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INDOT Research Program Benefit Cost Analysis—Return on Investment for Projects Completed in FY 2021

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SPR-4225 • Report Number: FHWA/IN/JTRP-2022/28 • DOI: 10.5703/1288284317579

INDOT Research Program Benefit Cost Analysis – Return on Investment for Projects Completed in FY 2021

(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

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December 2022

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Research Impacting the INDOT Strategic Plan

Contents

List of Tables

Introduction

To demonstrate the value of research and its implementation, 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 2021. Analyses on previous year's projects is necessary primarily due to the time it takes some project outcomes to be implemented, extending into the following year. Therefore, the FY 2022 analysis is completed in calendar 2021. The ROI analysis will supplement the annual IMPACT report by adding a more 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, a six-year period.

While the quantitative benefit cost analysis (BCA) was rigorous, results are limited to projects where benefits and costs could be quantified, where data is available to perform a quantitative analysis. Qualitative benefits are highlighted in the companion annual IMPACT report (https://www.in.gov/indot/files/Research-Program-Impact-Report-1.pdf).

In 2018, INDOT unveiled its new Strategic Plan. The Strategic Plan guides the priority research needs of the Research Program and in turn the research results support accomplishing the INDOT Strategic Plan, Strategic Objectives. A new Strategic Objective has been added to the INDOT Strategic Plan addressing Innovation & Technology. Additionally, INDOT created a new Office of Innovation. While the Research Program supports all of INDOT's Strategic Objectives, these new initiatives have further highlighted the importance of research and its role in achieving the Strategic Objectives outlined in the new INDOT Strategic Plan. There has been more emphasis of new research needs related to new technology changes and transformational technologies. This will help position INDOT for future growth, adoption of new technologies and partnering opportunities.

INDOT Strategic Plan Priorities are listed below.

Safety
Ensure road safety for motorists, contractors, and INDOT personnel

Mobility
Enhance end-to-end customer and freight journeys across all modes of transportation

Customer Service
Ensure local engagement, timeliness of service, and quality of responses

Economic Competitiveness
Enhance economic outcomes for Indiana

Asset Sustainability
Enhance ability to manage and maintain assets throughout their life cycle

Organization & Workforce
Provide employees with tools, training, and information to succeed

Innovation & Technology
Harness technology and innovation to develop more effective transportation solutions

Benefit-Cost Analysis Methodology

All FY 2021 completed projects were reviewed to determine if they were a viable candidate (quantifiable data existed) for BCA. Selection was based on (1) can the costs and benefits be quantified on outcomes that impact INDOT operations or users of the INDOT network, (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**. While Road User Cost (RUC) savings and Safety Cost (SC) savings are a primary goal of INDOT, savings accrued primarily benefit the customer (road user) and may not result in agency cost savings. In this year's analysis one quantifiable project included RUC and SC savings, rather than agency savings. Qualitative RUC and SC benefits are highlighted in the annual IMPACT report.

Quantitative benefits were calculated for each research project analyzed for the expected impact period where known or planned quantities (estimated in the INDOT Work Program) were available. The analysis period varied from five to fifteen years, each one based on impact periods. These analysis periods are explained in their individual analysis. Individual project costs are research and implementation costs. Net present value (NPV) for individual projects are calculated to 2021 dollars by combining costs and benefit cash flows. Individual project analyses are included in Appendix B. Backup documentation describing calculations and analysis for quantifiable projects will be kept by the INDOT Research and Development 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 ROIs to create a rolling average over time. The rolling average will be accumulative of six years, with FY 2016 being the first year. By using total program costs in the analysis, rather than just the individual project cost, a very conservative BCA ratio is obtained and actual cost savings may be considerably higher.

Benefit-Cost Analysis Results

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

- **Quantitative** – Implementation produces benefits that are measurable and quantifiable and where data exists. Each of these projects has an individual analysis performed and is included in Appendix B. The analysis, or impact period, is the time period benefits were available and 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 new test method, 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. Qualitative benefits are highlighted in the companion annual IMPACT report.
- **Not Successfully Implemented** – For various reasons the project outcomes could not be currently implemented. Common reasons are inconclusive results, logistical, technical difficulties, proof of concept, or legal issues.

Individual Project Analysis

Table 1 is the list of the six projects where benefits (NPV 2021$ - NPV of future cash flows in 2021 dollars) could be quantified and their individual analysis is found in Appendix B. One of the six projects will produce RUC savings, the other five Agency savings. Table 3, in Appendix A, is a complete list of all 30 projects completed in FY 2021 and considered for quantifiable cost analyses. Qualitative benefits are highlighted in the companion annual IMPACT report.

