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IMPACT OF THE DESIGN-BUILD PROJECT DELIVERY SYSTEM ON THE LONG-TERM PERFORMANCE OF TRANSPORTATION PROJECTS

Final Report

by

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DISCLAIMER

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EXCUTIVE SUMMARY

The trend to use the alternative Design-Build (DB) method, as opposed to the traditional Design-Bid-Build (DBB) project delivery method, is increasing, and more state Departments of Transportation (DOTs) are adopting DB to deliver their infrastructure projects. Much research has been conducted to analyze the benefits of DB with respect to project cost and schedule performance, yet research has not been performed to assess DB's impact on the long-term performance of the constructed pavements.

This research aims to discover the post-construction performance impact of DB delivery methods on pavement projects. The study uses road smoothness in terms of the International Roughness Index (IRI) as the performance metric of choice to gauge ride quality. The authors analyze data from 21 projects in two state DOTs using a Linear Mixed Effects Model (LME). The results from this study indicate DB projects show improved performance, compared to traditional DBB projects.

1.0 INTRODUCTION

Pavement smoothness is a main factor when rating highways on both a national and local level (MnDOT, 2007). In fact, transportation agencies work tirelessly to improve the ride quality of highways, specifically those on the National Highway System (NHS).

State Departments of Transportation (DOTs) perform diverse pavement rehabilitation projects each year. DOTs adopt Alternative Project Delivery Methods (APDMs), such as Design-Build (DB) for some of their rehabilitation projects because they were shown to improve both cost and schedule performance. The trend to employ DB for transportation projects is increasing (DBIA, 2017). Although becoming more prevalent, very little research has been conducted to find relationships between APDMs and long-term performance of pavements. Gransberg and Shane (2010) investigated the relationship between the project quality and project delivery method, specifically for Construction Management at Risk (CMAR) and Design-Bid-Build (DBB). Their survey found that owners and contractors expect CMAR to have better performance than DBB with respect to design quality outcomes. However, there has been no field research performed to confirm and quantify the exact relationship.

This report focuses on long-term pavement performance, measured by the International Roughness Index (IRI). The study statistically compares pavements delivered via traditional DBB delivery and alternative DB delivery. IRI is the key index used to quantify the ride quality of a road, and it is inspected annually for each milepost on the NHS. To adequately account for this longitudinal inspection characteristic of the IRI from a statistical perspective, this study uses Linear Mixed-Effects (LME) modeling. LME can take into account the time sequence characteristic while helping make a comparison between different pavements, by milepost.

2.0 LITERATURE REVIEW

2.1 ALTERNATIVE PROJECT DELIVERY METHODS (APDM)

A delivery system determines the relationships between the different project stakeholders and their timing of engagement to provide a built facility (El Asmar et al., 2013). The most common project delivery method is the traditional DBB which entails that the design and construction be under two separate contracts, with construction beginning after the design has been fully completed. However, due to several DBB limitations, various APDMs have evolved to fit projects and owners' needs.

Figure 1 illustrates different types of project delivery methods, based on the amount of design complete when the construction team is typically engaged. Construction Management/General Contractor (CM/GC) delivery allows the start of construction before the design is fully complete. DB builds on this overlap between design and construction by employing only one contract between the agency and the design-builder who is responsible for both design and construction of the project. These alternative delivery methods can offer several advantages by involving the interdisciplinary expertise of the construction team in the design stages of the project.

