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Impact of Life-Cycle Costs Threshold Criteria in the Alternate Design Pavement Bidding Practices of Public Transportation Agencies

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ABSTRACT

This paper proposes a model that enables DOT policy makers to quantify the expected volume of projects that will qualify for letting in their alternate design/alternate bid (ADAB) pavement bidding programs. Current guidance on alternate bidding recommends a fixed percentage as the life cycle cost (LCC) threshold criterion to determine whether pavement selection decisions should be made through ADAB bidding practices. The paper's analysis shows that the fixed LCC threshold percentage approach may have considerable shortcomings. Instead, a dynamic threshold value is proposed that can subsequently be calibrated by agencies, based on the desired size of their ADAB programs. The paper argues that since the costs of equivalent pavement designs exhibit considerable variation due to various project and agency-level factors, agencies' desired alternate bidding program levels can only be achieved by taking into account the variation of equivalent pavement type costs as opposed to the current blanket threshold percentage. The paper demonstrates with Kentucky Transportation Cabinet (KYTC) ADAB data that modelling this variability through a random distribution is not only a close representation of actual agency data, but it also distills those variables that drive a large share of the complexity in agency ADAB policy decisions. The paper's primary contribution is the derivation of a direct mathematical relationship between equivalent design premiums, agencies' threshold criteria, and alternate bidding program volumes that can be used by DOT policy makers to better manage their ADAB programs.

INTRODUCTION

The controversy over pavement type selection is both longstanding and complex (*1, 2*). The consensus solution is to include an analysis of pavement life cycle costs (LCC) in the design process, leading to selecting the alternative that minimizes LCC (*3, 4*). That process, however, ignores the impact of construction material volatility i.e. actual contract pricing, on the day a pavement project is let since it is based on pricing "assumptions made during the [pavement type] evaluation/selection process years before letting" (*5*). To further exacerbate the controversy, the ability to generate truly equivalent pavement designs has been in question ever since the idea of alternate pavement bidding schemes were authorized under the FHWA's Special Experimental Project 14 (SEP-14) in 2000 (*6*). On the bright side, there seems to be agreement that the use of alternate design/alternate bid (ADAB) procurement procedures reduces pavement prices by increasing the number of eligible bidders as both asphalt and concrete paving contractors can bid on the same ADAB projects (*7, 8, 9, 10*). It is because of ADAB's documented benefits that interest in identifying effective practices and procedures endures.

Therefore the objective of this paper is to fill a documented gap in the body of ADAB knowledge by proposing and demonstrating a rational, LCC-based method for identifying those pavement projects that are good candidates for ADAB procurement on a programmatic basis. With the advancement of the Mechanistic-Empirical Pavement Design Guide (MEPDG) methodology, agencies' ability to achieve equivalent designs has improved dramatically (*11*). This provides new incentives to open bidding to both industries and experience cost savings for the agencies. Alternate bidding programs can realize savings to agencies by giving them the ability to make final pavement design decisions where there is no clear preferred design alternative and market prices for different design types are volatile (*7*).

Agency decisions to select ADAB projects have important consequences and potentially impose sizeable opportunity costs for the agencies. Ideally, every pavement type selection decision could benefit if it were made by comparing real-time market prices for competing alternatives on the day of letting. However, using alternate bidding on every project has the potential to increase project development costs due to increased cost of producing equivalent designs, and the associated engineering effort in generating a set of plans and specifications for each alternative.

Although such costs could become marginal after alternative designs are established for agencies' typical pavement designs, the initial costs to implement an alternative bidding program can still be substantial. Further, adopting an alternative bidding program requires the agency to develop a locally acceptable method to calculate an LCC-based adjustment factor, which is the recommended approach to compare competing alternatives with differing future maintenance and rehabilitation costs (*12*). Such challenges leave agencies facing a tradeoff in weighing the expected benefits of an alternative bidding program against the costs of administering such award practices. Figure 1 illustrates the role of alternate bidding in pavement type selection decisions.

There is currently limited guidance on when to use alternate bidding. A commonly accepted practice is to call competing designs equivalent if they provide similar level of performance and their Net Present Value (NPV) is within a specified threshold value of each other (*13*). FHWA guidance on LCC thresholds suggests 10% as an appropriate level, i.e., the LCC of one alternative is lower than 10% of the LCC of the other (*13*). A common metric for assessing similar service levels, for instance, is to verify whether the expected IRI values of competing alternative pavement types remain in comparable condition over the analysis period

(IRI < 95 inches/mile for good condition, IRI < 170 inches/mile for fair condition, etc.) (*13*). Once design equivalence is established among the competing alternatives and their LCCs are calculated, it is expected that those alternatives that fall within the threshold margin of 10% are too similar in life-cycle costs to permit an outright decision to be made for a preferred alternative.