Table 1. Quantitative Benefits Project List

No	FY 21 Completed & Implemented SPR Projects	Title	Project Cost ($1,000)	Benefit Type	Analysis Period	NPV Project Benefit ($1000) 2021$
1	4122	Repair and Strengthening of Bridges in Indiana Using Fiber Reinforced Polymer (FRP) Systems	$298	Quantitative (Agency Savings)	15 Years	$15,559
2	4213	Determining Concrete Patch Locations other than Visual	$250	Quantitative (Agency Savings)	5 Years	$13,280
3	4230	Alternative Quality Assurance Methods for Compacted Subgrade	$47	Quantitative (Agency Savings)	5 Years	$647
4	4231	MEPDG Traffic Load Spectra for Local, Minor Arterial, Major Collector, and Minor Collector Roads	$176	Quantitative (Agency Savings)	5 Years	$2,205
5	4300	Investigation of Durability and Performance of High Friction Surface Treatment	$156	Quantitative (User Savings)	10 Years	$20,073
6	4417	Use of Recycled Asphalt	$127	Quantitative (Agency Savings)	5 Years	$1,857

Total Agency Benefits $ 33,548,000

Total User Benefits $ 20,073,000

The analysis periods varied from 5 to 15 years, due to estimated impact period. Project 4122 tested a product, fiber reinforced polymer (FRP) to repair bridge ends that have been damaged from winter chemicals. This method is faster and more economical than current bridge rehab methods and is expected to require 15 years to repair current bridge inventory. Projects 4213, 4230, 4231, and 4417 used 5 years based on INDOT Work Plan. Project 4300 used a 10-year period since high friction surface treatments have an expected life of ten years. Benefits from this project are road user savings.

Agency Savings

The total quantifiable savings from the five projects (4122, 4213, 4230, 4231, 4417) resulting in agency savings, during their analysis or impact period, was calculated at $33,548,000 (in 2021$). The *total* research program cost in FY 2021 was $5,531,000. Therefore, the agency savings BCA for FY 2021, for quantifiable projects, is: **$33,548,000/$5,531,000 = 6,** or 6 dollars in agency savings for every research dollar expended. **Said another way, the agency savings from these five projects more than offset the cost of the entire research program for the year.**

Due to the varying impact periods for these five projects (five to fifteen years) a summary table for agency savings is not practical. Each project write-up in Appendix B contains a summary table of agency savings.

User Savings

One project 4300 produces quantifiable user savings calculated to be $20,073,000. Therefore, the user savings BCA for FY 2021 is: **$20,073,000/$5,531,000 = 3.6**, or 3.6 dollars in user savings for every research dollar expended. Project 4300 has an impact period of ten years. A savings table is in the project write-up in Appendix B.

Cost Savings Summary

As previously noted, five projects produce quantifiable benefits that resulted in agency savings. A summary of these cost savings is described below.

4122–Cost savings come from using fiber reinforced polymer (FRP) to wrap bridge end areas compared to the costs for repairing these areas with conventional repair and rehabilitation methods and extending bridge life by 15 years. The FRP method was validated through full scale testing performed at the Purdue University Bowen Lab.

4213–Using ground penetration radar (GPR) and a third-party software WayLink3D, deep patching quantities were significantly reduced on an INDOT contract. A reduction in this work item quantities produced cost savings. This cost savings was applied to future contracts for the next five years, based on INDOT's 5-year Work Plan where deep patching will occur.

4230–This project demonstrated that by using a new testing approach with light weight deflectometer, INDOT has learned that the strength of chemically modified subgrades has been underestimated. With a stronger subgrade, pavement thickness can be reduced in these areas. This is the basis for cost savings.

4231–Pavement design methodology was refined for lower volume roads by updating truck volumes to more accurate levels. This change in truck volumes reduces pavement thickness in asphalt roads where these lower volumes occur. This thickness reduction is the basis for cost savings.

4417–An INDOT special provision was developed that allows the use of recycled asphalt pavement (RAP) to stabilize shoulders. The special provision gives the contractor the option for stabilizing or improving shoulders with either compacted aggregate or asphalt millings from the project. Using asphalt millings instead of aggregate is the basis for cost savings.

One project **4300**, will produce quantifiable user savings. This user savings is described below.

4300–High friction surface treatments (HFST) have proven to reduce vehicle crashes at friction-sensitive locations on INDOT roadways. A before and after analysis of HFST sites was performed which indicated these sites experienced a significant reduction in crashes and improves road user safety. Improved safety generates cost savings for road users and these savings are significant.

Summary

The aggregate benefit of all agency savings is approximately $34 million in 2021$. Direct agency savings of $34 million is a return of $6 for every $1 spent in research. The basis for the numbers used in the BCA came from INDOT databases, subject matter experts (SMEs), and research results. These are described in detail in the individual analyses located in Appendix B.

A review of the individual project analysis shows a conservative approach was taken in any assumption made in the calculations, and actual savings may be higher. This analysis indicates that INDOT continues to receive return on its research investment which will continue to grow due to the recently passed Federal Infrastructure Bill, authorizing more funding for construction, re-construction, and preservation, thereby impacting more projects.

For 24 projects completed in FY 2021, quantifiable benefits could not be calculated or data was not available, however other qualitative benefits resulted that brought significant value to the Agency and Road Users and are highlighted in the companion annual IMPACT report. A complete listing of all research projects completed in FY 2021 is shown in Table 3 in Appendix A.

