JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

INDOT Research Program Benefit Cost Analysis—Return on Investment for Projects Completed in FY 2016

Bob McCullouch

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INDOT Research Program Benefit Cost Analysis – Return on Investment

For Projects completed in FY 2016

(SPR – 4225)

This Annual Return on Investment (ROI) Report for the INDOT Research Program was prepared at the request of the Governor's Office and INDOT Executive Staff

Bob McCullouch PE, Ph.D.

School of Civil Engineering

Purdue University

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Introduction

The Governor's Office requested an annual financial analysis of the INDOT Research Program to determine the return on the research investment (ROI). The current financial analysis is for research projects that completed in FY 2016. Analyses on previous year's projects is necessary primarily due to the time it takes some project outcomes to be implemented goes into the following year, so FY 2016 analysis is done in 2017. This analysis will supplement the annual IMPACT report (qualitative and quantitative benefits) by adding a rigorous quantitative benefit cost analysis (BCA) to the Research Program. Previous financial analyses used the approach of calculating net present values of cash flows to determine a benefit cost ratio and this report uses the same approach. Additionally, an overall program rate of return (ROI) is reported and will be accumulated over time into a rolling 5-year average.

Benefit-Cost Analysis Methodology

All FY 2016 completed projects were reviewed to determine if it is a viable candidate for BCA. Selection was based on 1) can the costs and benefits be quantified on outcomes that impact INDOT operations, 2) what are the implementation costs, and 3) what is the expected impact time period?

The ROI analysis included the following savings components:

- **Agency savings and costs.** This was based on research findings, engineering judgment/estimates from INDOT BO (business owner) and SME (subject matter experts), available data, and projected use of the new product/process.
- **Road User Costs (RUC) Savings.** RUC includes value of time (VOT), and vehicle operating costs (VOC). RUC unit values will be obtained from current INDOT standards which INDOT provided.
- **Safety Costs (SC) Savings.** Safety costs (SC) can include a before and after evaluation or engineering judgement from BO/SMEs to calculate the reduction in crashes (e.g. property damage, fatalities, etc.). SC unit values will be obtained from current INDOT standards which INDOT provided.

Accrued Benefits will be the combination of **Agency savings, RUC cost savings,** and **SC savings**.

Quantitative benefits were calculated for each research project analyzed for the expected impact period where known or planned quantities (estimated in the INDOT 5-year work program) were available. A five-year analysis period was used on eight of the ten projects while a 24 and 75 year periods used on two others, which are explained in their individual analysis. Individual project costs are research and implementation costs. Net present value (NPV) for individual projects are calculated to 2016 dollars by combining costs and benefit cash flows. Individual project analyses are included in the Appendix. Backup documentation describing calculations and analysis for qualifying projects will be kept by the INDOT Research Division and are available for review.

The ROI is expressed as a BCA ratio, which is commonly used by State DOTs and national transportation research agencies when expressing the return on the research investment. This methodology will be used annually to calculate a FY ROI which will be combined with other FY ROI to create a rolling average over time. The rolling average will accumulate up to a maximum of the five recent years, with FY 2016 being the first year.

Benefit-Cost Analysis Results

Project outcomes were classified as either Quantitative, Qualitative, or Not Successfully Implemented.

- **Quantitative** - Implementation produces benefits that are measureable and quantifiable. Each of these projects has an individual analysis performed and is included in the Appendix. The analysis or impact period is the time benefits were calculated.
- **Qualitative** - Implementation is successful and benefits occur, but cannot be quantified with certainty due to data not being available or easily discoverable. Examples of qualitative benefits could include a specification revision, a proof-of-concept study, a synthesis study that produces a summary of options and best practices, manuals or guidelines, or where cost comparison data is unavailable.
- **Not Successfully Implemented** - For various reasons the project outcomes could not be currently implemented. Common reasons are management, logistical, technical, or legal issues.

Individual Project Analysis

Table 1 is the list of the ten projects where benefits (NPV 2016$ - NPV of future cash flows in 2016 dollars) could be quantified and their individual analysis is found in the Appendix. Table 2, in the Appendix, is a complete list of all 42 projects completed in FY 2016.

Table 1. Quantitative Benefits Project List

No	FY 16 Completed & Implemented SPR Projects	Project Cost ($1000)	TITLE	Benefit Type	Analysis Period	NPV Project Benefit ($1000) 2016$
1	2938	$150	Materials Characterization for the AASHTO New Design Guide	Agency Savings	5 Years	$33,137
2	3403	$250	Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements	Agency Savings	5 Years	$5,643
3	3418	$97	Quantifications of Benefits of Subsurface Drainage	Agency Savings	5 Years	$4,174
4	3506	$240	Concrete Pavement Joint Deterioration	Agency Savings	5 Years	$544

5	3510	$100	Subbase Requirements for Utilizing Unsealed Joints in PCCP	Agency Savings	5 Years	$6,772
6	3617	$100	Bridge Preservation Treatments and Best Practices	Agency Savings	75 Years	$11,481
7	3624	$204	Optimizing Laboratory Mixture Design as it Relates to Field Compaction in order to Improve Hot-Mix Asphalt Durability	Agency Savings	5 Years	$7,531
8	3636	$416	LRFD of Bridge Foundations Accounting for Pile Group-Soil Interaction	Agency Savings	5 Years	$7,199
9	3705	$150	Performance Assessment of Road Barriers in Indiana	Agency Savings/RUC	24 Years	$273,714
10	3830	$235	Evaluation of Alternative Intersections and Interchanges	RUC	5 Years	$17,029

Total Benefits $367,227

Eight of the projects have a five-year analysis period. On these projects the annual benefits were based on planned installed quantities that resulted in immediate savings, such as construction cost savings. Project 3617 analysis period is based on the expected bridge life of 75 years, because the recommended maintenance program starts after construction and is in place throughout the life of the bridge. Project 3705 has a 24 - year analysis period because it uses barrier quantities estimated in the 5-year work plan and maintenance and user safety costs calculated during the 20-year barrier life.

The total quantifiable savings from the ten projects, during their analysis or impact period, was calculated at $367,227,000 (in 2016$). The total research program cost in FY 2016 was $6,264,000. Therefore, the program BCA for FY 2016 is: **$367,227,000/$6,264,000 = 59**, or 59 dollars returned in savings for every research dollar expended.

A combined table of all ten projects cash flows and project NPV was created. A condensed version of the table is shown in Table 2. The expanded version of the table cannot be incorporated into the report due to its size, but is provided as a supplementary file.

Table 2. Quantitative Projects Five Year Cash Flows

Project Description	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
2938 - Annual Benefit (5 year impact)*	0	11,569,300	7,424,500	6,183,700	6,051,700	5,814,100
Research and Implementation cost	-150,000					
Net benefit	-150,000	11,569,300	7,424,500	6,183,700	6,051,700	5,814,100
NPV FY 2016	**33,137,617**					
3403 - Annual Benefit (5 year impact)*		1,248,750	1,286,213	1,324,799	1,364,543	1,405,479
Research and Implementation cost	-250,000					
Net benefit	-250,000	1,248,750	1,286,213	1,324,799	1,364,543	1,405,479
NPV FY 2016	**5,642,615**					
3418 - Annual Benefit (5 year impact)*		960,000	960,000	960,000	960,000	960,000
Research and Implementation cost	-97,000					
Net Benefit	-97,000	960,000	960,000	960,000	960,000	960,000
NPV FY 2016	**4,174,290**					
3506 - Annual Benefits (5 year impact)*	0	165,000	169,950	175,049	180,300	185,709
Research and Implementation cost	-240,000					
Net Benefit	-240,000	165,000	169,950	175,049	180,300	185,709
NPV FY 2016	**544,632**					
3510 - Annual Benefit (5 year impact)*		1,457,533	1,501,259	1,546,297	1,592,686	1,640,466
Research and Implementation cost	-100,000					
Net Benefit	-100,000	1,457,533	1,501,259	1,546,297	1,592,686	1,640,466
NPV FY 2016	**6,772,236**					
3617 - Benefit, 75 year life (1)						
Research and Implementation cost	-100,000					
Net Benefit	-100,000	390,627	390,627	390,627	390,627	390,627
NPV FY 2016	**11,481,000**					
3624 - Annual Benefit (5 year impact)*		5,005,440	1,689,600	696,960	591,360	401,280
Research and Implementation cost	-204,000					
Net Benefit	-204,000	5,005,440	1,689,600	696,960	591,360	401,280
NPV FY 2016	**7,531,690**					
3636 - Annual Benefit (5 year impact)*		1,613,355	1,661,756	1,711,608	1,762,957	1,815,845
Research and Implementation cost	-416,000					
Net Benefit	-416,000	1,613,355	1,661,756	1,711,608	1,762,957	1,815,845
NPV 2016	**7,199,826**					
3705 - 24 year life (2)						
	FY2016	**FY2017**	**FY2018**	**FY2019**	**FY2020**	**FY2021**
Research and Implementation cost	-150,000					
Barrier Cost - INDOT 5 Year program*	-4,800,000	-4,944,000	-5,092,320	-5,245,090	-5,402,442	
Annual Maintenance Cost		-120,000	-247,200	-381,924	-524,509	-675,305

