Challenges in Engineering Estimates for Best-Value Design-Build Highway Projects

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Abstract

Traditional design-bid-build guidelines suggest that engineering estimates should be within +/- 10% of the lowest contractor bid and recommend this value as a reference to identify anomalies in the bidding process. This guidance, however, neglects delivery approaches such as design-build. This research examines 305 design-build highway projects procured using best-value and identifies the underlying reasons for bid dispersion and cost estimates inaccuracies. This study found an average bid dispersion of 27%, suggesting that a larger threshold (i.e., 25%) is needed to account for the inherent variability of design-build projects. This study also found that engineering estimates are on average 2% more than the awarded price. This result contradicts findings in existing literature and suggests that current practice in design-build best-value may be more conservative than other procurement methods. The study explores four potential reasons for bid dispersion and engineering estimate inaccuracies and suggests strategies for improvement. By

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providing a better understanding of bid dispersion and engineering estimate accuracy, this study will ultimately assist in the development of new policies and processes for best-value design-build projects.

INTRODUCTION

Design-build (D-B) is an alternative project delivery method that has been growing in recent years (Sullivan et al., 2017; FMI, 2018; Liang et al., 2020). One of the advantages of D-B, probably influencing its increased use, derives from the overlap of design and construction phases which result in reduced project durations. Within D-B, best-value procurement has also seen increased usage in the last years and has now become a common scenario (Molenaar et al. 2010). Compared to traditional approaches solely based on cost (i.e., low bid), best-value procurement considers price as well as other key factors to enhance the value of construction (Molenaar and Tran, 2015).

While several procurement methods (e.g., low bid, best-value, qualifications-based selection, etc.) can theoretically be combined with different project delivery systems (e.g., design-bid-build, design-build, etc.), highway agencies use low bid almost exclusively in design-bid-build. Design-bid-build is the traditional method in highway construction. Agency policy and legislation generally requires a low-bid approach in the traditional delivery method. Best-value procurement is preferred in design-build projects because it provides a balance between a low-bid procurement and qualification-based selection (Nguyen et al., 2018; Calahorra-Jimenez et al., 2020; Calahorra-Jimenez et al., 2021). In fact, many agencies require best-value selection for design-build projects because the price component corresponds to traditional low-bid selection of the builder and the qualification-based component corresponds to the traditional selection of the designer.

Design-build is typically chosen to accelerate project completion and has been proven to provide cost savings without compromising quality (FHWA, 2018). Compared to traditional project delivery methods (e.g., design-bid-build, D-B-B), D-B presents several advantages such as increased cost efficiencies, more opportunities for value-engineering, flexibility in risk allocation, reduced litigation throughout the project, and enhanced schedule performance (FHWA, 2006; Hale et al., 2009; Shrestha at al., 2012). Previous studies have compared the performance of D-B and other delivery systems (i.e., D-B, construction manager at risk (CMR), etc.) (Sullivan et al. 2017), with some studies focusing on specific project types including buildings (Shrestha and Fernane 2017), industrial projects (Franz et al., 2020), mechanical projects (Riley et al. 2005), and highway projects (El Asmar et al. 2020; Tran et al. 2018). According to the International Transport Forum, Organization for Economic Cooperation and Development (OECD) countries invest, on average, approximately 1% of their Gross Domestic Products on transportation infrastructure (OECD/ITF, 2013). Given the importance of transportation projects in the global economy, the scope of this study is focused on highway projects.

The overlap of design and construction phases in D-B projects results in an additional advantage: cost certainty (i.e., when an agency obtains a contracted price for the project) in D-B projects is 40% earlier than that of D-B-B (FHWA, 2017). However, agencies using D-B face challenges in the estimation of project costs because the scope and requirements of the project are not completely defined at the time of procurement (Molenaar and Gransberg, 2001).