Rolling Average BCA

Annual BCA provide an assessment of INDOT's investment in Research on an annual basis. For the last six years, 2016, 2017, 2018, 2019, 2020, and 2021 the investment indicates positive returns during the life of individual projects implemented. While a majority of the projects in the last five years, 151 out of 192 total research projects benefits are not quantifiable, due to the unavailability of quantifiable data, however, qualitative benefits were identified and are highlighted in the companion annual IMPACT report. 34 projects where benefits were quantified, produced significant agency savings and 7 projects produced significant road user cost savings. For the combined years of 2016 through 2021 the Agency and Road User BCA are:

BCA (2016 – 2021) Agency Savings = $375,274,000/$35,182,040 = 11 to 1

BCA (2016 – 2021) Road User Savings = $315,032,799/$35,182,040 = 9 to 1

BCA Rolling Average – 2016–2021

Table 2 compiles the estimated agency savings and road user savings for the last six analysis years. BCA averages are calculated from the six-year totals for research expenditures, estimated agency savings, and road user savings.

Table 2. BCA Rolling Average

Year	Research Investment	Estimated Agency Savings	Estimated Road User Savings	BCA Ratio Agency Savings	BCA Ratio Road User Savings	Total B/C
2016	$6,264,000	$76,481,000	$290,743,799	12	46	58
2017	$4,124,000	$189,668,000	$11,247,000	46	3	49
2018	$3,927,000	$39,910,000	$2,696,000	10	0.7	10.7
2019	$8,314,040	$35,668,000	0	4	-	4
2020	$7,022,000	$9,727,000	$50,384,000	1.4	7.2	8.6
2021	$5,531,000	$33,548,000	$20,073,000	6	3.6	9.6
Totals	$35,182,040	$375,274,000	$315,032,799	11 avg.	9 avg.	20 avg

Environmental Benefits

Two of the six projects, 4231 and 4417, provide environmental benefits in addition to quantifiable agency benefits.

SPR-4231 adjusted the design of low volume roads due to more accurate truck traffic counts, which allows for a reduction in asphalt pavement thickness. This correlates to less asphalt pavement quantities which translates to less native materials, asphalt and aggregate, improving the environmental impact of consuming and using these native materials and reducing the carbon footprint.

SPR-4417 expands the use of recycled asphalt millings for to stabilize or rehabilitate roadway shoulders. This substitution voids the cost and effort of obtaining aggregates and provides another option for the reuse of existing materials eliminating the need to dispose and thereby saving natural resources.

Appendix A

Table 3. Complete Research Project List – FY 2021

No	FY 21 Completed & Implemented SPR Projects	Project Title	Project Cost ($1,000)	Quantitative Benefits, Qualitative Benefits or Not Successfully Implemented	Project Benefits ($1,000)
1	3865	Trafficware Valence Pod Detection System INDOT Evaluation	$55	Qualitative	
2	3915	Implementing Effective Retrofits in Selected Steel Bridge Details	$230	Quantitative	
3	4122	Repair and Strengthening of Bridges in Indiana Using Fiber Reinforced Polymer (FRP) Systems	$298	Quantitative	**$15,559**
4	4165	Verification of Bridge Foundation Design Assumptions and Calculations	$330	Qualitative	
5	4212	Structural Evaluation of Full-depth Flexible Pavement using APT	$337	Qualitative	
6	4213	Determining Concrete Patch Locations other than Visual	$250	Quantitative	**$13,280**
7	4215	Rumble Stripes and Pavement Markings Delineation	$158	Qualitative	
8	4218	Performance of Right Turn Lane Designs at Intersections	$162	Qualitative	
9	4221	Post-Fire Assessment of Prestressed Concrete Bridges in Indiana (Phase I)	$304	Qualitative	
10	4222	Seismic Evaluation of Indiana Bridge Network and Current Bridge Database for Asset Management	$375	Qualitative	
11	4230	Alternative Quality Assurance Methods for Compacted Subgrade	$47	Quantitative	**$647**

12	4231	MEPDG Traffic Load Spectra for Local, Minor Arterial, Major Collector, and Minor Collector Roads	$175	Quantitative	**$2,205**
13	4300	Investigation of Durability and Performance of High Friction Surface Treatment	$155	Quantitative Road User Savings	**$20,073**
14	4301	Assessment of an Offset Pedestrian Crossing for Multilane Arterials	$110	Qualitative	
15	4302	Using of Emerging & Extraordinary Data Sources as Means to Improve Traffic Safety	$145	Qualitative	
16	4310	Legal and Permit Loads Evaluation for Indiana Bridges	$109	Qualitative	
17	4311	Evaluating Reserve Strength of Girder Bridges due to Bridge Rail Load Shedding	$138	Qualitative	
18	4314	Feasibility Study and Design of On-Road Electric Vehicle Charging Technologies	$315	Qualitative	
19	4315	Develop and Deploy a Safe Truck Platoon Testing Protocol for the Purdue ARPA-E Project in Indiana	$353	Qualitative	
20	4323	Extraction of Vehicle “CAN bus” Data for Enhanced Winter Roadway Condition Monitoring	$361	Qualitative	
21	4404	Improve and Gain Efficiency in Winter Operations	$150	Qualitative	
22	4405	Synthesis Study on Best practices for Mapping and Coordinating Detours for Maintenance of Traffic (MOT), including Risk Assessment/Management for Duration of Traffic Control Activities	$83	Qualitative	

23	4409	Safety, Mobility, and Cost Benefits of Closing One Direction of Interstate in Rural Areas During Construction Work	$130	Qualitative	
24	4411	Last Mile Delivery and Route Planning for Freight	$120	Qualitative	
25	4417	Use of Recycled Asphalt	$127	Quantitative	**$1,857**
26	4422	Automate the Generation of Construction Checklists	$130	Qualitative	
27	4424	Evaluation of Current Technologies for: Training, Web Apps, and New Technologies	$120	Qualitative	
28	4441	Public Acceptance of INDOT's Transportation Services	$123	Qualitative	
29	4444	Improved Live Load Lateral Distribution Factors for use in Load Rating of Older Continuous and T-Beam Reinforced Concrete Bridges	$105	Qualitative	
30	4446	An Assessment of the Workforce and Occupations in the Highway, Street and Bridge Construction Industries	$35	Qualitative	
			$5,531,000		

Total FY 2019 Research spending is $5,531,000.