Annual Benefit -2016 installation		3,200,000	3,296,000	3,394,880	3,496,726	3,601,628
Annual Benefit 2017 installation			3,296,000	3,394,880	3,496,726	3,601,628
Annual Benefit 2018 installation				3,394,880	3,496,726	3,601,628
Annual Benefit 2019 installation					3,496,726	3,601,628
Annual Benefit 2020 installation						3,601,640
Net Benefit-Cost	-4,950,000	-1,864,000	1,252,480	4,557,626	8,059,954	17,332,847
NPV 2016	**273,714,281**					
3830 - Annual Benefit (5 year impact)*		1,692,000	2,820,000	3,948,000	5,076,000	6,204,000
Research and Implementation cost	-235,000					
Net Benefit	-235,000	1,692,000	2,820,000	3,948,000	5,076,000	6,204,000
NPV 2016	**$ 17,029,518**					
NPV Total 2016	**$ 367,227,705**					
Research Program Cost	**$6,264,000**					
Benefit Cost Ratio - ROI	**59**					
Report Date	12/31/2017					
* Based on INDOT 5 Year Work Program						
1. The first 5 years of the 75-year cash flows are shown. See supplementary file for the additional cash flows.						
2. The first five years of the 24-year cash flows are shown. See supplementary file for the additional cash flows.						

Eight of the ten projects, with quantifiable benefits, resulted in agency savings, while two other projects resulted in a reduced road user cost (RUC). A summary of these agency cost savings and RUC are described below:

- **2938** – New pavement design procedure reduces asphalt pavement thickness on mainline pavements by 1.5" and concrete pavements greater than 12" thick by 1.5". The savings are lower pavement material costs.
- **3403** - Allows for a reduction in cement values for concrete pavements and an earlier opening date to traffic. Savings are lower concrete pavement costs.
- **3418** - A proper subsurface drainage layer below heavily traffic areas can improve pavement life. Benefit is longer pavement life in these areas.
- **3506** – A new concrete pavement joint design for transverse joints reduces material and construction costs.
- **3510** – Revising concrete pavement joint detail results in construction cost savings.
- **3617** – A new bridge deck maintenance program reduces life cycle costs in its maintenance and upkeep.
- **3624** – Changing asphalt pavement mix design increases pavement life and reduces pavement lifecycle costs of asphalt pavements.
- **3636** – A new pile driving formula results in higher pile capacities, lower pile quantities and lower pile costs.

- **3705** - Installing median cable barrier systems is more cost-effective than other barrier options due to lower maintenance and user safety costs.
- **3830** project benefits are classified as Road User Costs (RUC) as the Double Diamond Interchange option reduces travel time through the intersection.

Summary

The aggregate benefit is significant, resulting in more than $367 million in savings over the projected service lives (in 2016$). The basis for the numbers used in the BCA came from INDOT personnel, Industry Associations, and researchers. These are described in detail in the individual analyses located in the Appendix.

A ROI of 59 to 1 is considered an outstanding return on the research investment. While the ROI is significant, a review of the individual project analysis shows a conservative approach was taken in any assumption made and in the calculations, and actual savings may be much higher. This analysis indicates that INDOT is receiving a significant return on its research investment which will continue to grow due to recently passed legislation (HB 1002), authorizing more funding for construction, re-construction, and preservation.

For 29 projects completed in FY 2016, quantifiable benefits could not be calculated, however other qualitative benefits resulted that brought significant value to the Department and are highlighted in the annual IMPACT report. Ten of the projects were quantified and described herein, and three of the projects were not successfully implemented due to various reasons. A complete listing of research projects completed in FY 2016 is shown in Table 3 in the Appendix.

Appendix

Table 3. – Complete Research Project List – FY 2016

No	FY 16 Completed & Implemented SPR Projects	Project Title	Project Cost ($ 1000)	Quantitative Benefits, Qualitative Benefits or Not Successfully Implemented	Project Benefits ($1000)
1	2938	Materials Characterization for the AASHTO New Design Guide	$150		33137
2	3403	Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements	$250		5643
3	3418	Quantification of Benefits of Subsurface Drainage	$97		4174
4	3425	Improved Methods of Bridge Maintenance and Inspection	$75	Not Successfully Implemented	0
5	3506	Concrete Pavement Joint Deterioration	$240		757
6	3510	Subbase Requirements for Utilizing Unsealed Joints in PCCP	$100		6772
7	3512	Performance Evaluation of Deployed Cathodic Protection	$100	Qualitative Benefits	0
8	3523	Evaluation of Sealers and Waterproofers for Extending the Life Cycle of Concrete	$150	Qualitative Benefits	0
9	3533	Performance Evaluation of Crack Sealing and Filling Materials with Pavement Preservation Treatments	$118	Qualitative Benefits	0
10	3615	Active Corridor Management	$500	Qualitative Benefits	0
11	3617	Bridge Preservation Treatments and Best Practices	$100		11581

12	3624	Optimizing Laboratory Mixture Design as it Relates to Field Compaction in order to Improve Hot-Mix Asphalt Durability	$204		7531
13	3626	Enhanced Treatment Selection for Reflective Joint Cracking in Composite Pavements	$169	Qualitative Benefits	0
14	3630	Efficient Load Rating an Quantification of Life-Cycle Damage of Indiana Bridges for Overweight Loads	$173	Qualitative Benefits	0
15	3636	LRFD of Bridge Foundations Accounting for Pile Group-Soil Interaction	$416		7199
16	3704	Indiana State Highway Cost Allocation and Revenue Attribution Study / Estimation of Travel by Out-of-State Vehicles on Indiana Highways	$375	Qualitative Benefits	0
17	3705	Performance Assessment of Road Barriers in Indiana	$150		273714
18	3706	Laser Mobile Mapping Standards and Applications in Transportation	$234	Qualitative Benefits	0
19	3707	A Synthesis Study on Collecting, Managing, and Sharing Road Construction Asset Data	$145	Qualitative Benefits	0
20	3716	Relating Design Storm Events to Ordinary High Water Marks in Indiana	$125	Qualitative Benefits	0
21	3717	Streambank Stabilization Alternatives to Riprap	$108	Qualitative Benefits	0
22	3726	Upgrading RoadHAT - Collision Diagram Builder and HSM Elements	$165	Qualitative Benefits	0
23	3751	Evaluation of the Microstructural Characteristics of Soil Treated with Cement Kiln Dust (CKD) and Used as a Subgrade at US 24	$33	Qualitative Benefits	0

24	3800	Development of a Geographic Winter-Weather Severity Index for the Assessment of Maintenance Performance	$175	Qualitative Benefits	0
25	3802	Development of Standardized Component Based Equipment Specifications and Transition Plan Into a Predictive Maintenance Strategy.	$115	Qualitative Benefits	0
26	3805	Long Term Pavement Performance Indicators for Failed Materials	$140	Qualitative Benefits	0
27	3806	Verification of the Enhanced Integrated Climatic Module Soil Subgrade Input Parameters in the MEPDG	$132	Qualitative Benefits	0
28	3810	Analysis of the MSCR Asphalt Binder Test and Specifications for Use in Indiana	$210	Qualitative Benefits	0
29	3813	Performance of Warranted Asphalt Pavements: Smoothness and Performance of Indiana Warranted Asphalt Pavements	$120	Qualitative Benefits	0
30	3819	Element Level Bridge Inspection - Benefits and Use of Data for Bridge Management	$69	Qualitative Benefits	0
31	3828	Models to Support Bridge Management	$125	Qualitative Benefits	0
32	3829	Estimation and Prediction of Statewide Annual VMT by Vehicle Class and Highway Category	$100	Qualitative Benefits	0
33	3830	Evaluation of Alternative Intersections and Interchanges	$235		17029
34	3856	INDOT-JTRP Project/Program Implementation Improvement	$102	Qualitative Benefits	0