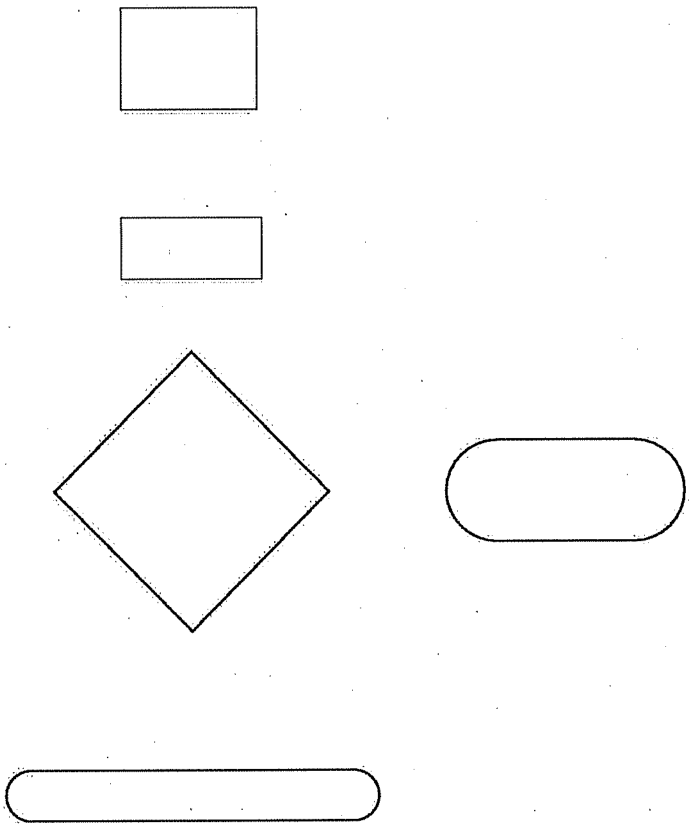

FIGURE 1 Alternate Bidding and Pavement Type Selection Decisions

There is no agreement on LCC threshold values for alternate bidding (*12*). This fluid nature of setting an LCC-based cutoff level is reflected in the agencies' ADAB practices. A content analysis in agency ADAB policies has found that the threshold levels can range from 10% to 20% (*14, 15, 16*). Other types of thresholds, such as roadway area and functional classification, are also common among agencies to identify qualifying projects. At this writing, there has been no formal research to establish what variables should be included in the threshold value setting decision nor the outcomes of establishing different threshold values, as well as identifying the factors that influence the outcomes.

The FHWA calls the 10% threshold value "appropriate due to the uncertainty associated with estimating future costs and timing of maintenance and rehabilitation" (*13*). However, such guidance, while focusing on the uncertainty over the LCC input variables, falls short of addressing the linkage between threshold levels and their impact on how many projects would be included under alternate bidding. Clearly, higher threshold levels imply a larger number of qualifying ADAB projects. Conversely, lower threshold levels make it more restrictive for potential candidate projects to be considered in the alternate bidding program.

The main tradeoff in the selection of the threshold value is the costs associated with alternate bidding and testing the true market costs of alternate pavement designs before a decision can be made. Ideally, if alternate bidding were cost free, all projects could be let using alternate bidding, which corresponds to a no threshold case. As the threshold level reduces to zero, qualification of projects for the ADAB program becomes increasingly restrictive, and fewer projects would be expected to let under alternate bidding.

Theoretically, agency's discretion in setting threshold values ranges from zero, where no alternate bidding is allowed, to infinity, where all projects are awarded through alternate bidding. Under the zero-threshold case, the agency's lowest cost alternate pavement design is assumed to be the most economical alternative in all cases. However, this approach also exposes the agency to the highest risk of foregoing the benefits of alternate bidding, as the market cost of the competing alternative remains untested. This was the situation before SEP-14 authorization to experiment with ADAB.

BACKGROUND

In response to the growing adoption of ADAB practices among the state agencies, the FHWA endorsed the use ADAB methods in 2012 (*13*). It is now clear that many states that use ADAB procedures have recorded tangible benefits from the practice (*17, 18, 19*). The main benefits include reduced project costs from increased competition *(7)*. Agency policies on ADAB procedures show a significant degree of variation of across states (*20, 21*).

Alternative pavement designs are compared based on common pavement life-cycle maintenance and rehabilitation strategies *(4)*. To achieve similar serviceability performances covering the selected analysis period, both initial design/construction costs and the future cost of maintenance/rehabilitation activities must be specified. The development of realistic LCC analysis that is consistent with local policies and procedures is crucial to compare alternatives based on LCCs.

There are two main groups of considerations that need to be addressed before alternates can be compared. First, the underlying assumption of all ADAB methods is the presence of design equivalence, without which competing alternates cannot be meaningfully compared. Adjusting for the differences in LCCs thus becomes an important consideration for alternate bidding practices.

Secondly, ADAB can be expected to be most applicable to the pavement type selection decisions when the expected LCCs of competing alternatives are reasonably close to one another and when there is not a preferred pavement type among the competing alternatives. While there is no consensus on a single threshold level among the state transportation agencies, thresholds in practice range from 10% to 20% (*12*).

Although agencies have differing approaches to achieving design equivalence among competing alternative pavement designs, the expected benefits of ADAB depends greatly on the design equivalence of competing alternatives. Given the design requirements on traffic level, reliability and service life, the pavement service levels are expected to sustain comparable levels of service over the period of the pavement design life. A similar level of service can be measured by the alternative designs' performance over the analysis period based on models that realistically reflect agency conditions. Since competing design methods often have unequal traditional design periods, the performance period should be made equal by including at least one major rehabilitation cycle (*13*).