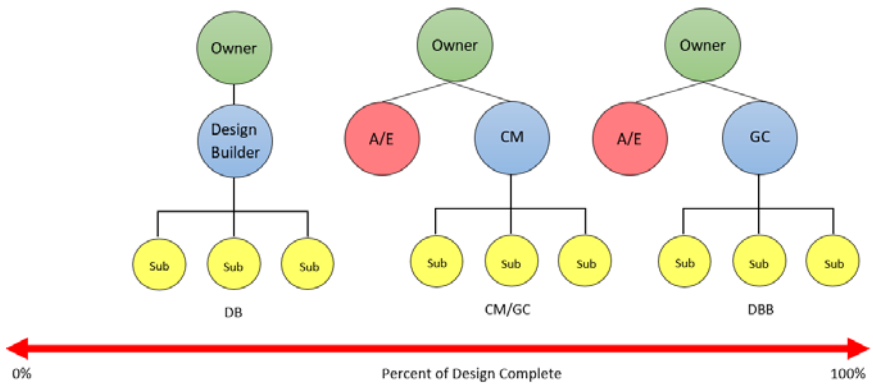


Figure 1: Delivery systems' relationships and timing of engagement (Adapted from El Asmar et al. 2013)

This report specifically focuses on DB. Several studies have quantified the advantages of DB; for instance, Ellis et al. (1991) analyzed transportation projects and found DB projects only experience 4.59% cost growth whereas DBB projects experience 18% cost growth. Other research studies have shown similar results (e.g., Molenaar 1999; FDOT, 2004; FHWA, 2006; Gransberg et al., 2008; Touran et al., 2011; Shakya, 2013).

Such advantages have accelerated the adoption of APDMs among DOTs throughout the United States (US). Figure 2 shows the use of DB on public projects in different states in the US. Most states have authorized DB as one of the procurement methods available to public agencies for Transportation.

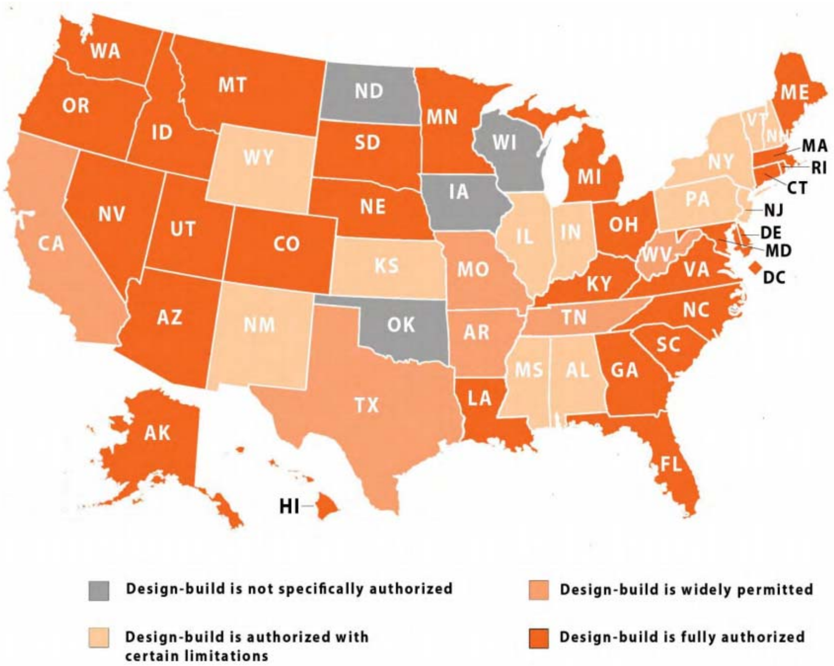


Figure 2: Design-Build authorization for transportation (DBIA, 2017)

From reviewing the literature, the authors found several advantages for DB, specifically when it comes to cost and schedule performance. Gransberg and Shane (2010) also investigated APDM quality using a survey of professionals. However, no study measured quantitative long-term performance data for DB versus DBB projects. This study aims to do that in order to determine the long-term performance of pavements.

2.2 INTERNATIONAL ROUGHNESS INDEX (IRI)

The IRI is a metric that measures pavement smoothness, which influences ride quality. It is measured annually and reported to the Federal Highway Administration (FHWA) regularly to indicate the NHS performance and develop management plans accordingly. Figure 3 presents the status of IRI or Rut, over time. The figure illustrates that IRI increases exponentially over time, between performing pavement rehabilitations. After each rehabilitation, IRI is reduced as represented by the discontinuous decreases in the plot. The improvement in performance related to construction can be measured by the difference in IRI values before and after the each project. Long-term performance refers to the assessment of measured IRI values collected after substantial time has passed since project completion.