35	3859	Culvert Inspection and Data Management	$25	Qualitative Benefits	0
36	3863	Use of Tablets and Apps to Enhance Construction Inspection Practices	$165	Qualitative Benefits	0
37	3864	Performance of Deicing Salts and Deicing Salt Cocktails	$85	Qualitative Benefits	0
38	3901	Synthesis Study: Best Practices for Maximizing Driver Attention to Work Zone Warning Signs (End of Queue Warning Devices)	$45	Qualitative Benefits	0
39	3907	Simplified Construction Scheduling for Field Personnel	$85	Not Successfully Implemented	0
40	3908	Algorithm and Software for Proactive Pothole Repair	$78	Qualitative Benefits	0
41	3941	Storm Water Pollution and Best Management Practice Guidance for Indiana	$36	Not Successfully Implemented	0
42	3944	Pre-Contract Scoping Processes – Synthesis of Best Practices	$46	Qualitative Benefits	0

Individual Project Analysis

SPR-2938: Materials Characterization for the AASHTO New Design Guide

Introduction

The Mechanistic-Empirical Pavement Design Guide (MEPDG) developed under NCHRP Project 1-37A and adopted by AASHTO presents a new paradigm of pavement design and analysis. The Guide considers the input parameters that influence performance, including traffic, climate, and pavement layer thickness and properties and applies the principles of engineering mechanics to predict critical pavement responses. Not only does the MEPDG change the process and design inputs, it also changes the way engineers think and implement strategies for more effective and efficient pavement design.

The Indiana Department of Transportation (INDOT) began implementation of the MEPDG on January 1, 2009. This project looks at the impact of its implementation and calculates its impact on projects starting in 2017.

Analysis

In the period January to December 2009, INDOT staff and consultants designed more than 100 pavement sections using the MEPDG procedure. As required by the FHWA Indiana Division for implementation of MEPDG, INDOT documented the pavement thickness design of all new pavements and provided comparisons of the thicknesses estimated using the AASHTO 1993 Guide for Design of Pavement Structures to those estimated using the MEPDG procedures. [2] In addition, the INDOT Executive Staff reviewed the cost savings attributed to the "more efficient" pavement designs provided by the MEPDG. Estimated cost savings are based on reducing asphalt base courses by 1.5" and concrete pavements 12" or greater by 1.5" inches. Savings will occur on mainline pavements and the below calculations are based on this. Overlay projects are not impacted.

<u>Calculations</u>

Savings calculations are broken into concrete and asphalt pavements.

Concrete

Based on quantities reported by the concrete paving industry[3], in 2016 and 2017 approximately 1,500,000 square yards (SY) of concrete pavement was placed. When pavements were greater than 12" thick, then the thickness could be reduced by 1.5". It is anticipated the same amount of concrete pavement will be placed between 2018 – 2021. [3]

Based on average concrete bid costs the cubic yards (CY) cost varies from $85 (from on-site batch plant) to $115 (purchased from supplier). Assuming concrete comes from an on-site batch plant (conservative assumption), then the material savings from reducing thickness by 1.5" was calculated as follows:

1,500,000 SY x 9 SF/SY x 1.5"/12" = 1,687,500 cubic feet (CF) of concrete reduced = 1,687,500/27 = 62,500 CY of concrete materials saved. Labor and equipment costs are minimally affected by less material quantity since the area (SY) of pavement does not change.

Annual concrete material saving = 62,500 CY x $85/CY = $5,312,500

Asphalt

Mainline asphalt quantities were obtained from INDOT records for current year projects and planned projects for the years 2018 – 2021.[4] 237 lane miles of asphalt pavement were placed in 2017. Base course thickness reduction was 1.5”.

Forecasted estimated mainline lane miles of asphalt pavement.[4]

2018	2019	2020	2021
80	33	28	19

Reduced thickness of 1.5” occurs in the base course. In 2017 base course material average cost was $50/ton.

<u>*Base Course Material Savings per Year*</u>

Base course weighs 100#/SY/in.

<u>CY 2017</u>
Pavement area = 237 lane miles x 5,280 ft./mile x 12’ (lane width) x 1 SY/9SF = 1,668,480 SY

Weight savings = 1,668,480 SY x 1.5”(thickness reduction) x 100#/SY/in. x 1 ton/2000 # = 125,136 tons

Cost savings = 125,136 tons x $50/ton = $6,256,800

<u>CY 2018</u>
Pavement area = 80 lane miles x 5,280 ft./mile x 12’ (lane width) x 1 SY/9SF = 563,200 SY

Weight savings = 563,200SY x 1.5”(thickness reduction) x 100#/SY/in. x 1 ton/2000 # = 42,240 tons

Cost savings = 42,240 tons x $50/ton = $2,112,000

<u>CY 2019</u>
Pavement area = 33 lane miles x 5,280 x 12’ x 1 SY/9SF = 232,320 SY

Weight savings = 232,320 x 1.5” x 100#/SY/in. x 1 ton/2000# = 17,424 tons

Cost Savings = 17,424 tons x $50/ton = $871,200

<u>CY 2020</u>
Pavement area = 28 lane miles x 5,280 x 12’ x 1/9 = 197,120 SY

Weight savings = 197,120 x 1.5” x 100#/SY/in. x 1 ton/2000# = 14,784 tons

Cost Savings = 14,784 tons x $50/ton = $739,200

<u>CY 2021</u>

Pavement area = 19 lane miles x 5,280 x 12’ x 1/9 = 133,760 SY

Weight savings = 133,760 x 1.5” x 100 x 1/2000 = 10,032 tons

Cost Savings = 10,032 tons x $50/ton = $501,600

These annual costs savings are calculated from asphalt base course material savings due to thickness reduction in pavement. Due to the variability in future concrete and asphalt prices, the average cost of concrete and asphalt in 2017$ was used, which are $85/CY and $50/ton, respectively.

The financial analysis takes a present worth approach for a five-year period with expected capital cost of 3%. No inflation was used in concrete or asphalt cost. The five-year period coincides with an INDOT proposed 5-year work plan which estimates expected pavement quantities. Benefits are expected to accrue after the 5-year period, but are not calculated as pavement quantities are unknown. Annual benefit numbers in the below table are combined for concrete and asphalt.

Project Benefits and Costs	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**
Research Cost	-150,000					
Annual Benefit		11,569,300	7,424,500	6,183,700	6,051,700	5,814,100
Net Benefit-Cost	-150,000	11,569,300	7,424,500	6,183,700	6,051,700	5,814,100
NPV	$33,137,617.19					
Benefits Cost Ratio	221					

Summary

The benefit cost ratio for this project is 221 to 1. The number is based on the following:

- Research cost of $150,000.
- 5 Year work program scheduling pavement estimates were used.
- Concrete cost of $85/CY and asphalt cost of $50/ton
- 3% cost of capital
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project’s cost to execute the research and implement.

References

[1] Pavement Cost Study by John Weaver, INDOT Statewide Asset Management Engineer, April 2017.

[2] The Mechanistic-Empirical Pavement Design Guide: A tool for Cost Savings, Tommy Nantung, INDOT Manager of Pavements, Materials, and Construction Research, INDOT Research Division.

[3] Cost, project, and estimated quantity data were provided by Mike Byers, Indiana Ready Mix Concrete Association.

[4] Quantities provided by John Weaver and Andrew Pangallo, INDOT Field Engineer, apangallo@indot.in.gov.

SPR-3403: Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements

Introduction

This project produced a special provision for early opening to traffic on concrete pavements. Through accelerated testing at the APT lab in the Research Division, test results indicate long term performance is not impacted, at certain thicknesses, with early opening as tensile stresses are lower than expected. With lower actual tensile stresses, lower strength concrete can be used, allowing a reduction of cement quantities in concrete.

Analysis

The basis of the cost benefit analysis is the reduction in cement requirements for a cubic yard of concrete by allowing its strength to reduce form 500 psi to 425 psi. This strength reduction saves approximately 50 lbs. of cement per cubic yard of concrete. At current cement prices this saves approximately $2.50/cubic yard.[1]

Calculations

Research cost was $250,000. Indiana Ready Mix Concrete Association and Tommy Nantung, INDOT R&D, provided data in the benefit cost analysis.