The specification of similar service levels over the common performance period depends on the underlying maintenance and rehabilitation strategy assumptions for each alternate. Each strategy must reflect realistic agency-level maintenance and rehabilitation costs, calibrated to simulate the pavement service levels with associated future costs (*22*). Since the timing and nature of maintenance and rehabilitation activities drives LCCs, as well as the resultant bid adjustment factors in comparing alternative pavement types, such costs need to be included the selection process for a project's pavement design. A review of recommended maintenance and rehabilitation strategies can be found in the NCHRP Report 703, *Guide for Pavement Type Selection* (*12*).

ALTERNATE BIDDING AND THRESHOLD CRITERIA

Since the goal of the analysis is to demonstrate that the number of qualifying ADAB projects is a direct function of threshold values, the point of departure is the distribution of project sizes within a given agency. Commonly, agency design type decisions involve at least two types of pavement designs (for example, hot mix asphalt (HMA) and Portland cement concrete (PCC) pavement types).

Without loss of generality, the default pavement design is called Alternative 1, and the competing pavement type Alternative 2. Figure 2 shows the probability distribution of the expected project costs within an agency when a default pavement type (Alternative 1) is selected for all projects. Reflecting the cost difference between alternative pavement designs, Alternative 2 is assumed to be a linear transformation of Alternative 1 with a premium coefficient (*P*) that varies randomly. The expected project costs under Alternative 2 can thus be calculated once the default pavement type costs and equivalent design premium distributions are known. Since the alternate bidding decisions are typically based on the net present value (NPV) value of LCCs, in what follows, the terms "cost" and "LCC" are used interchangeably.

Let A_d be the set of all expected LCCs of agency projects ($NPV_{Alt\,1}(x)$) if built under the default pavement type alternative (Alternative 1). Similarly, define A_c as the set of the expected project costs ($NPV_{Alt\,2}(x)$) under the competing pavement design (Alternative 2) as follows:

$$NPV_{Alt\,2}(x) = P \times NPV_{Alt\,1}(x) \qquad (1)$$

This analysis assumes the agency project costs under the default pavement design alternative to be lognormally distributed. As with many price distributions, lognormal distribution provides a realistic fit of project sizes, primarily because, unlike the normal distribution, it does not permit negative values for project sizes, and has been found by previous research to be the best fit for pavement projects of all types (*23*). However, it should be noted that any other type of distribution that does not allow negative project costs could also be used, since the following discussion holds independently of the assumed project cost distribution. Let the equivalent design premium of the competing design type (*P*) be equal to a normally distributed random variable with mean (*p*) and standard deviation (σ_p):

$$P \sim N(p, \sigma_p^2) \qquad (2)$$

The preceding formulation of competing pavement design costs allows a realistic modelling of equivalent design alternatives. Rather than assuming a fixed premium for each competing design type over the default type, it is acknowledged that premiums over the default type costs are variable, and depending on the standard deviation of alternative pavement premiums (σ_p), the competing alternative costs are permitted to be lower than the default alternative's costs. Although alternative equivalent design premium distributions could be also considered, the normal distribution provides a reasonable fit to agency data based on a list of alternate bid tabulations provided by the Kentucky Transportation Cabinet (KYTC) (*24*).

As noted earlier, agency ADAB decisions are based on a comparison of LCCs among different pavement designs. Since this comparison is equivalent to the LCC ratio of design alternatives, following the FHWA's convention (higher cost alternative over the lower cost alternative), the LCC ratio for any project of x is computed by Equation 3.

$$LCC\ Ratio(x) = \frac{NPV_{Alt\,2}(x)}{NPV_{Alt\,1}(x)} \tag{3}$$

Clearly, given the definition in Equation 1, the LCC ratio reduces to the equivalent design premium (*P*). Put differently, the LCC ratio of competing alternatives in ADAB decisions can be interpreted as the expected premium for the competing pavement designs (Equation 4).

$$LCC\ Ratio \sim N(p, \sigma_p{}^2) \tag{4}$$

This finding provides the basic framework to study the impact of LCC thresholds in alternate bidding, and as will be shown shortly, it greatly simplifies the analysis, enabling the analyst to focus on the two critical variables of the equivalent design premium distribution—the expected premium for the alternative design type (*p*), and its standard deviation (σ_p). The probability of project LCCs meeting the ADAB threshold criteria can be then calculated as shown in Equation 5.

$$Pr(T \geq LCC\ Ratio \geq 1) = F(T) - F(1) \tag{5}$$

F(T) and *F(1)* stand for the cumulative densify function of the normal distribution for the two critical values (the threshold level, *T*, and *1*, respectively). Given the normal distribution assumption for the *LCC Ratio*, the probability of including agency projects in ADAB (Equation 5) can be rewritten as seen in Equation 6.

$$Pr(Alternate\ Bidding) = F\left(\frac{T-p}{\sigma_p}\right) - F\left(\frac{1-p}{\sigma_p}\right) \tag{6}$$

As Equation 6 indicates, the frequency of agencies' ADAB practices is a function of three variables:

1. *T*, the ADAB threshold value;
2. p, expected equivalent design premium for competing pavement type; and
3. σ_p, the standard deviation of equivalent design premiums.

