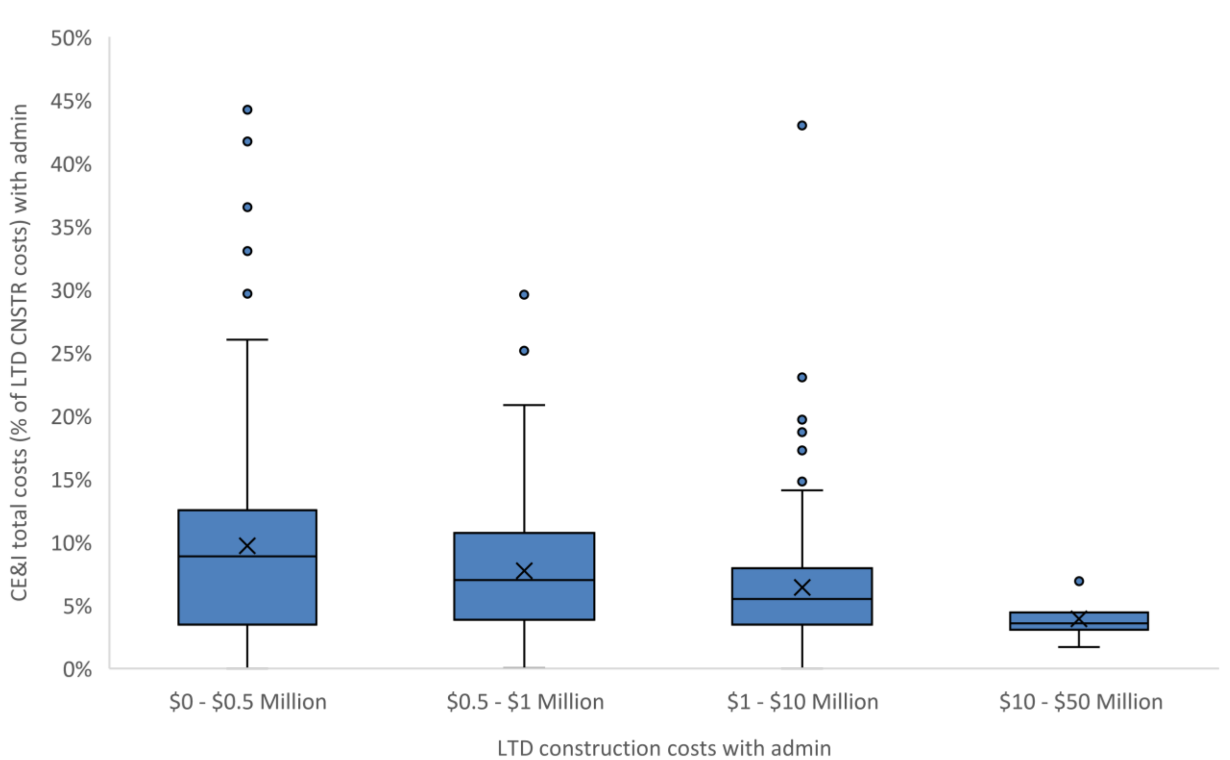

Figure 4: Bridge Replacement—total CE&I costs as a percentage of the total LTD construction costs