Potential Savings

With an estimated material savings in concrete of $2.50/cubic yard from cement reduction, the annual cost savings calculations are:

- Average concrete pavement thickness is 12”.
- Using the average annual placement of concrete pavement at 1,500,000 SY*, the annual volume of concrete placed is 1,500,000 SY x 12”/36” = 499,500 CY
- Annual cost savings = 499,500 x $2.50 = $1,248,750
- The financial analysis takes a present worth approach for the next five-year construction period with expected capital cost and inflation of 3%.

Below is the benefit cost analysis for a five-year work plan.

Project Benefits and Costs	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**
Research Cost	-250,000					
Annual Benefit		1,248,750	1,286,213	1,324,799	1,364,543	1,405,479
Net Benefit-Cost	-250,000	1,248,750	1,286,213	1,324,799	1,364,543	1,405,479
NPV	$5,642,614.76					
Benefits Cost Ratio	23					

Summary

The benefit cost ratio for this project is 23 to 1. This number is based on the following:

- Research cost of $250,000.
- 5 Year work program scheduling 1,500,000 SYS of concrete pavement annually.
- Cement savings of 50#/CY equates to a cost saving of $2.50/CY.
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1]Cost, project, and estimated quantity data were provided by Mike Byers, Indiana Ready Mix Concrete Association and Tommy Nantung , INDOT Division of Research.

SPR-3418: Quantifications of Benefits of Subsurface Drainage

Introduction

Performance information available indicates properly designed and constructed permeable bases virtually eliminate pumping, faulting, and cracking. A review of current design and construction practices has proven permeable base pavements can be designed and constructed to rapidly drain moisture that infiltrates the pavement surface.

Typical INDOT permeable base materials for asphalt pavement are asphalt open-graded aggregates and concrete pavement unbound # 8 aggregates. The objectives of this project were to evaluate the performance of current INDOT sub-drainage systems and to evaluate maintenance procedures for existing edge drains and outlets. The study presents a comprehensive pavement performance evaluation to determine the effectiveness of subsurface drainage in the following aspects: INDOT existing materials specifications for permeable and filter layer, lab testing of subgrade materials due to the moisture accumulation, numerical modeling of water infiltration into pavement, pavement distress field survey, outlet spacing and maintenance inspection, and annual evaluation of pavement performances and pavement structure strength.

The contribution of the positive subsurface drainage to the strength of the pavement can be categorized in two ways: the improvement of the stiffness of the subgrade and the increase of HMA (Hot Mix Asphalt) modulus to prevent stripping and cracking. Undrained pavement results in approximately $40,000 to $60,000 more in (maintenance) costs for each lane-mile. Traffic can cause significant differences in pavement life and heavy traffics, 30 million equivalent single axel loads (MESALS) result in thickness differences between undrained and drained pavement, compared to that under medium traffic (10 MESALs). This indicates that moisture under heavy traffic loading causes more pavement damage than under light traffic.

Analysis

An estimated $40,000 to $60,000 per lane-mile can be saved at the traffic level of 10 to 30 MESALs if a drainage layer is installed properly [1]. Therefore, providing adequate drainage to a pavement system has been considered an important design implementation to ensure satisfactory performance of the pavement, particularly from the perspective of life cycle cost and serviceability.

Calculations

The cost analysis is based on the following:

- Proper subsurface drainage layers can extend pavement life and reduce damage particularly in heavily traffic areas.
- Heavily traffic areas are those segments that experience 10-30 MESALs.
- When these segments are rebuilt, $40,000 - $60,000 (maintenance/capital cost?) per lane mile in savings occur when a proper drainage layer is installed.
- Estimated maintenance savings are based on a projected five-year work plan for reconstructing heavy traveled interstate sections.

MESAL data was provided by the INDOT GIS section [2]. Below is a map showing where these segments occur in the state.

These heavy traffic segments total to 5,600 lane miles [2].

Using the lower unit cost of $40,000 per lane mile, the following analysis is based on 120 lane miles to be reconstructed over the next 5 years, according to the Next Level Roads Program. An average lane mile of 1/5 per year, 120 x 1/5 = 24 is used.

Project Benefits and Costs	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Research Cost	-97,000					
Annual Benefit		960,000	960,000	960,000	960,000	960,000
Net Benefit-Cost	-97,000	960,000	960,000	960,000	960,000	960,000
NPV	$4,174,290.19					
Benefits Cost Ratio	43					

Summary

The benefit cost ratio is 43 to 1. This number is based on:

- Research cost is $97,000.
- Savings of $40,000 per lane mile for the next five years for a properly installed drainage system.
- Twenty-four lane miles, based on the Next Levels Five Year Road Program, are reconstructed each year for the period, 2017-2021.
- No inflation factor applied.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1.] Final Report # FHWA/IN/JTRP -2015/xx, *Quantification of Benefits of Subsurface Drainage,* Richard Ji, Qi Qi.

[2] MESAL data provided by Kevin Munro, Statewide GIS Asset Manager, INDOT.

SPR-3506: Concrete Pavement Joint Deterioration

Introduction

In recent years the number of reported joints deteriorating prematurely in concrete pavements around Indiana has increased. Changes over the past 45 years in INDOT specifications, pavement materials and design, construction practices, and deicing materials were examined related to the durability of concrete joints in existing pavements.

This study identified that one or more of the following variables influenced the durability of the concrete at joints examined: the draining ability of the base at the joints, original air void system, reduced air void parameters due to lining and infilling of the air voids with secondary minerals, compromised hydration of the concrete at the joint face, and increased moisture at the joint.

To combat increased moisture at the joint, a new joint detail was recommended to reduce the entry of moisture into the joint.

Analysis

The basis of the cost benefit analysis is the savings in maintaining concrete pavements at the joints resulting from a new joint design.

Calculations

Research cost was $240,000. The Indiana Ready Mix Concrete Association[1] and Tommy Nantung, INDOT R&D, provided data used in the benefit cost analysis. Tie bar requirements came from INDOT Design Standards. [2]

Estimated tie bar cost from contractor - #5 = $1.68 ea., #6 = $2.12 ea., #7 = $2.68 each
Concrete pavement panel size = 12'x 15' = 180 square feet = 20 SY

SY – square yard, SYS – square yards

Concrete pavement 12" or thicker with transverse joints spaced 15' on center bar requirements are:

a. Previous standard: concrete pavement w/ transverse joints spaced at 15'. At 3 ft. spacing # of bars in a pavement panel = 15'/3' = 5 spacings which is 4 bars. At 2 ft. spacing # of bars in a pavement panel = 15'/2' = 7 spacings which is 6 bars.

   Longitudinal joint bars
   #7 @ 3' = 4 bars x $2.68 = $10.72/panel – $10.72/20 SY = $0.54/SY to cost of pavement
   #6 @ 2' = 6 bars x $2.12 = $12.72/panel – $12.72/20 SY = $0.64/SY to cost of pavement

b. New Standard for Joint Design: concrete pavement w/ transverse joints at 15 ft.
   Longitudinal joint bars
   #6 @ 3' = 4 bars x $2.12 = $8.48/panel - $8.48/20 SY = $0.43/SY to cost of pavement

Estimated Savings:
Comparing bar options
#7(old standard) vs. #6 (new standard) - $0.54 - $0.43 = $0.11/SY
#6(old standard) vs. #6 (new standard) - $0.64 - $0.43 = $0.21/SY

For the last several construction seasons INDOT has placed on average of 1.5 million SYS of concrete pavement. It is expected this quantity will continue in the next five-year construction plan.

Estimated cost saving range in 2017 is:
$0.11 x 1,500,000 SYS = $165,000 (#7 vs. #6)
$0.21 x 1,500,000 SYS = $315,000 (#6 vs. #6)

Potential savings range is $165,000 to $315,000 in 2017. For the cost benefit analysis, the lower number, $165,000, will be used, which is a conservative number, benefits could be higher.

Example project impact

1) On a SR 62 project (RS-35119) bid in April 2017 – there was 139,756 SF of partial depth joint repair on a project with 272,754 SYS of pavement.

2) Bids were received from three contractors for the 139,746 SF of joint repair.

Contractor bid #1 - $26.15/SF = $3,654,819 – or $13.40/SY impact
Contractor bid #2 - $27.50/SF = $3,843,290 – or $14.09/SY impact
Contractor bid #3 - $33.00/SF = $4,611,948 – or $16.9/SY impact
Avg. = $14.90/SY – Cost to fix concrete joint damage
Average bid cost = $4,036,686

For this one project, the average repair cost to fix deteriorated joint damage is nearly $4 million. This project illustrates how costly repairs can be. Going to a different joint design will mediate some of this damage, but to say that all damage will be eliminated cannot be substantiated or used in cost benefit calculations. Therefore, cost savings are calculated from construction bar savings alone, in the five-year program.