Setting threshold levels in alternative bidding to reap the benefits of increased competition from multiple industries, thus, cannot be accomplished without taking note of the close interaction between these three factors.

Three major conclusions immediately follow Equation 6. First, the probability of meeting ADAB criteria is a strictly increasing function of the threshold value, T. Second, the expected equivalent design premium for the higher cost alternative, p, has a generally negative impact on the frequency of meeting the ADAB threshold criteria. That is, for most realistic values of p, the higher the expected premium levels, the lower the ADAB probability. Third, ADAB probability is a strictly decreasing function of the standard deviation of the equivalent design premium, σ_p.

The finding that ADAB probability increases with higher threshold values is both intuitive and expected. Agencies that have no threshold levels for ADAB are expected to practice an all-inclusive ADAB program. The next two findings, however, to our knowledge, have not been recognized in the literature thus far. Together they show that ADAB threshold levels should be determined by considering the relative values of expected equivalent design premiums and their statistical variation. Illustrating this point will be the focus the following discussion.

SENSITIVITY OF ALTERNATE BIDDING THRESHOLDS TO EQUIVALENT DESIGN PREMIUMS

This section will consider an example to illustrate the sensitivity of ADAB thresholds to equivalent design premium distributions. Although available data to generate typical project cost distributions for equivalent alternative designs is sparse, the following discussion is based on distribution parameters obtained from a sample of project bids under the KYTC's ADAB program. This data was selected merely because it was both cogent and easily accessible. The KYTC was an early SEP-14 ADAB experimenter and the results of their pilot projects were generally representative of those observed in other ADAB SEP-14 applicants. Figure 2 illustrates the probability density functions (PDF) for a representative agency's project costs. The set of all project LCCs under the default (A_d), and the competing pavement designs (A_c) are labeled as Alternative 1 and Alternative 2 LCCs, respectively. Note that the relationship between the default and competing design costs were previously defined in Equation 1.

The calculated model parameters are shown in Equation 7. The KYTC ADAB program witnessed equivalent design premiums, P_K, over the lowest cost alternative type at an average of 10 percent ($p = 0.10$) and a standard deviation of 11 percent ($\sigma_p = 0.11$). As expected, the average project cost under the competing pavement type alternative is 10 percent higher than the average project cost under the default pavement design alternative ($10 million vs. $11 million in Figure 2). The threshold value, T, was also assumed be 10 percent. Note that although the threshold value and the expected equivalent design premium were assumed to be both 10 percent in the baseline scenario, they need not be equal. In fact, the upcoming analysis will vary the equivalent design premium to examine the sensitivity of alternate bidding probability to this variable.

$$P_K \sim N(0.10, 0.11^2) \quad (7)$$

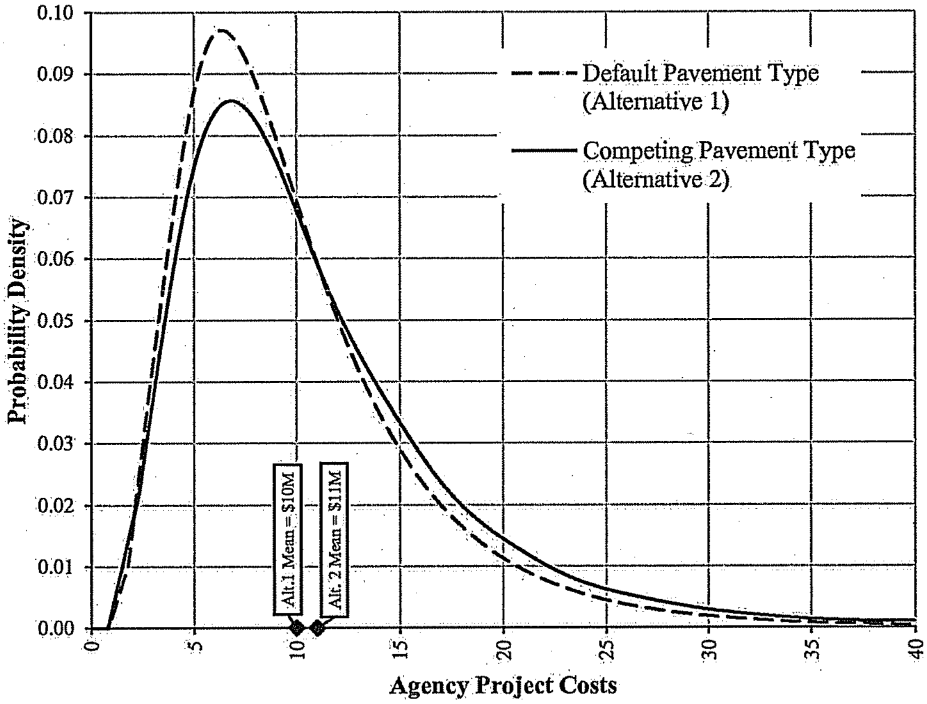

FIGURE 2 Project Cost Distributions (PDF) under Multiple Pavement Type Alternatives