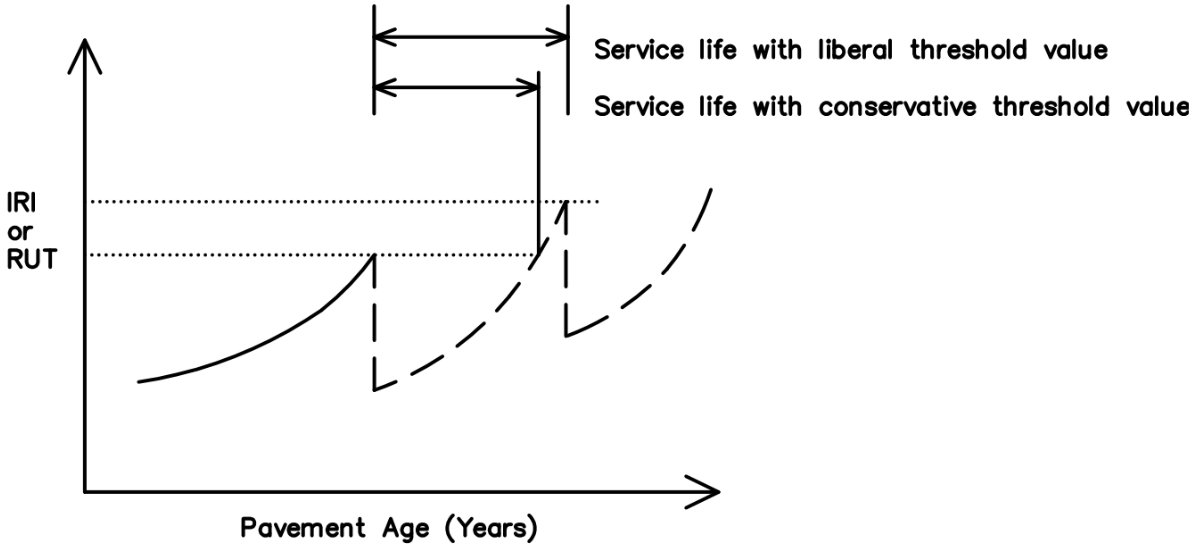


Figure 3: Effect of different trigger values on service life (Irfan M. et al., 2009)

This study set the IRI as the objective function to quantify the long-term performance of pavements. The main reason why the authors chose IRI as the performance metric is that IRI is a universal index used to measure ride quality, and all DOTs collect data annually for each milepost along the NHS. Therefore, IRI can provide sufficient information about the studied roads' conditions over time.

3.0 RESEARCH METHOD

The objective of this study is to evaluate the long-term performance impacts of DB versus DBB by comparing DB projects to their counterpart DBB projects. Figure 4 portrays the research method for this study: yearly IRI data from state DOTs was collected for comparable pavement projects, and analyzed using LME. For the LME statistical analysis, the objective function is the IRI and the considered variables are project delivery method, pavement type, location of the road, and mileposts.