Early cost estimates in D-B projects are particularly difficult because of the low level of design and complex risk allocation at the time of procurement (Molenaar et al. 2006). Before the procurement process starts, agencies develop in-house engineering estimates to understand the project needs and requirements and estimate the total project cost. Engineering estimates help stakeholders in the decision-making process related to project funding, resource allocation, and planning. Accurate engineering estimates, with cost estimates as close as possible to the cost of the award-winning proposal, are important for all the stakeholders involved in the project. Inaccurate estimates can cause inefficient utilization of taxpayers' money and waste of planning efforts (Oberlender and Trost, 2001). Previous studies have found that project planners may often consider optimistic assumptions and unintentionally underestimate project costs in an intent to secure public funds and avoid them being committed to other projects (Karaca et al. 2020; Flyvbjerg et al. 2002; Jennings, 2012).

An additional challenge for accurate engineering estimates is related to the dispersion in design-builders price proposals (i.e., the range from lowest to highest price proposal). On traditional D-B-B projects, non-regulatory guidance from the FHWA (2014) states that the engineer's estimate should be within +/- 10% of the winning low bid. According to FHWA's guidance, if this threshold for accuracy is not being achieved, confidence in the engineer's estimate may decline. State Departments of Transportation (DOTs) have traditionally used this threshold to identify anomalies in the bidding process (FHWA 2019, Anderson and Blashcke 2004). Despite the fact that this FHWA non-regulatory guidance is widely accepted by DOTs, the agencies differ on their interpretation. This results in miscalculations and differences in the threshold value used (FHWA 2019 and Anderson and Blashcke 2004). Several states use a single percentage, such as 5%, 7%, or 10% over the engineer's estimate, whereas other states use ranges expressed by both under and over the engineer's estimate, such as 20% below and 10% above or 15% under or 10% over (Anderson and Blashcke 2004). Given the lack of consensus on the threshold used to define adequate accuracy levels in engineer's estimate, there is a need to empirically define a reasonable value of engineer's estimate accuracy.

An additional limitation of the traditional 10% threshold is that this criterion has not been rigorously evaluated since it was introduced in the early 1980s (FHWA 2019). As a result, FHWA's guidance has not kept pace with more recent project delivery approaches, such as design-build. A recent audit concluded that FHWA’s 2004 guidance is out of date and lacks a validated threshold to assess the accuracy of engineer’s estimates (FHWA 2019).

Anecdotal evidence has shown that this range may be too narrow for D-B, but further there is a lack of empirical evidence (Molenaar et al. 2006, FHWA 2019). Several factors have been identified as triggering price proposal dispersion in design-build projects, such as the implications of contract provisions on design-builder’s risk appetite and the variation in the design-builders design approach and quantities (Molenaar et al. 2006). With these factors relying on the design-builder approach to the bid, agencies can expect dispersions in price proposals that are not necessarily under their control and it would be desirable for public agencies to have guidance on reasonable values of bid dispersion.

Developing accurate engineering estimates and maintaining reasonable expectations for bid-dispersion is a challenge for agencies procuring projects using best-value design-build. The goal of this paper is to diagnose current practices related to cost estimating in design-build best-value (D-B/BV) highway projects and provide guidance on the underlying reasons for bid dispersion and engineering estimates inaccuracies. To achieve this goal, this study analyzes 305 D-B/BV projects from DOTs across the United States and combines quantitative and qualitative approaches to evaluate current engineering estimate’s accuracy, price proposal dispersion, and the underlying reasons for these phenomena. This research contributes to the body of knowledge in innovative project delivery through empirical examination a first-of-a-kind database of 305 transportation infrastructure projects using D-B/BV to: (1) identify challenges and limitations in current practice related to cost estimating, (2) provide guidance on reasonable expectations for cost estimates and price dispersion, (3) identify the main reasons leading to bid dispersion and cost estimate inaccuracies, and (4) recommend strategies to improve current practice.