Appendix B
Individual Project Analysis

SPR-4122–Repair and Strengthening of Bridges in Indiana Using Fiber Reinforced Polymer (FRP) Systems

Introduction

Bridge repair can be an expensive and time-consuming activity; this project investigated the use of a product named fiber-reinforced polymer (FRP) to repair concrete girder bridges. Specifically, two types of bridge repairs were experimented: improving the flexural strength of girders and repairing girder end areas that deteriorate from the use of anti-icing and de-icing chemicals in winter operations. Figure 1 shows the testing of an FRP wrap at a bridge end.

Figure 1. FRP wrap test at bridge end.

The flexural strengthening program specifically investigated and tested box beam bridges. Where the end beam repair focused on pre-stress concrete girders and the use of FRP wrap in this region, which proved to be highly effective. This bridge end repair technique is a cost-effective option and a cost benefit analysis was performed with the help of personnel in INDOT Bridge Asset and Bridge Design Departments.

Analysis

INDOT Bridge Asset and Bridge Design Departments[1] collaborated and determined a sample set equating to 25% of the pre-stressed, multi-beams bridge, with superstructure condition rating of 6, would be a reasonable assumption for this study on FRP Beam end repair. Using the appropriate filters applied to the National Bridge Inventory database, it was determined that there were 186 assets meeting this criterion and when reduced to the noted 25%, became 46. INDOT's knowledge of past beam repair projects suggest a possible increase of service life to be around 15 years.

INDOT[1] generated a simplified model representing a 75-year service life for a typical bridge and a reduced, 60-year service life for the damaged bridge (deteriorated beam ends). Both models assumed the bridge to be replaced at the same point where the condition rating dropped from 5 to 4. A median bridge size of 9,000 square feet was assumed and a unit cost of $450 per square foot was used. The unit cost is an average of an interstate and non-interstate bridge of the noted size.

The cost difference between the two models equated to $40 per square foot or $370,000 per median asset. Assuming 3 bridges per year based on the above numbers, a savings of $1.1 million annually would be anticipated for a fifteen year period.

Potential Savings

Cost savings come from using FRP to wrap bridge end areas compared to the unit costs for repairing these areas with conventional repair and rehabilitation methods. The FRP method was validated through full scale testing performed at the Purdue University Bowen Lab.

Another potential source for cost savings is using FRP to improve box beam girder flexural strength. This was tested at Bowen Lab and the results indicate this repair method is not effective in improving flexural strength capacity. This method will not be pursued by INDOT.

Table 1 shows expected future cash savings for 15 years by using FRP to repair pre-stress girder bridge ends. Due to page size limits only a portion of the cash flows and the net present value (NPV) calculations are shown in Table 1.

Table 1. 4122 Cash Flow Analysis

Years	2021	2022	2023	2024	2025	2026	2027	2028	2029	…	2036
Research Cost	$ (298,000)										
FRP savings		$ 1,110,000	$ 1,165,500	$ 1,223,775	$ 1,284,964	$ 1,349,212	$ 1,416,673	$ 1,487,506	$ 1,561,881		$ 2,197,724
NPV Savings	$ 15,857,143										
Net Savings	$ 15,559,143										
B/C	52										

NPV – net present value.

Net savings = NPV Savings – Research cost.

Summary

The BC ratio is **52** due to calculated savings that is more than the research cost. The savings come from using FRP to repair bridge ends over conventional methods and extending the bridge life 15 years.

These numbers are based on the following:

- Research cost for 4122 is $298,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2021$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2021 benefit cost analysis is based on total program costs.

References

[1]INDOT Bridge Asset Management Department personnel.

Rich, W. B., Jacobs, R. R., Williams, C. S., & Frosch, R. J. (2021). *Repair and strengthening of bridges in Indiana using fiber reinforced polymer systems: Volume 2–FRP flexural strengthening and end region repair experimental programs* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2021/10). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317310

SPR-4213–Detection and Classification of Concrete Patches by Integrating GPR and Surface Imaging

Introduction

INDOT has used different approaches to determine the size and location of pavement patches when defining project scope and determining bid quantities on road rehab projects. This research project used the technologies of Ground Penetration Radar (GPR) and WayLink3D Imaging System to determine patching locations and size on a road project in Marion County on I-465 between I-70 E to I-65 S.

Conventional methods were used to develop deep patching bid quantities. Then INDOT Research & Development used these two technologies to develop bid quantities with the quantities difference being significant. Based on using these technologies together, deep patching quantities may have been overestimated previously costing INDOT to make this repair. Results from this project are the basis for the ROI calculation.