The financial analysis utilized a present worth approach for a five-year period with expected capital cost and inflation of 3%. The five-year period coincides with an INDOT proposed 5-year work plan which estimates pavement quantities. Benefits are expected to accrue after the 5-year period, but are not calculated as pavement quantities are unknown.

Following is the benefit cost analysis for the next five-year work plan.

Project Benefits and Costs	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Research Cost	-240,000					
Annual Benefit 2017 Installation		165,000	169,950	175,049	180,300	185,709
Net Benefit-Cost	-240,000	165,000	169,950	175,049	180,300	185,709
NPV	$544,631.92					
Benefits Cost Ratio	2					

Summary

The benefit cost ratio for this project is 2 to 1. This number is based on the following:

- Research cost of $240,000.
- 5 Year work program scheduling 1,500,000 SYS of concrete pavement annually.
- Longitudinal joint uses #6 bar @ 3 ft. vs. #7 bar @ 3 ft.(previous).
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1]Cost, project, and estimated quantity data were provided by Mike Byers, Indiana Ready Mix Concrete Association.

[2]Tommy Nantung, Manager for Pavement, Materials, and Construction Research, Indiana Department of Transportation, Division of Research and Development.

SPR-3510: Subbase Requirements for Utilizing Unsealed Joints in PCCP

Introduction

The primary objective of this study was to investigate the possible cost benefits that can be achieved through the use of sealed and unsealed joints and various subbase treatments to extend the pavement life, without compromising pavement performance. The second objective of this study was to investigate the performance of sealed/unsealed joints on treated/untreated permeable subbase test sections.

Six concrete test pavement segments were constructed on US-24 with different types of subbases and separation materials, and sealed and unsealed joints. The overall performance of the unsealed joints was marginally better than the sealed joints in the pavement survey. Test sections 0 and 1 exhibited similar performance for unsealed joints on the same permeable subbase. Sections 3 and 4, which had higher construction costs, performed overwhelmingly better. The research concluded that using unsealed joints can be a good practice with its low maintenance cost.

Analysis

The basis of the cost benefit analysis is the elimination of the second cut, backer rod, and sealant in transverse joints.

Calculations

Research cost was $100,000. Indiana Ready Mix Concrete Association and Tommy Nantung, R&D, provided cost and quantity data used in the analysis[1,2].

Potential Savings

Based on contractor bids[1], it is costing approximately $9.55/ft.* to install transverse joints in concrete pavements. This project recommended modifying the joint by eliminating the second joint cut, backer rod, and joint sealant. Concrete paving contractors estimate, with this modification, a savings of 17% in joint cost is possible[2]. This equates to a saving of $1.62/ft.

Concrete pavements are typically 12 ft. wide with transverse joints spaced at 15 ft. on center. A lane mile of pavement is 7,040 SY. Based on current and recent year concrete pavement quantities, INDOT is placing on average approximately 1,500,000 SY of concrete pavement[1]. The linear feet of transverse joint then is calculated to be:

- Number of transverse joints in a lane mile of pavement = 5,280/12 = 352 joints
- Number of lane miles in 1,500,000 SY of pavement = 1,500,000/7040 = 213 lane miles
- Annual linear feet of transverse joints = 352 x 213 x 12 ft. = 899,712 ft.
- Projected annual savings = $1.62/ft. x 899,712 ft. = $1,457,533

The financial analysis takes a present worth approach for a five-year period with expected capital cost and inflation of 3%. The five-year period coincides with an INDOT proposed 5-year work plan which estimates expected pavement quantities. Benefits are expected to accrue after the 5-year period, but are not calculated as pavement quantities are unknown.

Below is the benefit cost analysis for a five-year work plan.

Project Benefits and Costs	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**
Research Cost	-100,000					
Annual Benefit		1,457,533	1,501,259	1,546,297	1,592,686	1,640,466
Net Benefit-Cost	-100,000	1,457,533	1,501,259	1,546,297	1,592,686	1,640,466
NPV	$6,772,235.84					
Benefits Cost Ratio	68					

Summary

The benefit cost ratio for this project is 68 to 1. This number is based on the following:

- Research cost of $100,000.
- 5 Year work program, scheduling 1,500,000 SYS of concrete pavement annually.
- Transverse joint saving is $1.62/ft.
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1]Cost, project, and estimated quantity data were provided by Mike Byers, Indiana Ready Mix Concrete Association.

[2] Tommy Nantung, Manager for Pavement, Materials, and Construction Research, Indiana Department of Transportation, Division of Research and Development.

SPR-3617: Bridge Preservation Treatments and Best Practices

Introduction

This project reviewed bridge maintenance activities recommended by current literature and to examine those maintenance activities conducted by the Indiana Department of Transportation (INDOT) districts, as well as maintenance activities performed by other DOT agencies. This review created a list of ten bridge preventive maintenance activities that improve the effectiveness of bridge maintenance operations in Indiana. The required conditions and frequency to perform each activity was analyzed, and the cost and benefit of such operations was studied to ensure that the proposed activities are economically feasible and sustainable. Based upon the analysis, all ten preventative maintenance activities were found to be cost effective and are recommended as an effective means of bridge preservation. The recommended ten maintenance activities are:

1. Bridge deck cleaning and washing
2. Bridge concrete deck maintenance. Repeat this procedure every five years.
3. Bridge joints
4. Bridge Bearings
5. Bridge approach slab
6. Superstructure cleaning and washing
7. Spot painting
8. Vegetation control
9. Removing debris from piers/abutments
10. Pin and hanger connection maintenance

Analysis

The project reported a life cycle cost analysis for deck maintenance, item 2 in the list. The other nine maintenance activities are difficult to quantify savings. So the basis of the cost benefit analysis is to calculate savings from implementing a deck preventative maintenance program.

<u>Calculations</u>

Research cost was $100,000. The square foot costs for four different deck maintenance options were created in the final report and are based on information provided by INDOT. For each option a NPV was calculated based on a bridge service life of 75 years; a discount rate of 4%; and a salvage value of $0 at the end of the service life. These four option are:

1. Current INDOT Policy, no routine deck maintenance activities, PV (cost) = $80.63/SF
2. Sealing every 5 years and overlay at 35 years, PV(cost) = $43.30/SF
3. Sealing every 5 years, patching at 10 years, Overlay at year 35, PV(costs) = $48.18/SF
4. Sealing every 5 years, overlay at year 30, replace deck at year 50, PV(costs) = $59.96

Option 2 has the lowest annual cost for the bridge deck life of a new bridge. The estimated cost savings is the cost difference between options 1 and 2, which is the estimated annual savings from using option 2 over the current INDOT approach.

- Estimated annual savings = $80.63 - $43.30 = $37.33/SF
- $37/SF during the 75-year deck life is used in the calculations.

- Since future deck quantities are difficult to estimate, an average of past year new bridge deck quantities is used in the calculations.[2] In the years 2013-2017 there were a considerable number of new bridges built on the new I-69 segments, US 31, SR 25 (Hoosier Heartland), I-65 southern Indiana, and the Ohio River bridges. With the increased funding provided in the last two legislative sessions through HB 1001 and 1002, new bridges will be constructed, but likely not at the same level experienced in the 2013-2017 time period. Since the Ohio river bridges have very large decks and are not built every year, their quantities were not included. Deck quantities for the I-69 bridges were removed as well. This produces a conservative cost savings number.

- Average annual deck area for new bridges (2013-2017) = 313,000 SF

- Average cost savings for a new bridge (75-year life) using option 2 maintenance plan is:

  313,000 SF * $37.33/SF = $11,581,000 (one year of new bridges constructed)

- NPV Benefits (75 years) = $11,581,000

  Convert to annual benefits for 75 years = $11,581,000 (A/P @ 3%)

  Annual cash flow benefit = $11,581,000 * .03373 = $390,627, annual cash flow, see table

- Benefit cost ratio = $11,581,000/ $100,000 = 115.81

Summary

The benefit cost ratio for this project is 115 to 1. This number is based on the following:

- Research cost of $100,000.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1] Bowman, M. D., & Moran, L. M. (2015). *Bridge preservation treatments and best practices* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2015/22). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284316007.

