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 2023

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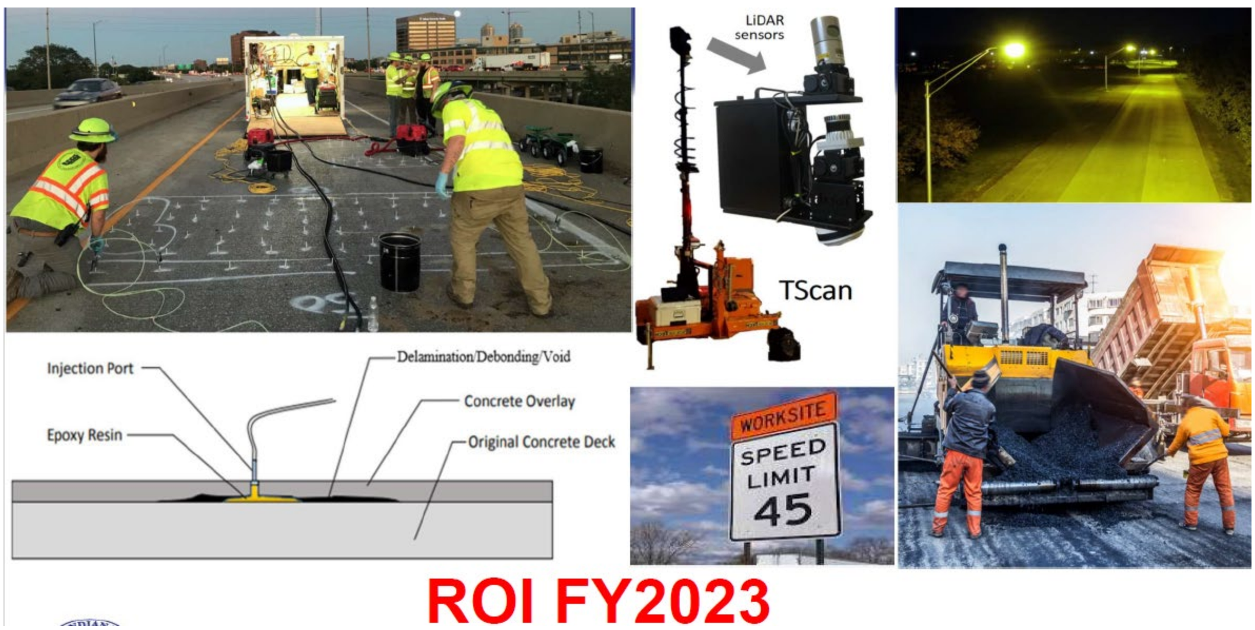
INDOT Research Program Benefit Cost Analysis – Return on Investment

for Projects Completed in FY 2023

(SPR-4865)

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 2024

Research Impacting the INDOT Strategic Plan

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Introduction

To demonstrate the value of research and its implementation, the Governor's Office initially requested an annual financial analysis of the INDOT Research Program to determine the return on the research investment (ROI). The INDOT Research & Development (R&D) has continued to publish an annual Return on Investment report. The current financial analysis is for research projects that completed in FY 2023. Analyses on previous year's projects is necessary primarily due to the time it takes some project outcomes to be implemented, and verifiable data generated, extending into the following year. Therefore, the FY 2024 analysis is completed research projects in calendar 2023. 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 7-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.pdf).

In 2018, INDOT unveiled its Strategic Plan. The Strategic Plan is reviewed annually and guides the priority research needs of the Research Program and in turn the research results support accomplishing the INDOT Strategic Plan, Strategic Objectives. A Strategic Objective was added to the INDOT Strategic Plan addressing Innovation & Technology. Additional emphasis has been given to Safety and numerous research projects are addressing safety from various perspectives including worker safety and road user safety. INDOT also created an Office of Innovation. While the Research Program supports all of INDOT's Strategic Objectives, these initiatives have further highlighted the importance of research and its role in achieving the Strategic Objectives outlined in the INDOT Strategic Plan. There has been additional emphasis on new research needs related to new technology and transformational technologies. This increased emphasis will help position INDOT for future growth, adoption of new technologies and identifying 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 2023 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), vehicle operating costs (VOC), and crash reduction costs. RUC unit values were obtained from current INDOT standards.
- **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 were obtained from current INDOT and FHWA standards.

Accrued Benefits will be the combination of **Agency savings, RUC 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 three quantifiable project included RUC 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 5 to 10 years, with 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 is calculated to 2024 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 8 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 2024$ - NPV of future cash flows in 2024 dollars) could be quantified and their individual analysis is found in Appendix B. Three of the six projects will produce RUC (road user cost) savings, the other two Agency savings. Table 3, in Appendix A, is a complete list of all 29 projects completed in FY 2023 and considered for quantifiable cost analyses. Qualitative benefits are highlighted in the companion annual IMPACT report.