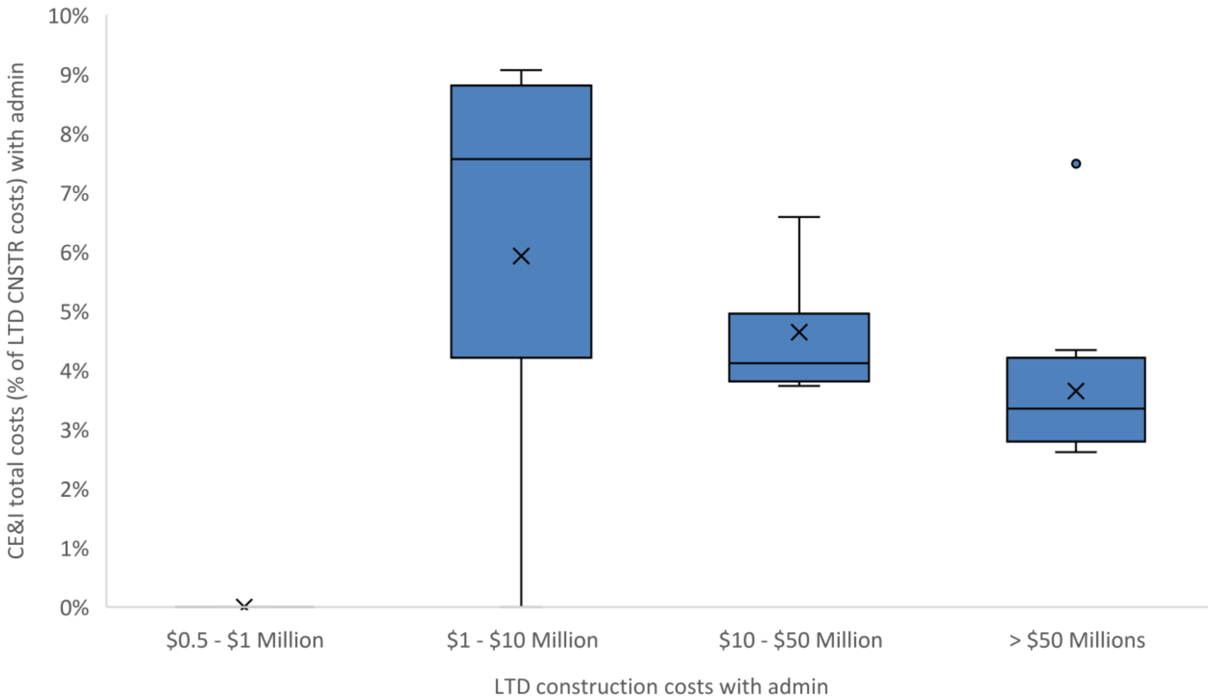

Figure 5: Widen Freeway—total CE&I costs as a percentage of the total LTD construction costs

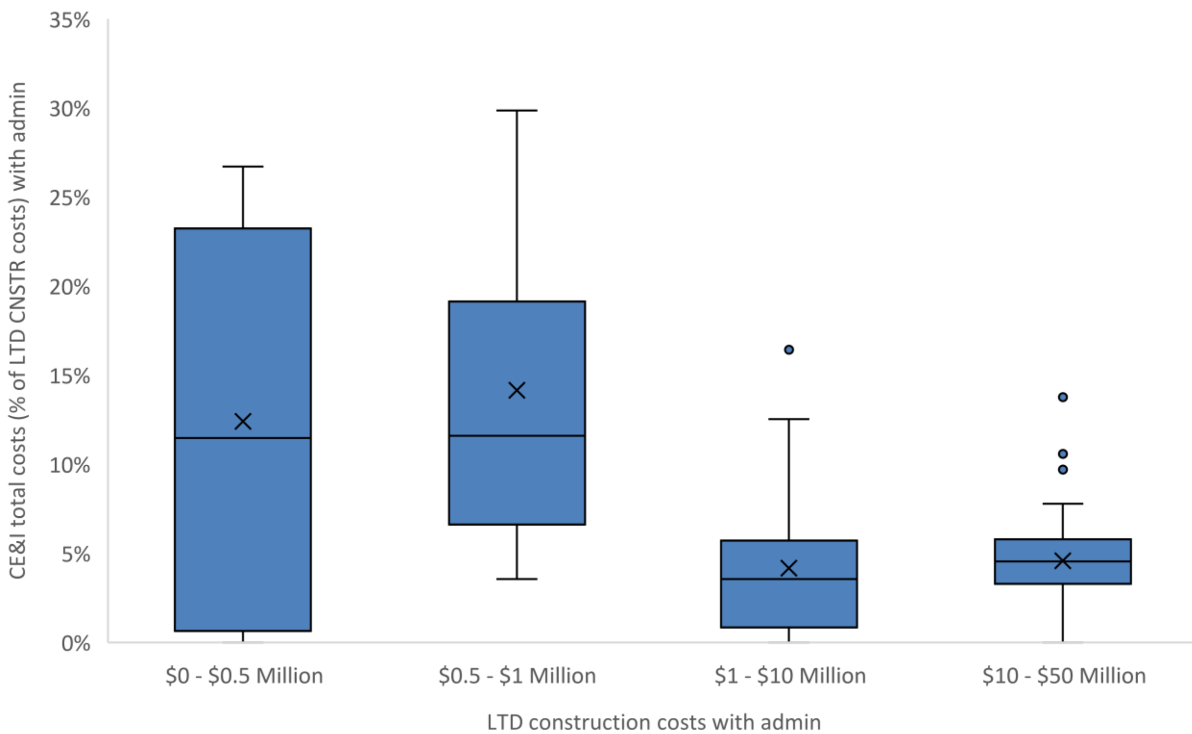

Figure 6. Widen Non-Freeway—total CE&I costs as a percentage of the total LTD construction costs