Figure 1. INDOT GPR Testing Equipment

Analysis

The I-465 project, contract R-41351, used GPR to identify patch locations and quantities after it was released for bid. The schedule of pay items, which is used to estimate contract quantities; estimated Full Depth Patching, pay item 506-06333, at 10,647 SYS (square yards). When the bids were submitted all the contractors bid on a quantity of 1,500 SYS, a reduction of 9,147 SYS or 85%.[1] The lower bid quantity came from the GPR/Waylink 3D analysis that was performed by INDOT Research.

Potential Savings

Using Deep Patching data from contract R-41351 is the basis for calculating cost savings.

To determine annual quantities for the pay item 506-06333, Bid item summaries were obtained for 2021 and 2022 contracts. The below table 1 shows bid item quantities and average unit bid prices.

Table 1. Annual Full Depth Patching quantities and Costs

Year	Deep Patching quantity (SYS)	Average Bid price($)	Total Estimated Patching Cost ($)
2021	25,779	293	7,553,247
2022	40,107	397	15,922,479
Two Year Average	32,943	345	11,365,335

Contract R-41351 experienced an 85% reduction in Full Depth patching quantity. Annual cost savings would be a percentage of these quantities. Instead of 85% a conservative number of 25% is used. Also, annual deep patching areas for the next 5 years is the two-year average calculated in Table 1.

Estimated Annual savings = $11,365,335 × 25% = $2,841,333

Projected annual savings for a five-year period and a corresponding benefit/cost analysis is shown in Table 2. Cost of research is $250,000.

Table 1. 4213 Cash Flow Analysis

Years	2021	2022	2023	2024	2025	2026
Research Cost	$(250,000)					
Analysis savings		$ 2,841,333	$ 2,983,400	$ 3,132,570	$ 3,289,198	$ 3,453,658
NPV Savings	$ 13,530,157					
Net Savings	$ 13,280,157					
B/C	53					

NPV – net present value.
Net savings = NPV Savings – Research cost.

Summary

The BC ratio is **53** due to calculated savings is more than the research cost. The savings come from lower quantities of full depth deep patching by using GPR/Waylink 3D analysis.

These numbers are based on the following:

- Research cost for 4213 is $250,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2021$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2021 benefit cost analysis is based on total program costs.

References

[1] Mike Byers, Executive Director, Indiana Chapter of the American Concrete Pavement Association.

Cheng, P., Krogmeier, J. V., Bell, M. R., Wang, K., Li, J., & Yang, G. (2021). *Detection and classification of concrete patches by integrating GPR and surface imaging* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP2021/18). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317320

SPR-4230–Alternative Quality Assurance Methods for Compacted Subgrade

Introduction

When specifying new pavement construction (e.g., added travel lanes, new alignment, etc.), INDOT requires that pavement subgrades be constructed using some type of subgrade treatment. INDOT generally prefers that cement be used for subgrade chemical treatment because cement treatment tends to have better quality control. The majority of INDOT new pavement construction contracts involve chemical modification using type I Portland cement (i.e., subgrade treatment type IBC).

INDOT has used light weight deflectometer (LWD) testing since 2016 for compaction testing and this project tested LWD on chemically modified subgrades. Previously the Dynamic Cone Penetration (DCP) test method was used.

Comparing results from LWD and DCP testing indicates the strength of chemically modified subgrades (indicated by resilient modulus) has been underestimated by 35% to 45%[1]. This modulus is used in pavement design to determine mix design and pavement thickness a stronger modulus can reduce pavement costs. This is the basis for cost savings.

Figure 1. Cement Treated Subgrade

Analysis

LWD verified that a resilient modulus of 13,000 psi (pounds per square inch) could be used in pavement design; a modulus of 9.000 psi was previously used from DCP testing. This 4,000 psi increase impacts pavement thickness design by reducing asphalt pavement base course thickness ¼”. This is not a practical pavement thickness reduction; instead, what can be done is to replace a portion of the asphalt base course with a less expensive material, for example compacted aggregate number 53.

Using this approach INDOT pavement engineers have developed an asphalt pavement design over a cement treated subgrade layer with a resilient modulus of 13,000 psi, consisting of 4” layer of compacted no. 53 aggregate which will reduce the asphalt base course by 1-1/2”.

Concrete pavement design uses a modulus of subgrade reaction to calculate pavement thickness. Using the previous 9,000 psi for cement treated subgrade, this modulus is 306 pci (pounds per cubic inch); with the higher 13,000 psi value, the modulus of subgrade reaction is 338 pci, an increase of 32 pci which is not significant enough to affect pavement thickness. Therefore, the higher resilient modulus does not impact concrete pavements thickness.

Return on Investment Analysis (ROI) will be based on estimated cost savings obtained from reducing asphalt base course thickness.

Potential Savings

In 2021, 1,147,390 square yards (SYS) of cement modified subgrade treatment was installed on pavement projects, which has been a consistent quantity for the past couple years.[1] These pavement contracts allow the contractor to install asphalt (HMA) or concrete (PCCP) pavements. One assumption in the cost analysis is half of new pavement quantities will be HMA, creating cost savings from reducing base course thickness and adding 4 inches of granular material on top of the subgrade.