[2] Bridge deck quantities provided by Jaffar G. Golkhajeh, Bridge Asset Management Office, Division of Bridges, INDOT. Email: jgolkhajeh@indot.in.gov. Bridges where deck or superstructure were replaced, deck areas came from SPMS. Existing bridges which were replaced or built on new alignments came from the Bridge Inspection Application System (BIAS).

SPR- 3624: Optimizing Laboratory Mixture Design as it Relates to Field Compaction in order to Improve Hot-Mix Asphalt Durability

Introduction

The objective of the research was to optimize asphalt mixture laboratory design compaction as it relates to field compaction in order to increase asphalt pavement durability, without sacrificing the permanent deformation characteristics of the mixtures. INDOT's current asphalt mixture design method specifies a design air voids content of 4 percent. Asphalt mixtures thus designed are typically placed with 7 percent air voids, or higher. This can result in lower than desired asphalt pavement service lives due to durability loss as the asphalt prematurely ages.

Compacting asphalt pavements to 5 percent in-place air voids, without the possibility of further densification from traffic would make them more durable thus extending asphalt pavement life. Thus, producing asphalt mixtures with in-place air voids of 5 percent should yield better rutting performance than compacting mixtures to in-place air voids of 7-8 percent, as is done currently. Asphalt mixtures designed in the laboratory at 5 percent air voids can be compacted to 5 percent air voids in the field. A field test performed at a project near Fort Wayne and tests performed at the National Center for Asphalt technology indicates this can be done without additional compaction effort.

Changing the mix design through aggregate composition improves the durability of asphalt payments, which translates to longer pavement life. The mix design asphalt content and the field compaction effort will not change. The new design will not increase the cost of asphalt or the construction costs to place and compact.

Analysis

The benefits of the project could be substantial. The possible increase in pavement life is conservatively estimated at 2 to 3 years, a 12- 20 percent increase. This increase in pavement life result in a significant reduction in life cycle pavement costs.

Calculations

Asphalt pavement life in Indiana is currently 15-20 years. Using a twenty-year life with an estimated increase life of 12 percent (conservative) an extra 2.5 years is expected to be gained from this new mix design. Using bid quantities, the area cost of asphalt pavement for a twenty-year period was calculated. Using mainline pavement quantities, used in the SPR-2938 project analysis, the following table indicates asphalt pavement lane miles for 2017 (actual) and 2018 – 2021 (estimated).[3]

2017 (actual)	2018 (est.)	2019 (est.)	2020 (est.)	2021 (est.)
237 lane miles	80 lane miles	33 lane miles	28 lane miles	19 lane miles

From a typical cross-section for mainline pavement, the three asphalt courses have these area weights.

- Surface – 165#/SY
- Intermediate – 275#/SY
- Base – 990#/SY for 25mm and 715#/SY (see 2938 calculations) for 19mm. Using the lower of these two numbers will lower the sq. ft. cost of the pavement, therefore this number was used.

For 1 SY of pavement the asphalt weight is 165+275+715 = 1155#, approximately ½ ton.

Asphalt cost (2017$, average) is estimated at $50/ton, so the in-place cost for 1 SY of mainline pavement is $50/2(half ton) = 25$/SY.

Estimated new pavement value for each year is calculated.

- 2017 – 237 miles x 5280 ft./mile x 12 ft. wide pavement x 1 SY/9SF x $25/SY = $41,712,000
- 2018 – 80 x 5280 x 12 x 1/9 x $25 = $14,080,000
- 2019 – 33 x 5280 x 12 x 1/9 x $25 = $5,808,000
- 2020 – 28 x 5280 x 12 x 1/9 x $25 = $4,928,000
- 2021 – 19 x 5280 x 12 x 1/9 x $25 = $3,344,000

Using an estimated 12 percent life increase, the extra value added for each year new pavement is:

- 2017 - $41,712,000 x .12 = $5,005,440
- 2018 - $14,080,000 x .12 = $1,689,600
- 2019 - $5,808,000 x .12 = $ 696,960
- 2020 - $4,928,000 x .12 = $ 591,360
- 2021 - $3,344,000 x .12 = $ 401,280

These cost savings result from an additional pavement life value of 12 percent. The financial analysis takes a present worth approach for a five-year period with expected capital cost of 3 percent. The five-year period coincides with an INDOT proposed 5-year construction work plan which estimates expected pavement quantities. Benefits are expected to accrue after the 5-year period, but are not calculated, as pavement quantities are unknown.

Below is the benefit cost analysis for a five-year work plan.

Project Benefits and Costs	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Research Cost	-204,000					
Annual Benefit		5,005,440	1,689,600	696,960	591,360	401,280
Net Benefit-Cost	-204,000	5,005,440	1,689,600	696,960	591,360	401,280
NPV	$7,531,690.31					
Benefits Cost Ratio	37					

Summary

The benefit cost ratio for this project is 37 to 1. The number is based on the following:

- Research cost of $204,000.
- 5 Year work program scheduling asphalt pavement estimates were used.
- Asphalt cost of $50/ton (2017$ cost)
- 3% cost of capital
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1] Aschenbrener, T., R. Brown, N. Tran, P. Blankenship. *Demonstration Project for Enhanced Durability of Asphalt Pavements Through Increased In-Place Pavement Density*. NCAT Report 17-05. National Center for Asphalt Technology at Auburn University, Auburn, AL., 2017.

[2] SPR- 3624 Final Report. Optimizing Laboratory Mix Design as it Relates to Field Compaction in Order to Improve Hot-Mix Asphalt Durability. Available through Purdue e-Pubs.

[3] Quantities provided by INDOT, John Weaver, INDOT Statewide Asset Management Engineer and Andrew Pangallo, INDOT Field Engineer, apangallo@indot.in.gov.

SPR-3636: LRFD of Bridge Foundations Accounting for Pile Group-Soil Interaction

Introduction

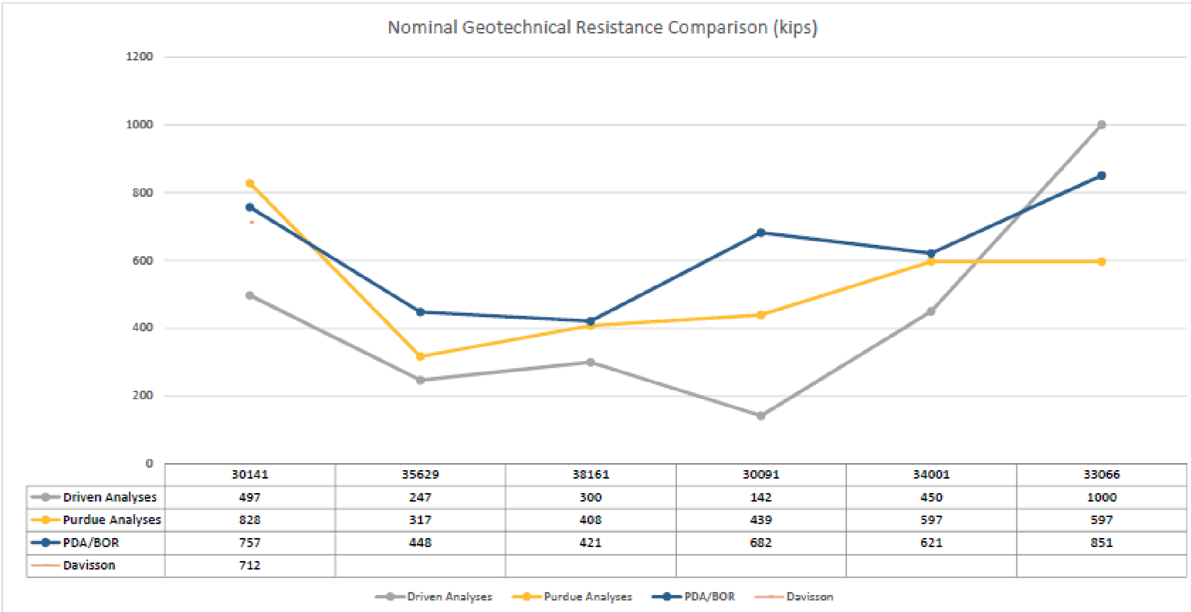
Pile group foundations are used in most transportation structures. Traditionally, design of pile group foundations has been performed in the United States using working stress design (WSD), which uses a single value factor for safety to account for the uncertainties in pile design. A method that would enable designs to reflect uncertainties in a more precise manner and be associated with a target probability of failure would be advantageous with respect to WSD. Recognizing this, the Federal Highway Administration (FHWA) mandated that load and resistance factor design (LRFD) be used for designing the foundations of all bridge structures initiated after September 2007. In LRFD, load variability is reflected in load factors applied by multiplication to the loads the foundations must carry, and resistance variability is reflected in resistance factors applied by multiplication to the foundation resistances. If load and resistance factors are determined using reliability analysis, it is possible to link them to a probability of failure. In order to develop a comprehensive and reliable LRFD pile design framework, it is necessary to have clear, detailed, and accurate understandings of the mechanism of resistance development in pile groups. This project developed a number of analyses that provide insights into pile group response that were not previously available. It then uses these analyses to develop a first iteration of an LRFD design framework for pile groups. [1]

Analysis

A total of six contracts; two in Crawfordsville District, three in Greenfield District and one in LaPorte District were analyzed (2). Three projects have 14-inch pipe piles and the rest have steel H piles 12”x74’ or 14”x89’ driven to required nominal geotechnical resistances. This analysis compares two design methods, the FHWA Driven pile analysis method and the INDOT-Purdue pile analysis method developed through this JTRP project. Both these methods are compared with the results with pile dynamic load test (PDA) at the beginning of restrike (BOR). Only one contract included Static Load Test (SLT) and a comparison of the two design methods would not be conclusive.