Although D-B has extensively been used in the last decades and is expected to grow in the coming years (Duggan and Patel, 2014; FMI, 2018), some public agencies still consider D-B as a limited option (DBIA, 2019). By analyzing the challenges in engineering estimates for D-B/BV highway projects, this study aims to guide policy-makers, agencies, and researchers on setting reasonable expectations for cost estimates and price dispersion and formulate new policies and processes for D-B/BV projects.

LITERATURE REVIEW

Current practices in cost estimation of highway projects are well documented in Anderson et al. (2007). In the recent years, a growing body of knowledge have proposed data modeling methods aimed at improving the accuracy of cost estimates (He et al., 2021). Some of the data-driven techniques used in previous studies include structural equation modeling (Alroomi et al. 2016), data mining (Liang et al. 2019), advanced time-series models (Ilbeigi et al. 2017), and artificial neural networks (Karaca et al. 2020), among others. In response to the increase usage of D-B as an alternative project delivery method, previous studies have extensively analyzed the schedule and cost performance of D-B projects and how they differ from other project delivery methods (Michin et al., 2013; Chen et al., 2016; Sullivan et al., 2017; Antoine et al., 2019; Choi at al., 2020; Moon et al., 2020; Franz et al., 2020). With respect to cost performance, previous studies have developed statistical models to determine the impact of project features on cost overruns (Creedy et al., 2010; Ramsey et al., 2016; Lu et al., 2017; Liang et al., 2020). Previous studies have found that agencies tend to overestimate project costs by unintentionally introducing optimistic assumptions (Karaca et al. 2020; Flyvbjerg et al. 2002; Jennings, 2012).

Despite the extensive work done on the cost performance of D-B projects, there is a limited number of studies focused on bid dispersion and the accuracy of engineering estimates. This information is crucial for public agencies to define reasonable expectations on engineering estimates accuracy and bid dispersion. The American Association of Cost Engineering (AACE 2019) suggests that D-B projects with 10% to 30% design development should have an estimate accuracy ranging from -30% to +50%. Empirical studies analyzing D-B/BV in highway projects in the United States have shown average accuracies of 7%, suggesting that engineering estimates in D-B/BV projects are within reasonable values (FHWA, 2017). However, these studies also showed that the accuracy of cost estimates in D-B/BV is significantly lower than other delivery methods. Alleman et al. (2017) compared the accuracy of cost estimates in highways projects across four delivery methods: D-B-B, D-B/BV, design-build/low bid (D-B/LB), and construction manager/general contractor (CM/GC) and found that agencies obtain the highest estimating accuracy for CM/GC projects. The high accuracy of CM/GC project estimates is due to the negotiation of price with one contractor and greater involvement between the contractor and the agency in understanding the project scope, costs, and risks. This level of involvement of the agency-contractor is absent in D-B/BV projects because of the design and project competition involved in these procurements, which negatively impacts the accuracy of engineering estimates.

In D-B/BV, some specific reasons why engineering estimates deviate from award-winning price proposals may be due to several facts inherent to the procurement method (Molenaar et al., 2006): (1) projects are pushed towards procurement at an early stage of project development; (2) proposals differ in scope due to the opportunity of value-engineering, innovation, and risk appetite of the design-builder; (3) difficulty in predicting the cost of risks associated; and (4) varied degree of agencies experience in D-B/BV projects.

Given the inherent characteristics of D-B/BV, some degree of bid dispersion and inaccuracy in cost estimates is to be expected and agencies would benefit from guidance on reasonable expectations for cost estimates and price dispersion. This paper analyzes a first-of-a-kind dataset comprising 305 D-B/BV projects from State Departments of Transportation (DOTs) across the United States to diagnose current practices related to cost estimating in design-build best-value (D-B/BV) projects and provide guidance on the underlying reasons for bid dispersion and engineering estimates inaccuracies.

RESEARCH APPROACH

The study considered a two-step approach. First, a quantitative analysis was performed to diagnose current practices related to cost estimating in D-B/BV highway projects by evaluating the price proposal dispersion and the degree of accuracy of engineering estimates. Second, a qualitative analysis was performed to identify the underlying reasons for the inaccuracy in engineering estimates and price proposal dispersion. In this qualitative analysis, projects having extreme values (either high or low) in their accuracy and bid dispersion were further analyzed using interviews with DOT personnel to identify the underlying factors behind these phenomena.