The annual area of installed asphalt pavement is 1,147,390 SYS/2 = 573,695 SYS. This quantity of new HMA pavement is projected annually for the next 5 years, which is a conservative estimate based on INDOT's five-year construction plan.

Material unit costs from 2021 are HMA base course is $72.55 per ton; and compacted aggregate base no. 53 is $49.18/CY[1]. Calculations for these cost differences are shown next.

HMA base course 1-1/2" thickness reduction cost reduction

Asphalt weighs approximately 140 PCF (pounds per cubic foot).

Converting pavement area to square feet (SF), 573,695 SY x 9 SF/SYS = 5,163,255 SF

Volume of asphalt saved = 5,163,255 SF x 1.5"/12" = 645,406 CF

Weight of asphalt saved = 645,406 CF x 140 PCF = 90,356,962 pounds = 45,178 tons

Estimated annual cost savings in asphalt base course = 45,178 tons x $72,55 = $3,277,664

Added compacted 4"aggregate base cost

Estimated annual cost = 573,695 SYS x (4"/12")/3'/Yard = 63,680 CY x $49.18/CY = $3,131,790

Net annual cost savings = HMA base course savings – compacted aggregate cost

= $3,277,664 - $3,131,790 = $145,874

Projected annual savings for a five-year period and a corresponding benefit/cost analysis is shown in Table 1.

Table 1. 4230 Cash Flow Analysis

Years	2021	2022	2023	2024	2025	2026
Research Cost	$(47,000)					
Analysis savings		$145,874	$153,168	$160,826	$168,867	$177,311
NPV Savings	$694,638					
Net Savings	$647,638					
B/C	13.8					

NPV – net present value

Net savings = NPV Savings – Research cost

Summary

The BC ratio is **13.8 or 14** due to calculated savings is more than the research cost. The savings come from reduced thickness in HMA base course as LWD testing measures a higher resilient modulus.

These numbers are based on the following.

- Research cost for 4230 is $47,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2021$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2021 benefit cost analysis is based on total program costs.

References

[1] Peter J. Becker, PhD, PE, Research Engineer (Geotechnical Engineering), Indiana Department of Transportation, Division of Research and Development.

Becker, P. J. (2021). *Using the light weight deflectometer for performance-based quality assurance testing of cement modified subgrades* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2021/07). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317304.

SPR-4231–MEPDG Traffic Load Spectra for Local, Minor Arterial, Major Collector, and Minor Collector Roads

Introduction

In 2009, INDOT adopted the Mechanistic-Empirical Pavement Design Guide (MEPDG) for pavement design, resulting in improved cost-efficient pavement designs. Traffic volumes and loads, particularly trucks, have a significant influence on pavement thickness. At this adoption the Federal Highway Administration (FHWA) truck volume road groups were used and are shown in Table 1.[1] This project analyzed the influence of truck traffic volume on low volume roads, those with truck volumes are less than 3,000 per day, Group A roads.

Table 1 – FHWA Truck Volumes Groups

Group	Average Daily Truck Traffic
A	< 3,000
B	3,000–6,000
C	6,000–20,000
D	>20,000

One project outcome was improved traffic design input into MEPDG for Group A roads. These roads were further divided into load categories, or load spectrum as shown in Table 2.[1]

Table 2 – Load Spectrum Daily Truck Traffic Volumes for Group A Roads

Load Spectrum Category	Average Daily Truck Traffic
A1	1–100
A2	100–500
A3	500–1,000
A4	1,000–3,000

A MEPDG design analysis was performed for the four Group A categories, A1-A4 and in Groups A3 and A4 it was determined that asphalt pavement thickness can be reduced by 1 inch. This thickness reduction is the basis for cost savings in A3 and A4 roads.

Analysis

To calculate cost savings from reducing pavement thickness 1 inch in A3 and A4 pavements, 2021 annual lane miles of reconstruction/pavement replacement for these categories was obtained from the INDOT Pavement Asset group [2] and are shown in Table 3.

Table 3 – Annual Lane Miles of Pavement Reconstruction and Replacement for Group A Roads

Load Spectrum Category	2021 Annual Lane Miles of Pavement Reconstruction/Replacement
A1	1.5
A2	13.9
A3	4.4
A4	13.8

Annual lane miles in Table 3 for A3 and A4 is 4.4 + 13.8 = **18.2**., or 18 lane miles which is used in the cost savings calculations. Using this annual mileage and unit pricing for asphalt, annual cost savings are calculated.

Potential Savings

Material unit cost for hot mix asphalt (HMA) base course in 2021 was $72.55 per ton and asphalt weighs approximately 140 PCF (pounds per cubic foot).[1] A lane mile is typically 12 ft. wide. Converting pavement area to square feet (SF) = 18 miles x 5,280 ft./mile x 12 ft. = 1,140,480 SF of pavement whose thickness can be reduced by 1 inch. The reduction in HMA volume and weight translates to cost savings and these calculations are shown.

Volume of asphalt saved from 1” thickness reduction = 1,140,480 SF x 1.0”/12” = 95,040 CF

Weight of asphalt saved = 95,040 CF x 140 PCF = 13,305,600 pounds = 6,653 tons annually

Annual cost saving = 6,653 tons x $72.55/ton = $482,675

Since the cost of HMA is volatile, future cash savings will use an annual base value of $500,000, most likely a conservative value.