Table 1. Quantitative Benefits Project List

No.	FY 23 Completed & Implemented SPR Projects	Title	Project Cost ($1,000)	Benefit Type	Analysis Period	NPV Project Benefit ($1000) 2024$
1	4320	Implementation of Epoxy Injection of Concrete Overlaid Bridge Decks	$149	Quantitative (Agency Savings)	5 Years	1,595,000
2	4439	Guidelines for Evaluating Safety Using Traffic Conflicts: Proactive Crash Estimation on Roadways with Conventional and Autonomous Vehicle Scenarios	$215	Quantitative (Road User Cost Savings)	10 Years	2,182,857
3	4442	Highway Lighting Test Bed on INDOT Facility (Off-Roadway)	$171	Quantitative (Road User Cost Savings)	5 Years	238,095
4	4504	Development of INDOT Slab Jacking Program	85	Quantitative (Agency Savings)	5 Years	6,190,476
5	4637	Speed Enforcement in Work Zones and Synthesis on Cost-Benefit Assessment of Installing Speed Enforcement Cameras on INDOT Road Network	146	Quantitative (Road User Cost Savings)	5 Years	3,924,365
6	4652	Synthesis Study on Best Practices of Cleaning Tools & Paving Equipment	52	Quantitative (Agency Savings)	5 Years	166,667

Total Agency Benefits $7,952,143

Total Road User Cost Benefits $6,345,317

The analysis periods varied from 5 to 10 years, due to estimated impact period. Projects 4320, 4442, 4504, 4637 and 4652 analysis periods are based on INDOT Work Plans. Project 4439 used a 10-year analysis based on the life of the TScan equipment used in intersection analysis. Agency savings come from 4320, 4504 and 4652. Benefits from 4439, 4442, and 4637 are RUC savings.

Agency Savings

The total quantifiable savings from the three projects 4320, 4504 and 4652 resulting in agency savings, during their analysis or impact period, was calculated at $7,952,143 (in 2024$). The majority of savings come from using foam jacking as a maintenance activity rather than concrete patching. The *total* research program cost in FY 2024 was $3,996,160. Therefore, the agency savings BCA for FY 2023, for quantifiable projects, is: **$7,952,143/$3,996,160 = 2.0,** or 2 dollars in agency savings for every research dollar expended.

All three projects use a 5-year analysis period, with total estimated annual savings for a 5-year period is shown in Table 2. Each project write-up in Appendix B contains a table of agency savings.

Table 2. Estimated Annual Agency Savings

Projects	2025	2026	2027	2028	2029
4320	$334,950	$351,698	$369,282	$387,746	$407,134
4504	$1,300,000	$1,365,000	$1,433,250	$1,504,913	$1,580,158
4652	$35,000	$36,750	$38,588	$40,517	$42,543
Total	$1,669,950	$1,753,448	$1,841,120	$1,993,176	$2,029,835

Road User Savings

Three projects produce road user cost **(RUC)** savings: **4439, 4442**, and **4637**. The three projects together are estimated to produce RUC savings of **$6,345,317**. Therefore, the RUC savings BCA for FY 2023 is **$6,345,317/$3,996,160 = 1.6**, or 1.6 dollars in road user cost savings for every research dollar expended. Project 4439 savings calculation is based on a 10-year period due to the expected 10-year life of the TScan equipment. Projects 4442 and 4637 use a 5-year analysis which is based on INDOT 5-year work plan.

Cost Savings Summary

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

4320 – Of the 6,000 state-owned bridges, 1,575 bridges have latex modified concrete overlays, and 770 of these have overlay condition ratings of 5 or 6 making them candidates for epoxy injection. The project recommended each district (6 INDOT districts) inject 5 bridge decks annually to introduce epoxy injection into INDOT operations. The savings come from epoxy injection of bridge deck overlays replacing deck patching.

4504 – Agency savings come from using a developed maintenance activity, foam jacking, to repair deteriorated concrete pavements rather than using deep patching which removes the defected area and replacing with new concrete. One product was a field manual on how to perform this activity.

4652 – Since 2020 INDOT had 4 flash fire events while cleaning asphalt residue from equipment and tools. Three of these resulted in injuries, the other resulted in superficial damage to the equipment with no injury. The savings come from eliminating flash fire incidents during asphalt paving operations.

Three projects: **4439, 4442, and 4637**, will produce road user cost savings. These savings are described below.

4439 – The cost benefit analysis is based on making safety improvements to two (2) INDOT intersections per year for 10 years (service life of a TScan unit) and the corresponding improvements in safety costs and their associated equipment and operating costs. The savings come from reduced intersection crash costs.

4442 – The savings come from eliminating closing INDOT rest areas to test and evaluate new luminaire products over a 25-year period which is the expected life of the test bed facility.

4637 – Traffic speed in INDOT work zones consistently exceed posted speed limits which is a main cause of accidents at these locations. The savings come from reducing crashes in INDOT work zones through the use of automated speed enforcement.

Potential Future Savings

Two projects **4336–Improvement of Scaling Resistance of Pavement Concrete Using Titanium Dioxide (Tio2) and Other Nano-additives**; and **4513–Determining Optimal Traffic Opening Time through Concrete Strength Monitoring – Wireless Sensing**; are first step type projects with future research investment will produce significant quantifiable returns. These two projects are indicators of future quantifiable returns from the 2023 projects.