As part of the quantitative analysis, the research team collected cost data from 305 D-B highway projects procured using BV in 15 DOTs. The information was collected from publicly available online data and from requests to DOTs personnel across the United States. For each project, the required data included: (1) successful price proposal, (2) unsuccessful price proposals, and (3) engineering estimates. The timeframe for procurement of these projects ranged from 2005 to 2018.

To analyze this data, different metrics (Eq (1) to (3)) were used to measure bid dispersion and engineering estimates accuracy. Bid dispersion (*BD*, Eq (1)) measures the variability of price proposals when compared to the award-winning price proposal for a particular project.

$$BD = \frac{Highest\ Price\ Proposal - Lowest\ Price\ Proposal}{Award\ Winning\ Price\ Proposal} \qquad \text{Eq (1)}$$

The accuracy of engineering estimates was assessed using two metrics: the accuracy of engineering estimates when compared to the average of all the price proposals for a particular project ($EE_{average}$, Eq (2)) and with respect to the actual award-winning price proposal ($EE_{winning}$, Eq (3)). This last metric is also known in the literature as award growth (FHWA, 2017). Descriptive statistics and probability density functions (PDF) were developed for each of these metrics (*BD*, $EE_{average}$, and $EE_{winning}$) to quantify bid dispersion and engineering estimates accuracy in D-B/BV highway projects.

$$EE_{average} = \frac{Average\ of\ Price\ Proposals - Engineers\ Estimate}{Engineers\ Estimate} \qquad \text{Eq (2)}$$

$$EE_{winning} = \frac{Award\ Winning\ Price\ Proposal - Engineers\ Estimate}{Engineers\ Estimate} \qquad \text{Eq (3)}$$

To analyze the underlying reasons behind these phenomena, the research team performed a qualitative analysis of projects showing extreme values (either positive or negative) in their bid dispersion and/or engineering estimates accuracy. For each of the metrics described above, extreme values were those lying beyond the 80% confidence interval of the probability distribution function. For instance, if 80% of the projects have a bid dispersion (BD) within 7% and 54.8%, projects having a bid dispersion lower than 7% or higher than 54.8% were considered extreme values.

The qualitative approach consisted of interviews with the agency personnel (i.e., estimating managers and design-build program managers). The objective of these interviews was to identify the potential factors affecting engineering estimate accuracy and price dispersion. The key questions asked during the interview were:

- What is your interpretation for the small/significant difference between low price proposals and high price proposal?
- What are your interpretations for the small/significant deviation of the engineering estimates from average/winning price proposal(s)?

Qualitative analysis involved and examination of trends in agency personnel replies. Since these qualitative results are exploratory in nature, findings for both trends and individual responses are reported.

A DIAGNOSIS OF CURRENT PRACTICES IN COST ESTIMATING: RESULTS AND DISCUSSION

Cost data including successful and unsuccessful price proposals from 305 projects across 15 states in the US were collected in this study. 71% of these projects included information on engineering estimates. This information was not available for all the projects because some DOTs have policies limiting their ability to publish their cost estimates. Thus, the accuracy of engineering estimate was calculated for 218 projects whereas the dispersion of price proposals was analyzed for all the 305 projects. In terms of project size, 41% of the projects had an awarded amount between 5 and 35 million dollars (Figure 1).

FIGURE 1

Quantitative Analysis of Bid Dispersion and Engineering Estimate Accuracy

Table 1 summarizes the descriptive statistics of the metrics used to measure bid dispersion (*BD*) and engineering estimates accuracy when referred to the average bid price ($EE_{average}$) and the award-winning proposal ($EE_{winning}$). This table presents results of average, median and mode values, extreme values (minimum and maximum), variability (measured in terms of standard deviation), and upper and lower limits defining the 80% confidence interval.