Projected future savings are based on five-year work plan quantities similar to 2021 and shown in Table 3.

Projected annual savings for a five-year period and a corresponding benefit/cost analysis is shown in Table 4.

Table 4. 4231 Cash Flow Analysis

Years	2021	2022	2023	2024	2025	2026
Research Cost	$(175,000)					
Analysis savings		$ 500,000	$ 525,000	$ 551,250	$ 578,813	$ 607,753
NPV Savings	$ 2,389,952					
Net Savings	$ 2,205,952					
B/C	12.6					

NPV – net present value.
Net savings = NPV Savings – Research cost.

Summary

The BC ratio is **12** due to calculated savings is more than the research cost. The savings come from lower quantities of asphalt needed for reconstruction/replacement of A3 and A4 roads.

These numbers are based on the following:

- Research cost for 4231 is $175,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2021$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2021 benefit cost analysis is based on total program costs.

References

[1] Tommy Nantung Ph.D. PE, Indiana Department of Transportation, Division of Research and Development.

[2] Kayleigh Cowles, Indiana Department of Transportation, Pavement Asset Manager.

Bao, J., Hu, X., Peng, C., Jiang, Y., Li, S., & Nantung, T. (2020). *Truck traffic and load spectra of Indiana roadways for the mechanistic-empirical pavement design guide* (Joint Transportation Research Program Publication No. FHWA/IN/ JTRP-2020/21). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317227.

SPR-4300–Investigation of Durability and Performance of High Friction Surface Treatment

Introduction

High friction surface treatments (HFST) have proven to reduce vehicle crashes at friction-sensitive locations, sharp horizontal curves, intersection approaches, bridge decks, interstate ramps, and long steep grade sections. This project investigated physical and mechanical properties of HFST; their effectiveness over time for crash mitigation; what pavement distresses occur from HFST; and field evaluation.

Figure 1. High Friction Surface Treatment

Analysis

The analysis uses crash data from 25 specific locations where HFST was applied and is the basis for ROI.[1] Crash data 3 years prior to HFST is compared to approximately 8 months of crash data after HFST, to determine if HFST results in reduced friction related crashes. Since the before data was for a longer time period, 3 years, it was adjusted to an 8-month time period for an equal comparison. Crashes caused by winter weather, driver impairment, and deer collisions are ignored. Crash data was collected on twenty-five HFST sites, before and after as previously described. Figure 2 shows these statistics.

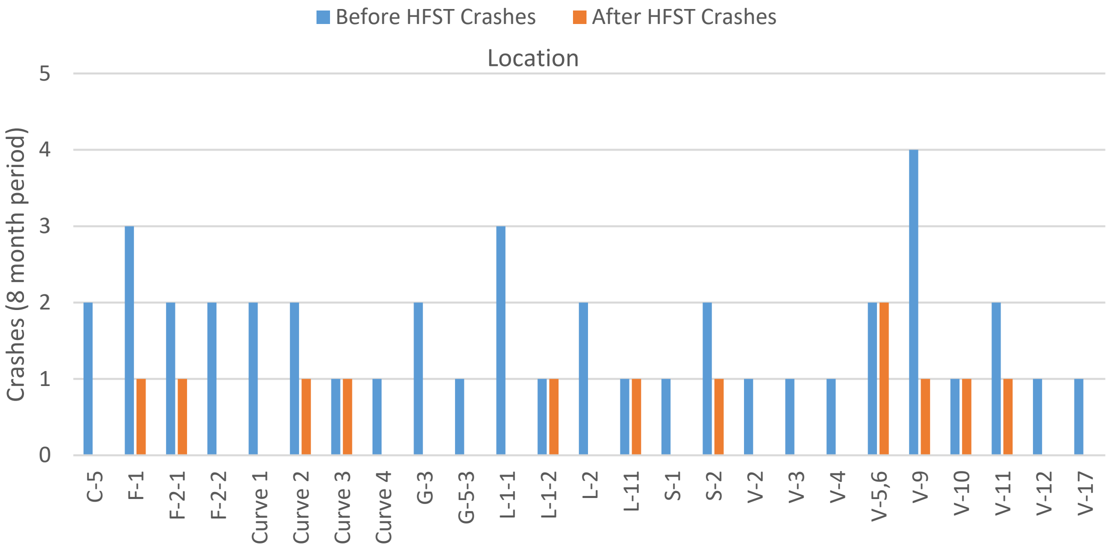

Figure 2 – Crash Data

The comparison is based on an 8-month time period before and after. Before HFST these 25 sites (rural two-lane highways) experienced 42 crashes; afterward 12 crashes. All 25 sites experienced a crash, with 13 sites having multiple crashes before HFST; afterward there were 10 sites that experienced one crash and one site that had multiple crashes, a total of 11 sites.

A reduction in the number of crashes, 42 to 12 (a 72 % reduction) and crash sites, 25 to 11 (a 56% reduction), indicates that HFST improves safety. Improved safety generates cost savings for road users and these savings are calculated in the next section.