4 DISCUSSION

The dataset used in this study had significant noise; however, using box and whisker plots (e.g., in Figure 2) enabled the research team to identify trends in CE&I costs based on total construction costs and project types. The first trend identified is that CE&I costs (when expressed as a percentage of construction costs) have an inverse relationship with construction costs—i.e., as the construction contract size increases, the percentage CE&I costs decrease. Figure 2 indicates that, using all selected projects, the average, median, and third quartile values of CE&I costs decrease when the range of project size increases. Figures 3 to 5 indicate that such an inverse relationship exists for projects whose classifications are Miscellaneous Construction, Bridge Replacement, and Widen Freeway. Figure 6 indicates that this relationship for projects whose classifications are Widen Non-Freeway is slightly different since mean and average CE&I costs are larger for projects in the $0.5–$1 million range than in the $0–$0.5 million range. This anomaly might be related to the fact that Widen Non-Freeway projects, similarly to Widen Freeway projects, are typically large projects that cost tens of millions of dollars. In the dataset used for this study, only four out of 133 Widen Non-Freeway projects are in the $0–$0.5 million range, and four are in the $0.5–$1 million range. Figure 6 indicates that, for this project classification, CE&I costs are significantly greater for projects with total construction costs of more than $1 million than for projects with total construction costs of less than $1 million.

The second trend identified is that CE&I costs vary based on project types (see Table 1). Noticeably, project types of interest in this study were Miscellaneous Construction and Bridge Replacement, given the high total construction costs and CE&I costs (as percentage of construction costs) associated with those projects. Figures 3 and 4 show that those two project classifications have more than six outliers with CE&I costs between 14% and 45% in the $1–$10 million range. Those outliers might be responsible for the high total CE&I costs identified in Table 1 for those two project classifications. These results thus highlight the critical role of such outliers and we believe that this study can help STAs identify such outliers. We recommend that agencies keep in mind the total CE&I costs when planning and contracting: based on this study, CE&I costs represent 3.8% of the total construction costs registered. More specifically, CE&I costs greater than 10% of the total construction costs can identify a need for quality checks. Additionally, the results of this study support the decision made by TxDOT to withdraw in 2017 the classification Miscellaneous Construction from the list of classifications available when inputting project information in its dataset of projects. Our analysis indicates that having a catchall project classification can potentially increase the likelihood of large projects having extremely high CE&I costs (e.g., higher than 14%) when compared to average CE&I costs (3.8%). We thus recommend that project classifications similar to Miscellaneous Construction are either used carefully or avoided altogether. Doing so can additionally help STAs obtain more homogeneous project classifications that can be better used for future research and analysis purposes.

5 CONCLUSION

For this study, a list of 7,094 projects, conducted between 2000 and 2017, was obtained from TxDOT. Out of those projects, 6,577 were selected for analysis. After developing scatter plots of CE&I costs versus LTD construction costs, the research team noticed that the noise in the data provided was high. Since construction contracts may contain several individual design projects (CSJs), the cleaned-up CSJs were aggregated at the contract CSJ level, providing a dataset of 2,370 aggregated projects that underwent further analysis. The noise in the data as compared to pre-aggregation noise was reduced—but not significantly enough to mitigate the challenge of obtaining regressions that could be further analyzed. The research team thus decided to use box and whisker plots for ease of interpretation in this paper.

The figures obtained and presented in this study seem to align with the results presented in previous TxDOT reports. Notably, the trend of CE&I costs as a percentage of total LTD construction costs is similar to trends identified by TxDOT in 2008, while being on average more than 1% lower for projects with costs exceeding $1 million.

The results indicate that CE&I costs (when expressed as a percentage of construction costs) have an inverse relationship with construction costs and vary based on the project type. Noticeably, project types with the highest percentage of construction costs used for CE&I are traffic signals (8.3%), Landscape and Scenic Enhancement (7.8%), and Bridge Replacement (6.0%). This study additionally highlighted a potential need for attention for projects larger than $1 million in total construction costs and whose classifications are Miscellaneous Construction and Bridge Replacement. The results of this study also indicates that catchall project classifications such as Miscellaneous Construction can potentially misrepresent CE&I costs as a greater percentage of construction costs than they actually require. A potential solution for STAs is to try to reduce the use of such classifications. The results from this study can help STAs effectively plan budget and resource needs for CE&I functions and their geographical allocation. The findings of this study can be useful for other STAs and transportation agencies outside of the US as they indicate a potential need for attention to specific project types (e.g., replacement of bridges) and sizes when allocating resources to CE&I functions.

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