Data from these contracts are shown in the below table. Based on this data, it appears that the Purdue method developed in this project is more reliable.
Better design methods should predict resistances more accurately and precisely. It is difficult to compare the impact of design methods in terms of cost, because pile length and resistance versus depth is dependent on the specific soil profile and the distribution of axial and lateral loads. However, it is possible to compare the impact of design methods on the excess capacity required to achieve a specific level of reliability.

The below graph and table [2] shows a comparison of different pile capacity methods with the Purdue method predicting higher capacities than the current used method and a closer correlation with PDA results.



Comparison of the FHWA and Purdue Pile Analyses Methods with PDA (BOR) and SLT

Contract	District	County	Pile Size	FHWA Driven Analyses	Purdue Analyses	PDA/BOR	Static Load Test - Davisson	Driven Vs. PDA (BOR)	Purdue Vs. PDA (BOR)	Driven Vs. SLT	Purdue Vs. SLT	PDA(BOR) Vs. SLT*
30141	LaPorte	Marshall	14 inch	497	828	757	712	65.65%	109.38%	69.80%	116.29%	106.32%
35629	Greenfield	Hamilton	12x74 HP	247	317	448		55.13%	70.76%			
38161	Crawfordsville	Clinton	14 inch	300	408	421		71.26%	96.91%			
30091	Crawfordsville	Vigo	14 inch	142	439	682		20.82%	64.37%			
34001	Greenfield	Hamilton	14x89 HP	450	597	621		72.46%	96.14%			
33066	Greenfield	Marion	14x89 HP	1000	597	851		117.51%	70.15%			
							Average	67.14%	84.62%	69.80%	116.29%	106.32%

* Only one contract analyzed had static load test
Table Reads resistances in Kips.

Calculations

Between 2008 to 2014, there have been 1,196,956 linear feet of piles installed on INDOT projects at a total cost of $56,941,969 which corresponds to a unit cost of $47.57 per foot.[2] Based on the test piles driven on these six contracts which is 336 ft. and the load capacities between the current driven analysis method and the Purdue method is 1845 kips to 2230 kips, or a 17% savings in pile driving costs. Using the total pile cost between CY 2008-2014, the 17% savings is, $56,941,969 x .17 = $ 9,680,134. This is over a 6-year period, or an annual savings $1,613,355.

The financial analysis used a present worth approach for a five-year period with expected capital cost and inflation of 3%. The five-year period coincides with an INDOT proposed 5-year work plan which estimates expected bridge quantities. Estimated bridge quantities are estimated at the quantities experienced during the 2008 to 2014 time period. Benefits are expected to accrue after the 5-year period but are not calculated as bridge quantities may vary.

Project Benefits and Costs	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**
Research Cost	-416,000					
Annual Benefit		1,613,355	1,661,756	1,711,608	1,762,957	1,815,845
Net Benefit-Cost	-416,000	1,613,355	1,661,756	1,711,608	1,762,957	1,815,845
NPV	$7,199,825.62					
Benefits Cost Ratio	17					

Summary

The benefit cost ratio for this project is 17 to 1. This number is based on the following:

- Research cost of $416,000.
- 5 Year work program scheduling 1,196,956 LF/6 years ~ 200,000 LF of piling annually.
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1]Han, F., Lim, J., Salgado, R., Prezzi, M., & Zaheer, M. (2015). *Load and resistance factor design of bridge foundations accounting for pile group–soil interaction* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2015/24). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284316009

[2]Provided by Mir A. Zaheer, Supervisor of the Geotechnical Design Services at INDOT

SPR-3705: Performance Assessment of Road Barriers in Indiana

Introduction

This research project investigated the performance of three types of median barriers: concrete walls, W-beam guardrails, and high-tensioned cable barriers. A comparison of safety costs with respect to installation costs shows the high-tensioned cable barrier option preferred.

Another outcome was to improve INDOT's decision-making relative to all manner of barrier installation, principally by optimizing economic benefits against cost of barrier hardware installation and recurring maintenance.

Analysis

The basis of the cost benefit analysis is to project benefits of installing cable barriers that are planned in the current five-year construction work plan. Possible future installations are expected, but are not included in the analysis.

Calculations

Research cost was $150,000. The following analysis costs were provided by INDOT Division of Traffic Engineering and Division of Maintenance.

Single-run high-tension cable barrier cost is approximately $120,000 per mile (1). Double-faced steel W-beam barrier cost is approximately $170,000 per mile [1]. Rigid concrete barrier cost is approximately $1.5 million per mile (including necessary drainage inlets, extra offset of shoulder pavement width, etc.) [1]. Each type has unique recurring maintenance costs.

A typical mile of high-speed (posted 70 mph) freeway with a conventional 60-foot-wide median and elevated traffic volume, the design selection procedures developed in SPR-3705 reveal a per mile safety cost benefit of $80,000 annually (2016$) produced by high-tension cable barrier relative to no barrier separation, $30,000 annually in incremental benefit relative to double-faced W-beam, and $160,000 annually relative to rigid concrete barrier [1]. Comparing the three options on a benefit/cost basis: cable - 80,000/120,000 = 0.66, W beam – 30,000/170,000 = 0.176, Concrete – 160,000/1,500,000 = 0.11. The cable option has the highest benefit ratio and will be used in the financial analysis.

While actual mileage of median barrier consideration/construction on INDOT roads varies yearly, based on past year records, 40 linear highway miles is a typical value and is used in the analysis. A five-year new installation program will be calculated since it is scheduled in the work program. Barriers have an expected service life of 20 years. Annual maintenance costs are $3,000 (2016$) per mile, which is comparable to four other state's cost [2].

The analysis will use the above basis for benefits, a service life of 20 years, and expected cost of capital and inflation of 3%.

Below is the benefit cost analysis for the five-year work plan showing costs and benefits for a twenty-year time period. For viewing purposes, the table is in two parts.

Project Description	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021	FY2021	FY2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2027
Research Cost	-150,000												
Barrier Cost - 5 Year program (a)	-4,800,000	-4,944,000	-5,092,320	-5,245,090	-5,402,442								
Annual Maintenance Cost (b)		-120,000	-247,200	-381,924	-524,509	-675,305	-695,564	-716,431	-737,924	-760,062	-782,864	-806,350	-830,540
Annual Benefit -2016 installation (c)		3,200,000	3,296,000	3,394,880	3,496,726	3,601,628	3,709,677	3,820,967	3,935,596	4,053,664	4,175,274	4,300,532	4,429,548
Annual Benefit 2017 installation			3,296,000	3,394,880	3,496,726	3,601,628	3,709,677	3,820,967	3,935,596	4,053,664	4,175,274	4,300,532	4,429,548
Annual Benefit 2018 installation				3,394,880	3,496,726	3,601,628	3,709,677	3,820,967	3,935,596	4,053,664	4,175,274	4,300,532	4,429,548
Annual Benefit 2019 installation					3,496,726	3,601,628	3,709,677	3,820,967	3,935,596	4,053,664	4,175,274	4,300,532	4,429,548
Annual Benefit 2020 installation						3,601,640	3,709,689	3,820,980	3,935,609	4,053,678	4,175,288	4,300,547	4,429,563
Net Benefit-Cost	-4,950,000	-1,864,000	1,252,480	4,557,626	8,059,954	17,332,847	17,852,833	18,388,418	18,940,070	19,508,273	20,093,521	20,696,326	21,317,216