TABLE 1

The DOTs participating in this study have different maturity levels in the implementation of D-B, resulting thus in a non-homogeneous distribution of projects among the 15 states participating in the study. Specifically, Florida DOT has a large experience using D-B project delivery and contributed to 40% of the projects in the sample. Non-parametric Wilcoxon-Mann-Whitney tests (Wilcoxon 1945) were performed to assess whether the bid dispersion and engineers estimate accuracy of Florida DOT projects differ from other DOTs. Results from this test (with p-values of 0.57, 0.42, and 0.16 for *BD*, $EE_{average}$, and $EE_{winning}$, respectively) allowed to conclude there is not a statistically significant difference.

Results in Table 1 show that bids have an average dispersion of 27%. This means that, on average, the difference between the highest and lowest price proposal is 27% of the award. Eighty percent (80%) of the projects have a bid dispersion ranging from 7 and 55% (these values are defined by the upper and lower limits of the 80% confidence interval). From the distribution of the bid dispersion metric (Figure 2), it can be seen that the probability density function (PDF) shows a skewness to the left, meaning that most of the projects are on the lower end of this range.

FIGURE 2

These results of bid dispersion suggest that the traditional +/- 10% guidance used to identify anomalies in engineer's estimates accuracy may not be appropriate for design-build projects. Instead, we propose to use a larger threshold (i.e., 25%) to account for the inherent variability of design-build projects. Transportation agencies can therefore use 25% as a more appropriate threshold in design-build projects and use this rule of thumb to identify unreasonable outcomes from a bid. Authors explored which may be the potential reasons for bid dispersion and found that bid dispersion is not correlated with award price ($R^2 = 0.023$). This result suggests that other factors, such as risk-appetite and innovation (i.e., reflected in different design solutions), may be driving bid dispersion. The influence of these factors on bid dispersion have not been fully explored in this research because this data was not available. We suggest owners could explore these differences on a project-by-project basis. Future research is suggested to explore this at a national scale and we envision that differences in design could be quantified using proxies such as technical best value scores or differences in the number of alternative technical concepts that are submitted.

With respect to average accuracy, engineering estimates were found to be underestimated by 8% the average price proposal and overestimate the awarded price by 2% (Table 1). In 62% of the cases, engineering estimates are lower than the average price proposal, whereas they tend to overestimate the awarded price in 56% of the projects. The accuracy of engineering estimates with respect to the award-winning proposal ($EE_{winning}$) shows a lower average, median, and mode values than the accuracy of the average price ($EE_{average}$). This indicates that engineering estimates are generally closer to the awarded price than to average price proposals.

This study also found that, although these projects were procured using best-value, 82% of them were awarded to the lowest price proposal. This finding suggests a misalignment with the core principle of best-value procurement, which is aimed at selecting the most advantageous proposal by evaluating other factors in addition to price (Molenaar and Tran, 2015). With engineering estimates being generally closer to the awarded price than to average price proposals, it can be concluded that engineering estimates are generally better predictors of low-cost bids.

FIGURE 3

FIGURE 4

When analyzing the PDF of the metrics used to measure the accuracy of engineering estimates (Figure 3 and Figure 4), it can be seen that in 80% of the cases, engineering estimates are within 34% and -20% of the average price proposal and 19% and -27% of the award-winning proposal. As far as the accuracy of engineering estimates is concerned, 67% of the projects showed adequate levels of accuracy based on the recommendations from the Association for the Advancement of Cost Engineering (AACE), which recommends an accuracy bracket of +20% to -10% for projects with a level of design of 10% to 40% (AACEI, 2019). The PDF of engineering estimates accuracy to the award-winning proposal (Figure 4) shows a slight skewness to the right, meaning that accuracy is slightly leaning towards the upper end of this range.