The probability of the agency's projects to meet the ADAB threshold criteria can be then calculated as

$$P(Alternate\ Bidding) = F\left(\frac{1.1-1.1}{0.11}\right) - F\left(\frac{1-0.1}{0.11}\right) \quad (8)$$
$$= 0.5 - 0.182$$
$$= 0.318$$

The result of Equation 8 (31.8 %) is equivalent to the region delineated between the two vertical lines in Figure 3. The area above the lower bound of the LCC Ratio, where both alternate LCCs are equal, and below the threshold value of 10 percent ($1 \leq LCC\ Ratio \leq 1.10$) captures the share of agency projects that will be screened for potential alternate bidding. In this example, approximately 32 percent of the agency projects are expected to meet the ADAB threshold criteria. This result can be of immediate use to the agency as policy makers calibrate the agency's ADAB threshold in an effort to balance the anticipated costs and benefits of alternate bidding practices.

Figures 4 and 5 illustrate the sensitivity of the expected ADAB program size as the expected equivalent design premium levels (p) and its standard deviation ($\sigma_{\bar{p}}$) change. As the equivalent design premium characteristics are both allowed to increase, the ensuing reductions in expected ADAB program size corroborate the major findings identified previously. Figure 4 shows the effect of an increased level of equivalent design premium of 15 percent. Due to the rightward shift in the probability density function due to this increase, the ADAB region for qualifying projects shrinks to 23.8 percent. Similarly, Figure 5 demonstrates the effect of higher volatility in the LCCs of equivalent alternative designs.

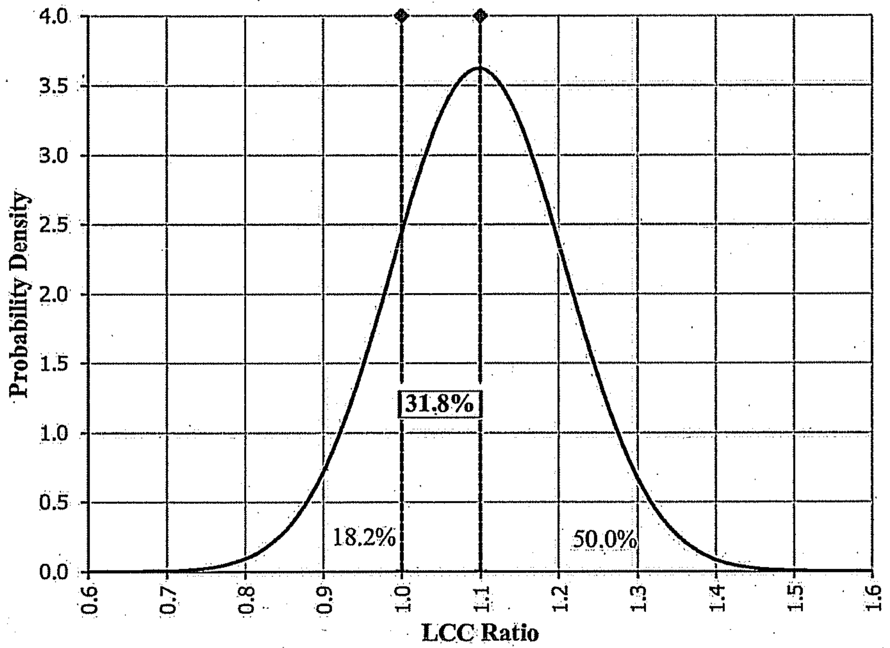

FIGURE 3 LCC Ratio PDF (Baseline Case: $T = 10\%$ $p = 10\%$; $\sigma_p = 11\%$)

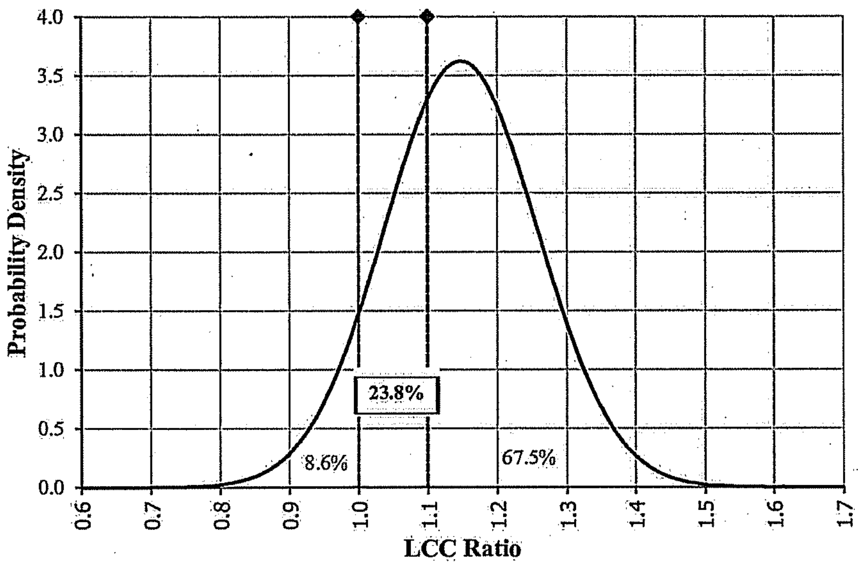

FIGURE 4 LCC Ratio PDF (High Expected Premium: $T = 10\%$; $p = 15\%$; $\sigma_p = 11\%$)