Project Description	FY 2028	FY 2029	FY 2030	FY 2031	FY 2032	FY 2033	FY 2034	FY 2035	FY 2036	FY 2037	FY2038	FY2039
Research Cost												
Barrier Cost - 5 Year program (a)												
Annual Maintenance Cost (b)	-855,457	-881,120	-907,554	-934,780	-962,824	-991,709	-1,021,460	-1,052,104	-1,083,667	-1,116,177	-1,149,662	-1,184,152
Annual Benefit -2016 installation (c)	4,562,435	4,699,308	4,840,287	4,985,496	5,135,061	5,289,112	5,447,786	5,611,219				
Annual Benefit 2017 installation	4,562,435	4,699,308	4,840,287	4,985,496	5,135,061	5,289,112	5,447,786	5,611,219	5,779,556			
Annual Benefit 2018 installation	4,562,435	4,699,308	4,840,287	4,985,496	5,135,061	5,289,112	5,447,786	5,611,219	5,779,556	5,952,943		
Annual Benefit 2019 installation	4,562,435	4,699,308	4,840,287	4,985,496	5,135,061	5,289,112	5,447,786	5,611,219	5,779,556	5,952,943	6,131,531	
Annual Benefit 2020 installation	4,562,450	4,699,323	4,840,303	4,985,512	5,135,077	5,289,130	5,447,804	5,611,238	5,779,575	5,952,962	6,131,551	6,315,498
Net Benefit-Cost	21,956,733	22,615,435	23,293,898	23,992,715	24,712,496	25,453,871	26,217,487	27,004,012	22,034,576	16,742,671	11,113,420	5,131,346

NPV	273,714,281
Benefit Cost Ratio	1825

(a) Barrier cost = \$120,000 * 40 (miles) adjusted for inflation
(b) Annual maintenance cost = \$3,000 * (total installed cable barrier during the 5-year plan) adjusted for inflation
(c) Annual benefit = \$80,000 * 40 (miles) adjusted for inflation

Summary

The benefit cost ratio for this project is 1,825 to 1. This number is based on the following:

- Research cost of \$150,000.
- 5 Year work program scheduling 40 miles per year of cable median barrier installation.
- Cable barrier cost \$120,000 (2016\$) per mile.
- Estimated user cost savings is \$80,000 (2016\$) per mile per year.

- Estimated maintenance cost $3,000 (2016$) per mile.
- 20-year service life.
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

[1] Provided by Brad Steckler, INDOT Director of Traffic Engineering, INDOT unit cost

[2] Provided by Brad Steckler, verified by Todd Shields(INDOT Maintenance Field Support Manager) and unit costs from 4 other state DOT agencies.

SPR-3830: Evaluation of Alternative Intersections and Interchanges

Introduction

This project evaluated the effectiveness of Diverging Diamond Interchanges (DDI) when compared to Single Point Urban Interchanges (SPUI). Another product of the research was recommendations on single phase signal timing design which has proven to improve traffic movement by reducing red time. The final report provides recommendations on where to use DDI and has proven to be a reference manual on DDI designs.

To provide a better understanding of the differences in the designs, an example of each is shown below.

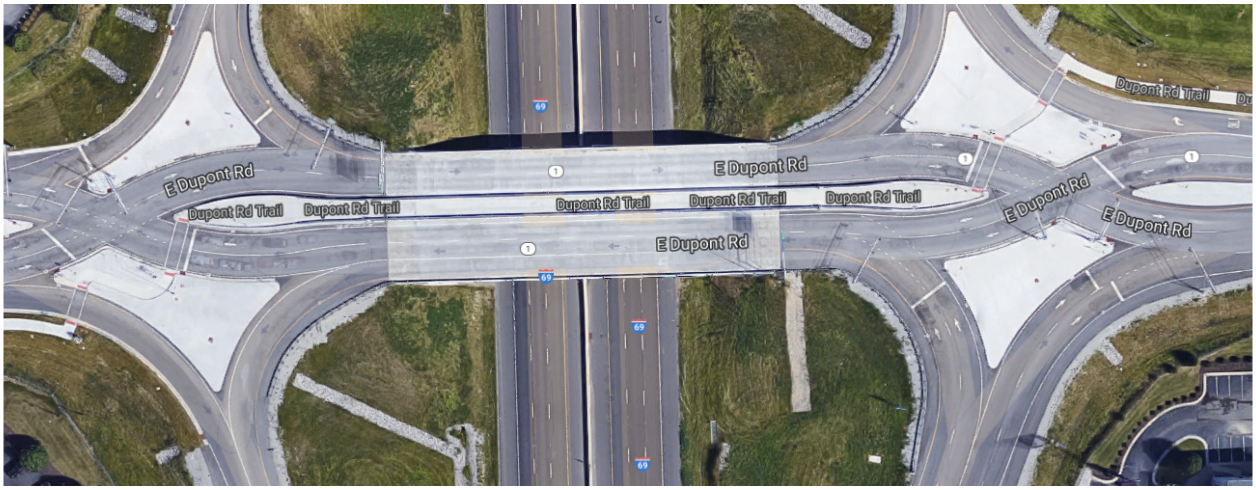
<u>SPUI</u>

I-465 and Emerson Avenue in Indianapolis

In this design the bridge is widened to accommodate turning and through traffic lanes. The enlarged bridge is an additional cost that is not included in the benefit cost analysis.

DDI

I69 and Dupont Road in Allen County



This design the bridge is smaller and traffic flows improved.

Analysis

Two DDI intersections were cited in the study. A DDI in Salt Lake City, Utah signals timing was studied and with proper timing scheme traffic green time improved from 53% to 92%. The second was I69 and DuPont Road in Allen County. At this interchange signal timing optimization was performed using Bluetooth vehicle sensors. The optimization improved intersection travel times so that user costs were estimated to save $564,000 annually. This number was calculated based on a methodology developed by the Texas Transportation Institute (TTI) located at Texas A&M University. TTI derived a cost of congestion equation which is determined by computing the average delay for a section and multiplying it by the expected traffic volume and the value of time. Added to the congestion cost is the CO_2 emission cost. Combining the congestion and emission costs is the user cost. AADT values for these calculations is provided by INDOT.

This study has determined DDI to be more cost effective than SPUI interchanges with certain site and traffic conditions. Currently INDOT has two more DDI interchanges at exit 210 on I-69 and exit 93 on I-65. Plans are to build two annually in the next four years. Using annual cost savings for each interchange and with 3 currently in place and plans to add 2 each year for the next 4 years is what the cost savings calculations are based on.

<u>Calculations</u>

2017 annual cost savings with the current 3 DDI interchanges = $564,000 x 3 = $1,692,000

2 additional DDI interchanges added each year for years 2018-2021. Cost savings for each year by using the DDI option over the SPUI configuration is shown below.

2018 – $564,000 x (3 (previous)+2) = $2,820,000

2019 - $564,000 x (5 (previous) + 2) = $3,948,000

2020 - $564,000 x (7 (previous) +2) = $5,076,000

2021 - $564,000 x (9 (previous) +2) = $6,204,000

Project Benefits and Costs	**FY 2016**	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**
Research Cost	-235,000					
Annual Benefit		1,692,000	2,820,000	3,948,000	5,076,000	6,204,000
Net Benefit-Cost	-235,000	1,692,000	2,820,000	3,948,000	5,076,000	6,204,000
NPV	$17,029,517.80					
Benefits Cost Ratio	72					

Summary

The benefit cost ratio for this project is 72. This number is based on the following:

- Research cost of $235,000.
- 3% cost of capital.
- NPV of future costs and benefits brought to 2016$.

The overall 2016 benefit cost analysis is based on total program costs. This analysis is for this project's cost to execute the research and implement.

References

1. Day, C. M., Stevens, A., Sturdevant, J. R., & Bullock, D. M. (2015). *Evaluation of alternative intersections and interchanges: Volume II—Diverging diamond interchange signal timing* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2015/27). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284316012

2. Remias, Stephen, M., T.M. Brennan, C.M. Day, H.T. Summers, D.K. Horton, E.D. Cox and D.M. Bullock, "Spatially Referenced Probe Data Performance Measures for Infrastructure Investment Decision Makers," Submitted to Transportation Research Board, , Paper No. 14-1062. In Press. August 1, 2013.

3. Phone Interview, Jim Sturdevant, 10/20/17 and 12/6/17.

About the Joint Transportation Research Program (JTRP)

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

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

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

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

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