In our study, the standard dispersion for engineering accuracy toward the award-winning proposal ($EE_{winning}$), also referred in the literature as award growth, was 22% (Table 1). This result is consistent with the findings of previous research conducted by FHWA (2017) that found the same dispersion in the analysis of 71 best-value design-build.

Discussion of Current Practices and Guidance on Reasonable Expectations

This study found that D-B/BV bids have an average dispersion of 27%, meaning that the average difference between the highest and lowest price proposal is 27% of the awarded price. Some degree of bid dispersion is inherent to the procurement method itself, as proposed designs in D-B/BV are expected to differ between proposals, leading thus to differences in scope, construction approaches, and quantities (Molenaar et al. 2006). Moreover, design-builders may have different risk-appetite, and therefore differ in their approach to the bid (Molenaar et al. 2006). Some degree of bid dispersion is therefore to be expected and this study provides guidance on reasonable values for this dispersion. In this study, 80% of the projects have a bid dispersion ranging from 7 and 55%. This range can be used by agencies to identify projects having a significantly high or low bid dispersion. If bid dispersion is found to be significantly higher than this upper limit (i.e., 55%), this may be an indicator of a poor definition of the request for proposals or an inadequate communication with proposers resulting in a high variability in proposed designs and, therefore, high bid dispersion. On the other hand, a very low bid dispersion may be an indicator of a very constrained request for proposals that limit the ability of design-builders to incorporate innovation.

With respect to average accuracy, engineering estimates were found to be underestimated by 8% the average price proposal and overestimate the awarded price by 2%. This finding is contrary to previous studies (Flyvbjerg et al. 2002; Jennings, 2012; Karaca et al. 2020), which have suggested that project planners may often consider optimistic assumptions and unintentionally underestimate project costs. This result suggests that current practices in cost estimating in D-B/BV may be more conservative than other procurement methods.

Another important finding of this paper is that current practice in D-B/BV seems to be biased toward price, suggesting a misalignment with the core principles of best-value procurement. Despite best-value is meant to enhance the value of construction by considering other factors in addition to price (Molenaar and Tran, 2015; Scheepbouwer et al. 2017; Gransberg 2020), this study found that 82% of the projects were awarded to the lowest price proposal. This practice seems to also impact cost estimating practices, as the results found in this study suggest that engineering estimates are generally better predictors of lowest bids.

UNDERLYING REASONS AND RECOMMENDATIONS TO IMPROVE COST ESTIMATES ACCURACY AND REDUCE BID DISPERSION

Sixteen projects showing extreme values (i.e., either high or low bid dispersion and/or cost estimate accuracy) were considered for further exploration in the qualitative analysis. To avoid inconsistency in the qualitative analysis, the projects were chosen if (1) the number of price proposals for the project is between three to five (including three and five); and (2) the engineer estimate of the project is greater than \$50 million. These assumptions were made to have a more homogeneous population when exploring trends. The small projects were excluded because the absolute difference in cost is relatively small when compared to projects greater than \$50 million.

The bid dispersion and engineering estimate accuracy of projects selected for the qualitative analysis are depicted in Figure 5. For each project, bid dispersion and estimate accuracy are shown to illustrate the reasons why these projects were selected for the qualitative analysis. Project 1, for example, was selected because its low bid dispersion and high accuracy of engineering estimates (both with respect to the average and winning price proposal). In contrast, project 16 shows high bid dispersion and low accuracies in cost estimates. The remaining projects (2 to 15) complete the spectrum by comprising projects with different metrics in terms of dispersion and accuracy. Among the selected projects, some of them excelled in all the criteria (e.g., projects 1, 2, and 3), while some did not (e.g., projects 15 and 16). Similarly, some projects partially excelled in some criteria and failed in the others (e.g., project 13 shows a good performance in terms of dispersion but low performance in accuracy). By analyzing projects showing extreme (i.e., either good or bad) performance in terms of dispersion and accuracy, the research is aimed at finding reasons for these phenomena from the perspective of the DOT.