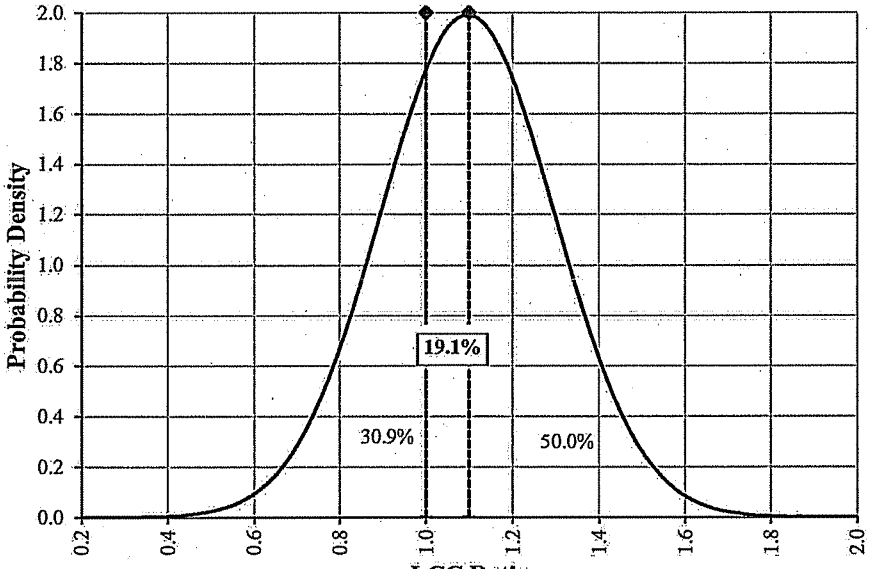

FIGURE 5 LCC Ratio PDF (High Premium Variation: T = 10%; p = 10%; σ_p = 20%)

Increased dispersion in equivalent design premiums reduces the ADAB probability to 19.1 percent. The policy implication of these observations for agencies is clear. If the agency's goal is to maintain the baseline 32-percent ADAB program volume, the ADAB threshold level must be increased. In this example, increasing the threshold percentage for the two scenarios considered to approximately 13 and 17 percent, respectively, would ensure the original 32-percent ADAB volume under the baseline scenario.

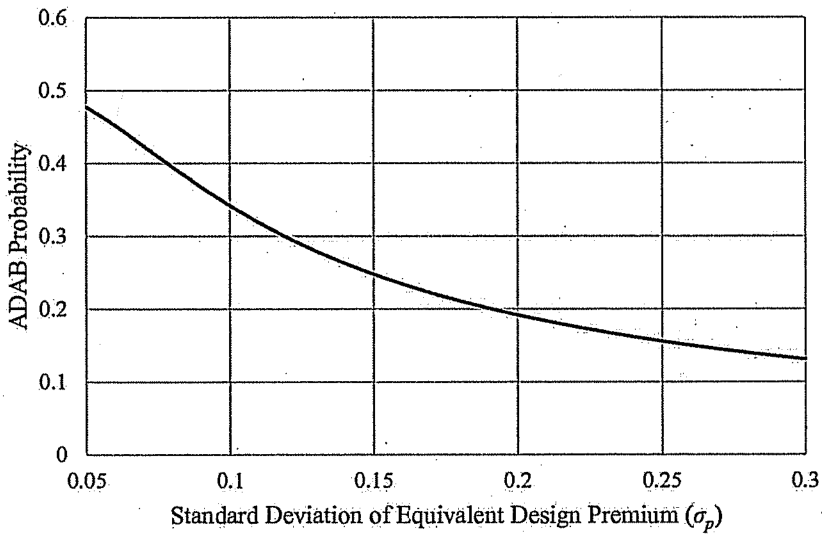

FIGURE 6 Sensitivity of ADAB Probability to Premium Variation (T = 10%; p = 10%)

Figure 6 presents the sensitivity of expected ADAB program volume (y-axis) as the standard deviation of equivalent design premium (x-axis) is allowed to vary. A similar analysis is depicted in Figure 7. In both figures, the variable of interest was changed by keeping the remaining baseline variables constant. The decreasing ADAB probabilities with changing equivalent design premiums further highlight the need for agencies to calibrate their ADAB thresholds to maintain their target program volumes.