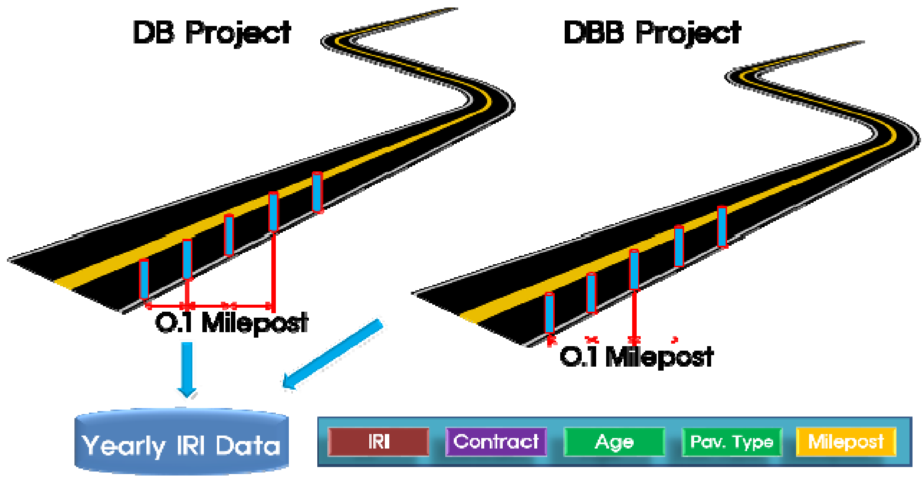


Figure 4: Research methodology

3.1 DATA COLLECTION

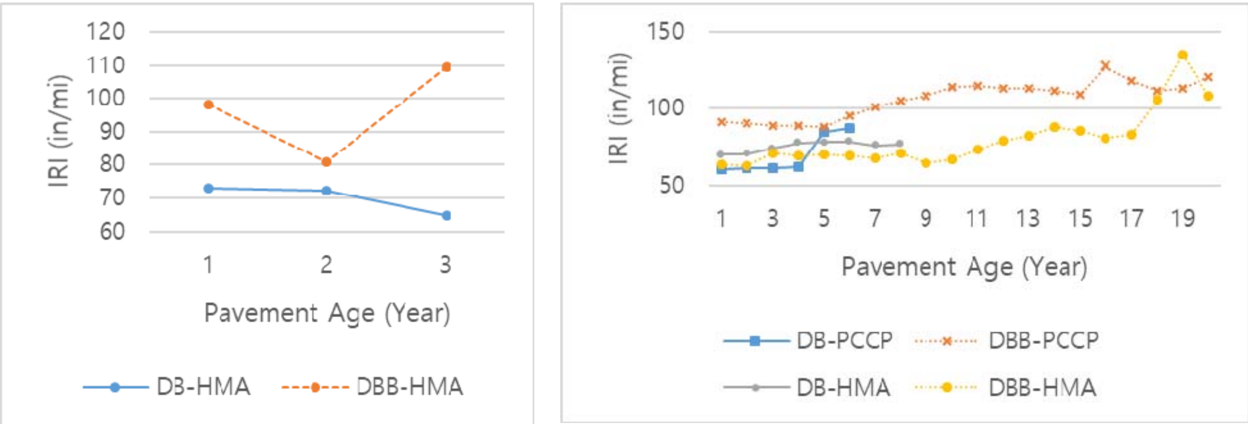
A list of twenty states was compiled using the Design-Build Institute of America (DBIA) information presented in Figure 2. Requests for DB projects that were recently completed on the NHS were made to state DOTs, along with their corresponding IRI data. For the ideal project comparisons, criteria were established to hold specific variables constant, therefore reducing variability to achieve an accurate analysis. These criteria for data collection are as follows: first, DB and DBB projects should be built using similar materials and on comparable soils; they have to have the same pavement structure and a similar traffic volume, as well as similar climatic conditions. In fact, the ideal pair of projects would have a DB and a DBB project on the exact same highway, one right after the other.

Data was collected from two DOTs that provided DB data and comparable DBB data. Table 1 provides the number of projects used for this study. One DOT shared three DB projects with three comparable DBB projects. The second DOT shared four DB projects and 11 comparable DBB projects.

Table 1: Data distribution

Data Pool	State 1		State 2	
	DB	DBB	DB	DBB
Projects	3	3	4	11
Subtotal	6 projects		15 projects	
Total	21 projects			

Figures 4(a) and 4(b) illustrate IRI findings for each state. Both figures show that generally DB projects have better IRI performance than DBB. However, the sample of HMA pavements type in State 2 showed the opposite. From this initial result, we can infer that DB generally shows better performance than DBB, but more statistical modeling is needed to confirm the existence of any outliers.