Potential Savings

INDOT's Office of Traffic Safety uses RoadHAT 4, a software tool developed by the Center for Roadway Safety at Purdue University. RoadHAT 4 evaluates crash hazards for road sections and intersections and provides the ability to calculate economic effectiveness of reduced crashes. The economic benefit published in RoadHAT 4 is used to calculate road user cost savings.

Different crash types have an associated cost. Crash types includes those resulting in death, incapacitating injuries, or non-incapacitating with this category the lowest cost of the three types. Using this category to determine savings from a reduction in crashes is a conservative approach since some of the crashes may include the first two which have higher costs.

From RoadHAT 4 a non-incapacitating injury crash cost is determined to be $354,000.

With a 72% reduction in crashes the annual cost savings per location is:

42-12 = 30 x $354,000/25 locations = $424,800 /location/year

Every year approximately 10 new locations in INDOT's network has an HFST applied with an expected life of 10 years. Annual road user savings for 10 years = $424,800 x 10 = $4,248,000

Projected annual road user savings for a ten-year period and a corresponding benefit/cost analysis is shown in Table 1.

Table 1. 4300 Cash Flow Analysis

Years	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Research Cost	$ (155,000)										
Road User Savings		$4,248,000	$4,460,400	$4,683,420	$4,917,591	$5,163,471	$5,421,644	$5,692,726	$5,977,363	$6,276,231	$6,590,042
NPV Savings	$20,228,571										
Net Savings	$20,073,571										
B/C	129.5										

NPV – net present value.

Net savings = NPV Savings – Research cost.

Summary

The BC ratio is **129** due to calculated road user savings is more than the research cost. The savings come from reduced crashes on roadway sections treated with HFST.

These numbers are based on the following:

- Research cost for 4300 is $155,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2021$.

This analysis is only for this project’s cost to conduct the research and implementation. In the summary report an overall 2021 benefit cost analysis is based on total program costs.

References

[1] Calvin Rizzo, 2019 INDOT summer intern, directed by Michael A. Holowaty, P.E., Manager, Office of Traffic Safety INDOT, Traffic Engineering Division.

SPR-4417–Use of Recycled Asphalt

Introduction

Reclaimed Asphalt Pavement (RAP) uses material obtained by removal or processing existing asphalt pavement through milling or full removal. Applications of RAP are use in hot or cold mix asphalt, granular bases, and as fill or embankment material. Project objectives were to improve the understanding of RAP's mechanical properties, determine the performance of RAP, and to develop guidelines for INDOT on its use.

One recommendation is to not use RAP in asphalt pavements as this causes pavement deterioration in the form of creep formations that reduces pavement life. Another recommendation is to use RAP on shoulders to replace virgin materials normally used, saving these materials and their cost, and recycling existing pavement materials at the project site.

An INDOT special provision was developed that allows the use of RAP to stabilize shoulders.[1] The special provision gives the contractor the option for stabilizing or improving shoulders with either compacted aggregate #73 or asphalt millings from the project. Using asphalt millings instead of #73 aggregate is the basis for cost savings.

Figure 1. RAP Shoulder

Analysis

Two INDOT contracts in the LaPorte District were let in the 2021 work program, R-42219 and R-4221.[1] Planned shoulder quantities for # 73 aggregate were 3087 tons and 9376 tons, respectively, a total of 12,463 tons. Since this special provision was approved for use starting with the 2021 work program it has not gained statewide usage as yet.

The ROI analysis will be based on a low volume of RAP material which will make the analysis conservative. For calculation purposes the annual volume of RAP material for shoulder work will be 10,000 tons.

Potential Savings

Aggregate #73 weighs 2,400 pounds/cubic yard and costs $50/cubic yard (based on 2021 lettings).[2] Using these unit values estimated annual cost savings by using RAP material to replace 10,000 tons of #73 aggregate is:

10,000 tons × 2,000#/ton = 20,000,000 pounds

20,000,000 pounds/2,400 pounds/CY x $50/CY = $416,667

For calculation purposes $400,000 annual savings is used and for a 5-year work program.

Projected annual savings for a five-year period and a corresponding benefit/cost analysis is shown in Table 1. Cost of research is $127,000.

Table 1. 4417 Cash Flow Analysis

Years	2021	2022	2023	2024	2025	2026
Research Cost	$(127,000)					
RAP Analysis savings		$416,667	$437,500	$ 459,375	$ 482,344	$ 506,461
NPV Savings	$1,984,129					
Net Savings	$1,857,129					
B/C	15					

NPV – net present value.
*Net savings = NPV Savings – Research cost.

Summary

The BC ratio is **15** due to calculated agency savings is more than the research cost. The savings come from shoulder work material savings by using RAP.

These numbers are based on the following.

- Research cost for 4417 is $127,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2021$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2021 benefit cost analysis is based on total program costs.

References

[1] Joe Novak, State Construction Engineer, Indiana Dept. of Transportation.

[2] Tommy Nantung PE, Ph.D. Indiana Department of Transportation, Division of Research and Development.

Ncube, A. T., & Bobet, A. (2021). *Use of recycled asphalt* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2021/14). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317316.

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.

About This Report

An open access version of this publication is available online. See the URL in the citation below.

McCullouch, B. (2022). *INDOT research program benefit cost analysis—Return on investment for projects completed in FY 2021* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2022/28). West Lafayette, IN: Purdue University. https://doi.10.5703/1288284317579