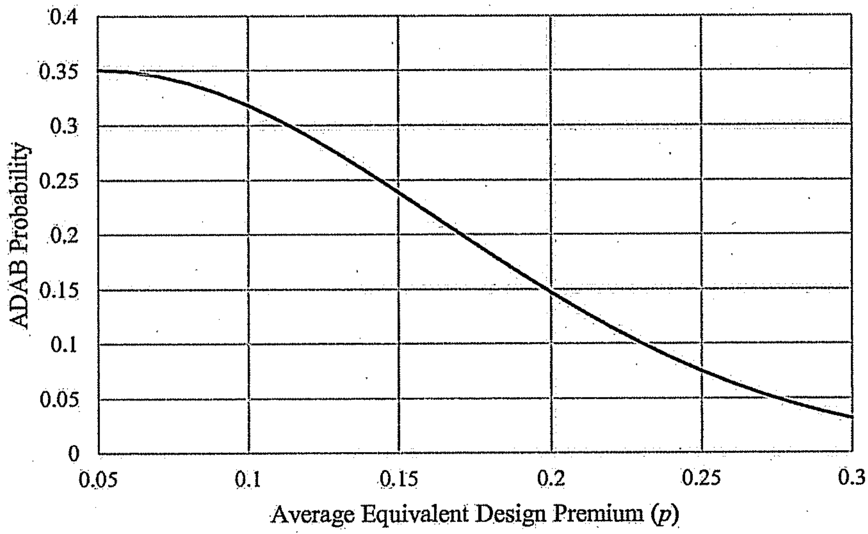

FIGURE 7 Sensitivity of ADAB Probability to Expected Premium (T = 10%; σ_p = 11%)

CONCLUSION

The paper's analysis provides a succinct framework for studying the underlying factors that drive the size of agency ADAB programs. Its output argues that the current guidance for setting ADAB threshold criteria to screen candidate projects in pavement type selection decisions could be overly simplistic. Instead, the paper proposes an alternative perspective for modelling the uncertainty in equivalent pavement design costs. The paper's primary finding is to prove that ADAB threshold criteria should be a function of the variability in equivalent design premiums. As the expected equivalent design premiums increase/decrease, the findings suggest a corresponding change in agency threshold levels to maintain the target volumes of ADAB programs.

When agencies select qualifying projects for ADAB based on a life-cycle cost comparison among the alternates, the specified threshold level becomes the only lever for the agencies to influence the desired outcomes of an ADAB program. Once the decision to proceed with ADAB has been made, the sole remaining relevant factor becomes the alternative pavement type premium. In modelling the equivalent design costs for competing pavement type alternatives, the above analysis assumes the alternative premium as a random variable that inflates the baseline pavement design cost. The premium aggregates two major sources of uncertainty in the calculation of LCCs. First, the volatility of major construction material costs under different alternative designs precludes a deterministic estimation of design alternatives. Secondly, the wide range of LCC analysis assumptions, including those for the discount rate, salvage value, maintenance and rehabilitation strategies and the service period of different pavement type alternatives, makes the calculation of LCCs sensitive to the analyst's assumptions. Therefore, modelling such uncertainty in the form of a random variable for equivalent design premiums not only provides a reasonably realistic representation of the complex relationship between the equivalent design alternatives, it vastly simplifies the complexity of the analysis. The results indeed show that valuable insights can be gained in assisting agencies to make rational decisions on their ADAB threshold criteria.

Rather than setting a threshold level that remains constant as the spread between alternatives contract or expand, the analysis shows, a dynamic threshold rate that takes into account input price volatility and future LCCs, can be used successfully, making the threshold levels relative to the alternative design premiums.

When selecting LCC thresholds, there is a direct relationship between the expected number of bids to be awarded through alternate bidding and the potential project cost ranges for each alternative pavement type. Setting higher threshold levels results in a higher number of projects qualifying for alternate bidding. Conversely, low LCC thresholds reduce the number of projects that could potential benefit from procurement using ADAB methods. Given the administrative and engineering bid costs associated with additional pavement designs, each agency can then balance the expected ADAB benefits, such as receiving market prices for competing alternatives, increasing competition, and reducing costs, against the costs of adopting ADAB practices.

The preceding discussion also provides the starting point in calculating the expected benefits of an agency's ADAB program. Clearly, achieving an agency's target ADAB program size is an exercise that should be tailored to each agency's unique requirements and market conditions. However, since any such analysis must start from an estimation of the share of the agency projects that would qualify for alternate bidding, the proposed analysis can be used as a basis to both quantify and compare the anticipated costs and benefits of an ADAB program. Finally, in addition to laying the groundwork for future research in this area, this paper offers highly relevant insights for transportation agencies and administrators of public contracts.

REFERENCES

1. Hennings, C. *Alternative Design / Alternative Bid: A Survey of the Evidence.* Nevada State Legislature 77th Session, April 25, 2013. https://nelis.leg.state.nv.us/77th2013/App#/77th2013/Committee/Meetings/Assembly/Transportation. Accessed July 30, 2016.
2. Anderson, S. D., & Russell, J. S. *Guidelines for Warranty, Multi-Parameter, and Best Value Contracting.* NCHRP Report 451Transportation Research Board, National Research Council, Washington, D.C., 2001.
3. Federal Highway Administration (FHWA). *Life Cycle Cost Analysis (LCCA) – Transportation Asset Management Case Studies. The Colorado Experience.* FHWA-HIF-10-007. 2009. http://www.fhwa.dot.gov/asset/if10007/if01007.pdf. Accessed July 30, 2016.
4. Walls, J. and Smith M.R. *Life-Cycle Cost Analysis in Pavement Design —Interim Technical Bulletin.* Federal Highway Administration. FHWA-SA-98-079, 1998.
5. Lenz, R. *TxDOT's Alternate Pavement Design and Bid Policy.* Presentation, 2010 Texas Asphalt Paving Association Annual Meeting, Austin, Texas, 2010, pp. 17.