FIGURE 5

The three potential reasons behind the price proposal dispersion and the engineering estimates accuracy that were observed through the interviews were (1) degree of effective communication of project goals to the design-builder; (2) implementation of innovative and value engineering techniques; and (3) implementation of a robust and rigorous risk-based estimation program.

Effective Communication of Project Goals

Effective communication was found imperative to reduce bid dispersion because it helps design-builders understand the project goals and minimize the chances to misinterpret the base design in the request for proposals. During the interviews, DOT personnel highlighted the importance of sharing with bidders the agency's project goals and holding meetings before the request of price proposals as a way to enhance communication.

To improve the effectiveness of communication, DOTs can use the five-dimensional project management (5DPM) approach that complements the DOT’s project management practices. This approach, described in Shane et al. (2013), consists of methods, tools, and techniques aimed at identifying and addressing critical issues related to cost, schedule, and technical aspects contributing to project complexity. A part of this approach focuses on these critical issues by providing information on effective communication regarding project cost, schedule, and technical aspects. 5DPM provides management approaches to facilitate an effective project development and is aimed at accelerating project delivery, reducing project costs, and minimizing project disputes. Implementing the 5DPM planning framework can result in improvements in the project development process and eventually increase project management efficiency.

Implementation of Innovative and Value Engineering Techniques

The second reason identified as affecting bid dispersion and engineering estimate accuracy was the implementation of innovative and value engineering techniques. The most common way proposers introduce innovation in D-B projects is through alternative technical concepts (ATCs). Antoine and Molenaar (2016) analyzed D-B/BV projects and found that DOTs used ATCs on 51% of them. ATCs can enhance constructability, innovation, mitigate risks, and eventually reduce the project cost (FHWA, 2019). Thus, the implementation of ATCs certainly causes bid dispersion and a consequent inaccuracy in the engineering estimates, as DOT personnel has not considered this innovation in their estimate. Design-builders also use value engineering techniques that lead to substantial cost-savings, which results in bid-dispersion. Both innovation in forms of ATCs and the use of value-engineering techniques are to be expected in best-value design-build projects as the design-builder's services are procured at the preliminary design stage. As some of the interviewed DOT personnel pointed out, ATCs may imply substantial changes in the project, thus causing important deviations in price proposals. These factors of innovation and value-engineering are well beyond the control of the DOT. Thus, DOTs should expect some level of innovation and value-engineering, which will eventually result in some degree of inaccuracy in engineering estimates and price proposal dispersion.

Risk-Based Cost Estimation Program

The third reason identified in the interviews as affecting bid dispersion and engineering estimate accuracy was the implementation of a risk-based estimation program to facilitate the risk allocation associated with D-B/B-V projects. In highly complex projects, with a high amount of risk involved, the price proposal depends on the design-builder risk strategy. Some design-builders may have an aggressive risk-taking strategy, while others may not. The varying risk appetite of design-builders often results in high bid dispersion. However, by implementing a risk-based estimation program, the DOT can effectively identify, address, and allocate most of the risks involved in the project. This would reduce the impact of design-builders perception of risks and would result in more accurate engineering estimates and low dispersed price proposals.

From the sample analyzed, most of the projects developed by the Washington State DOT (WSDOT) had high engineering estimates accuracy and low bid dispersion. With the help of interviews, it was found that WSDOT rigorously follows a risk-based cost estimation and validation program called CEVP (Cost Estimation and Validation Process). A study conducted by Molenaar (2005) on this program found it efficient in providing transparency in project costs and uncertainties. One of the features of this program is that it considers a range of cost output, rather than using point estimates at a conceptual design stage. This range cost output provides transparency and avoids underestimation of a project. The process involves multiple phases in which experts of planning, design, construction, contracting, program delivery strategy, cost-estimating, environmental programs, and economics identify project risks and alternative strategies. The process comprises different steps of the risk management process, from risk identification to risk mitigation. This thorough process results in an enhanced ability to identify high-risk items and mitigation measures to reduce uncertainty (Molenaar, 2005). As a result, having an in-house rigorous risk-based cost estimation plan or adopting one such program could help improve the accuracy of engineering estimates.