(a) State 1 IRI trend

(b) State 2 IRI trend

Figure 5: IRI trend for each state

3.2 LINEAR MIXED EFFECTS (LME) MODEL

The differences observed visually need to be tested statistically, in order to determine whether they are statistically significant. This study uses LME models for this purpose, which are extensions of linear regression models for data that are collected and summarized in groups. For modeling longitudinal data, parametric mixed-effects models are an effective tool (Wu and Zhang, 2006). Because of these advantages, the LME model was used for other pavement assessment research. For example, Onar et al. (2006) predicted Accelerated Pavement Testing (APT) results with LME models. Yu et al. (2007) built a predicting LME model for individual pavement conditions by Pavement Condition Rating (PCR). Hummer et al. (2011) measured road paint performance using LME models. Ker et al. (2012) suggested adopting LME to evaluate

AASHO Road Test Rigid Pavement Data. Finally, Khraibani et al. (2012) developed a model for pavement deterioration prediction by using fatigue cracking as parameter. All this existing research proves the usefulness and versatility of the LME modeling for pavement assessment research.

The equation below illustrates the LME model used:

$$y = X\beta + Zb + \varepsilon \tag{1}$$

y is the n-by-1 response vector, and n is the number of observations;

X is an n-by-p fixed-effects design matrix;

β is a p-by-1 fixed-effects vector;

Z is an n-by-q random-effects design matrix;

b is a q-by-1 random-effects vector; and

ε is the n-by-1 observation error vector.

As shown in Equation (1), the LME model is comprised of three parts: random effects vector, fixed effects vector, and an observation error vector. Fixed-effects and observation errors, which measure the population effects, are similar to those in a regression model. However, the additional random-effects part is included in the LME model. Random-effects are used for individual parameters in the group. In this research, the annual IRI data that is collected from different roads refers to the group and each road contains different mileposts representing the individual data points in the group. Therefore, the LME model can provide a statistically valid comparison for the IRI data at hand.

4.0 RESULTS OF THE LME ANALYSIS

The analyzed results for the 21 projects is shown in Tables 1 and 2. The LME model gives two separate results: random effects and fixed effects. The model is created with restricted (e.g., residual or reduced) maximum likelihood (REML), which produces unbiased estimators and produces less biased estimates.

Table 1 shows random effects of the model. This model defines each milepost per each project and region (state) as a random effect. To verify the suitability for each random effect group, Intraclass Correlation Coefficient 1 (ICC1) and ICC 2 is performed. ICC 1 represents the amount of individual-level variance that can be explained by group membership and ICC2 shows reliability of the group means (R Documentation). The result illustrates that the random effects can explain 45.73% with a reliability of 88.93%.

Table 2: Random effects

Groups	Variance	Standard Deviation
Project: Milepost	947.92	30.79
Milepost	69.34	8.33
Region	404.67	20.12
Residual	449.89	21.21

Fixed effects show relationships with IRI value to pavement age, delivery method, and intercept. The result in Table 2 depicts that IRI is significantly affected by age and delivery method. From this result, we can predict the IRI value is increasing by 1.54 in/mi per year. Moreover, the DB method has an IRI value that is 20.63 in/mi less than that of the DBB method. What this means is that the enhanced IRI performance provided by DB is the same as having the pavement to be 13 years younger, which is a major finding. This result proves that this sample of DB projects shows better long-term performance than DBB projects.

Table 3: Fixed effects

	Estimate (in/mi)	Std. Error	df	t value	Pr (>|t|)
(Intercept)	71.98	15.02	1	4.792	0.096
Age (year)	1.54	0.06	5,794	23.313	0.000
Pave type	18.25	3.13	1,143	5.832	0.000
Delivery Method	20.63	2.48	795	8.330	0.000

5.0 CONCLUSIONS

This study investigates IRI data from 21 projects in two state DOTs in the U.S., and compares DB projects with their DBB counterparts using LME models. The results of the analysis illustrate that the DB method exhibits improved long-term performance when compared to the DBB method, in the sample studied here. Moreover, this research shows how LME models can be very useful in analyzing the long-term performance of pavements. Future work is focused on collecting and analyzing a larger dataset of projects, and engaging additional DOTs, to perform more detailed analyses including additional variables in order to generalize these findings.

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