6. Federal Highway Administration (FHWA). *Improving Transportation Investment Decisions.* Washington, D.C., 2015. http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccafact.cfm. Accessed July 30, 2016.
7. Temple W., Zhang Z., Lambert J., Zeringue K. Agency process for alternate design and alternate bid of pavements. *Transportation Research Record: Journal of the Transportation Research Board No. 1900*, Transportation Research Board of the National Academies, Washington, D.C., 2004. pp. 122-31.
8. Ohio Department of Transportation (ODOT). *Final Report Special Experimental Project No. 14 for CLAIMAD-70*, Columbus, OH, December 2004. http://www.fhwa.dot.gov/programadmin/contracts/sep14oh2004b.cfm. Accessed July 30, 2016.
9. Newman, G. *Special Experimental Project No.14 (SEP-14) Evaluation of Alternate Pavement Bidding*, Kentucky Transportation Cabinet (KYTC). http://www.fhwa.dot.gov/programadmin/contracts/sep14kyeval.cfm. Accessed July 30, 2016.
10. Mikesell, L.A. *Alternative Pavement Bidding, SEP-14 Project Interim Report.* Montana Department of Transportation (MDOT), November 5, 2012. http://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm. Accessed July 30, 2016.
11. Pierce, L. M., and G. McGovern. *Implementation of the AASHTO Mechanistic-Empirical Pavement Design Guide and Software.* NCHRP Synthesis Report 457. Washington, D.C., 2014.
12. Hallin, J.P., Sadasivam S, Mallela J, Hein DK, Darter MI, Von Quintus HL. *NCHRP Report 703: Guide for Pavement-Type Selection.* Transportation Research Board of the National Academies, Washington, DC. 2011.
13. *Use of Alternate Bidding for Pavement Type Selection.* Technical Advisory T 5040.39, Federal Highway Administration (FHWA), U.S. Department of Transportation, 2012. https://www.fhwa.dot.gov/pavement/t504039.cfm. Accessed July 30, 2016.
14. Michigan Department of Transportation (MDOT). *Pavement Selection Manual*, MDOT, Lansing, MI, 2016. https://www.michigan.gov/documents/mdot/MDOT_Pavement_Design_and_Selection_Manual_257723_7.pdf. Accessed July 30, 2016.
15. Ohio Department of Transportation (ODOT). *Pavement Design Manual Section 100*, ODOT, Columbus, OH, 2014. http://www.dot.state.oh.us/Divisions/Engineering/Pavement/Pavement%20Design%20%20Rehabilitation%20Manual/PDM_Section_100.pdf Accessed July 30, 2016.
16. Kentucky Transportation Cabinet (KYTC). *Pavement Type Selection Policy*, KYTC, Louisville, KY, 2007. http://transportation.ky.gov/Highway-Design/Pavement%20Design/Appendix%20E.pdf. Accessed July 30, 2016.
17. Indiana Department of Transportation (INDOT). *Initial Evaluation Report, SEP-14, Alternate Bids on Pavement Type, Contract No. R-30106 & R-31948, US 31.* INDOT, Indianapolis, IN, 2009, pp-5. http://www.fhwa.dot.gov/programadmin/contracts/sep14in2009eval.pdf. Accessed July 30, 2016.
18. Ohio Department of Transportation (ODOT). *Final Report Special Experimental Project No. 14 for CLAIMAD-70.* ODOT, Columbus, OH, December 2004. http://www.fhwa.dot.gov/programadmin/contracts/sep14oh2004b.cfm. Accessed July 30, 2016.

19. Youngs, C. and Krom, B. SEP-14 Alternative Pavement Bidding: I-69 Design Build Finance, SEP-14 Project Interim Report, MDOT, Lansing, MI, July 10, 2009. https://www.fhwa.dot.gov/programadmin/contracts/sep14mieval2009.cfm. Accessed July 30, 2016.
20. Crawford, G. *Pavement Type Selection – Updated Guidance on Use of Alternate Bidding.* FHWA Presentation at the Virginia Concrete Conference, Richmond. 2014.
21. Jeong, D., Abdollohipour, S. *Alternate Bidding Strategies for Asphalt and Concrete Pavement Projects Utilizing Life Cycle Cost Analysis (LCCA).* Oklahoma Transportation Center, Midwest City, OK, 2012.
22. Von Quintus, H. L., and J. S. Moulthrop. *Mechanistic-Empirical Pavement Design Guide Flexible Pavement Performance Prediction Models for Montana Volume III- Field Guide Calibration and User's Guide for the Mechanistic-Empirical Pavement Design Guide.* Report No. FHWA/MT-07-008/8158-3. MDT, Helena, MT, 2007.
23. Tighe, S. Guidelines for Probabilistic Pavement Life Cycle Cost Analysis. *Transportation Research Record, Journal of the Transportation Research Board, No. 1769,* Transportation Research Board of the National Academies, Washington, D.C., 2001, pp. 28-39.
24. Looney, P. *Pavement Type Selection and Alternate Pavement Bidding.* Kentucky Transportation Cabinet Partnering Conference, August 2010.