During the interviews, it was observed that none of the DOTs had rules/policies regarding D-B/BV procurement bidding results. The DOTs generally use a rule-of-thumb of 10%, which means that a potential award-winning price proposal that deviates more than ± 10% with respect to engineering estimates requires the respective design-builder to go through a justification process. In these cases, the interviewed DOTs conduct studies to understand the reasons behind the deviation. The results from this research can help the DOTs understand the reasonable expectations for accuracy of engineering estimates and bid dispersion and accordingly formulate new policies for efficient procurement.

CONCLUSIONS

Developing engineering estimates for best-value design-build projects is challenging. The accuracy of engineering estimates and the bid-dispersion for such projects depend on several influencing factors, some of them inherent to best-value design-build procurement (e.g., projects are pushed towards procurement at an early stage of project development). Non-regulatory guidance from the FHWA (2014) states that the engineer's estimate should be within +/- 10% of the winning low bid. This threshold, however, was developed in the early 1980s and has not been updated to reflect the peculiarities of design-build. This study analyzed 305 best-value design-build highway projects to quantitatively evaluate the degree of inaccuracy of engineering estimates and bid-dispersion. This analysis was followed by a qualitative analysis aimed at identifying the reasons behind these phenomena.

This study found that D-B/BV projects have an average dispersion (the difference between the highest and lowest price proposal) of 27%. This result suggests that the traditional 10% threshold may not be adequate and a larger threshold (i.e., 25%) is needed to account for the inherent variability of design-build projects. Engineering estimates were found to be generally closer to the awarded price than to average price proposals. 82% of the projects in the data sample were awarded to the lowest bid, suggesting that best-value procurement is failing to account for other factors in addition to cost. These results also show that engineering estimates are generally better predictors of low-cost bids. On average, engineers overestimate awarded projects by 2%. This study shows that some inaccuracy and bid-dispersion should be expected in D-B/BV projects and provides guidance to help agencies define reasonable expectations in engineering estimates and price proposals.

From the qualitative analysis, the study identified three main reasons affecting bid dispersion and estimates accuracy: (1) degree of effective communication of project goals to the design-builder; (2) implementation of innovative and value engineering techniques; and (3) implementation of a robust and rigorous risk-based estimation program. The study recommends agencies to collaborate with the design-builder while developing the engineering estimates. This agency-contractor collaboration must occur prior to and after the final procurement. Holding communications before the award will help clarify and communicate the agency's goals and intent of the project effectively, whereas discussions after the award can provide valuable feedback to design-builders. This feedback can also be used by the agency to improve their future engineering estimates.

This study provides a diagnostic of current practice in D-B/BV procurement based on empirical evidence from highway projects. Future research is needed to overcome some of the limitations and challenges identified in this study. For example, guidance on how to better balance cost and non-cost factors in best-value procurement would be valuable to reduce the current bias of best-value selection toward lowest bids. Future research is also needed to empirically evaluate the effectiveness of the proposed strategies and their impact on bid dispersion and estimates accuracy, as well as the impact of design variations in bid dispersion. Finally, further research is suggested to explore the relations between bid dispersion and engineering estimates accuracies with project results.

DATA AVAILABILITY

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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DISCLAIMER

The views expressed in the article are exclusive of the authors and do not reflect the official policy or position of any US DOT.

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TABLES

Table 1: Descriptive statistics of bid dispersion and engineering estimates accuracy metrics

	BD	$EE_{average}$	$EE_{winning}$
Observations	305	218	218
Average	27%	8%	-2%
Median	22%	8%	-2%
Mode	20%	11%	0%
Max	185%	145%	112%
Min	0%	-59%	-50%
Std. Dev	23%	25%	22%
Upper limit 80% Confidence Interval	55%	34%	19%
Lower limit 80% Confidence Interval	7%	-20%	-27%

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