4336 – This is first step nano-silica research with the new cement type 1L, that will used to replace fly ash. To do a proper ROI analysis a life cycle cost should be determined, i.e., what time extension does nano-silica have on pavement life in all-weather situations. Future research and implementation will be able to produce an accurate ROI analysis.

4513 – Building on prior research (SPR-4210 and SPR-4513), this project advanced the electromechanical impedance (EMI) technique for in-situ concrete strength monitoring, which is crucial for determining safe traffic opening times. With the help of third-party manufacturers hardware equipment was developed that tested and validated the proof of concept. A field viable tool for testing cylinders and beams is a couple years away. When this occurs a ROI analysis can be performed that will quantify agency benefits.

Summary

The aggregate benefit of agency savings is approximately $8 million in 2024$. Direct agency savings of $8 million is a return of $2 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.

For 23 projects completed in FY 2023, 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 2023 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 8 years, 2016–2023, the investment indicates positive returns during the life of individual projects implemented. While many of the projects in the last 8 years, 200 out of 251 total research projects benefits are not quantifiable, due to the unavailability of quantifiable data, qualitative benefits were identified and are highlighted in the companion annual IMPACT report. Forty (40) projects where benefits were quantifiable, produced significant agency savings and 11 projects produced significant road user cost savings. For the combined years of 2016 through 2023 the Agency and Road User BCA are:

BCA (2016 – 2023) Agency Savings = $445,877,143/$45,421,900 = 10 to 1

BCA (2016 – 2023) Road User Savings = $334,117,116/$45,421,900 = 7 to 1

BCA Rolling Average – 2016–2023 = 17 to 1

Table 3 compiles the estimated agency savings and road user savings for the last 8 analysis years. BCA averages are calculated from the 8-year totals for research expenditures, estimated agency savings, and road user savings.

Table 3. 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
2022	$6,243,700	$62,651,000	$12,739,000	10	2	12
2023	$3,996,160	$7.952,143	$6,345,317	2	1.6	3.6
Totals	$41,425,740	$445,877,143	$334,117,116	10 avg.	7 avg.	17 avg

Environmental Benefits

Additionally, SPR-4652, provided environmental benefits in addition to quantifiable agency benefits.

SPR-4652 evaluated the use of environmentally friendly cleaning products compared to using diesel fuel in asphalt paving operations. Switching to these products will prevent asphalt damage, improve environmental and worker health benefits, and the elimination of worker fire hazard from flash fire events.

Appendix A - Complete Research Project List – FY 2023

Table 4. Complete Research Project List – FY 2023

No.	FY 23 Completed & Implemented SPR Projects	Project Title	Project Cost ($1000)	Quantitative Benefits, Qualitative Benefits or Not Successfully Implemented	Project Benefits ($1,000)
1	4320	Implementation of Epoxy Injection of Concrete Overlaid Bridge Decks	149.65	Quantitative	1,595.000 Agency Savings
2	4325	Development of Volumetric Acceptance and Percent Within Limits (PWL) Criteria for Stone Matrix Asphalt (SMA) Mixtures in Indiana	282.465	Qualitative	
3	4336	Improvement of Scaling Resistance of Pavement Concrete Using Titanium Dioxide (Tio2) and Other Nano-additives	134.364	Qualitative	
4	4406	Frontline Employee Training Using Virtual Reality Simulation of Field Conditions	149,977	Qualitative	
5	4407	Road Ditch Line Mapping with Mobile LiDAR	188.071	Qualitative	
6	4415	Determining Asphalt Mixture Properties Using Imaging Techniques	183.726	Qualitative	
7	4420	Estimating Strength from Stiffness for Chemically Treated Soils	123.637	Qualitative	
8	4432	Culvert Inspection Frequency Determination – Guidelines for INDOT	99.9	Qualitative	
9	4439	Guidelines for Evaluating Safety Using Traffic Conflicts: Proactive Crash Estimation on Roadways with Conventional and Autonomous Vehicle Scenarios	215	Quantitative	2,182.857 RUC Savings
10	4442	Highway Lighting Test Bed on INDOT Facility (Off-Roadway)	171.325	Quantitative	238.095 RUC Savings

11	4449	Focus Group Activities	5.000		
12	4452	Demonstration Project for Asphalt Performance Engineered Mixture Design Testing	100.000	Qualitative	
13	4504	Development of INDOT Slab Jacking Program	85	Quantitative	6.190.476 Agency Savings
14	4512	Pile Stability Analysis in Soft Soils - Guidance on Foundation Design Assumptions with Respect to Loose/Soft Soil Effects on Pile Lateral Capacity and Stability	214.464	Qualitative	
15	4513	Determining Optimal Traffic Opening Time through Concrete Strength Monitoring – Wireless Sensing	266.119	Qualitative	
16	4520	Development of an MSE Wall Construction Manual and Training Course	25	Qualitative	
17	4523	Applied Ergonomics	99.829	Qualitative	
18	4526	Predictive Analytics for Quantifying the Long-Term Predictive Analytics for Quantifying the Long-Term Cost of Defects during Bridge Construction	197.291	Qualitative	
19	4527	Shear and Bearing Capacity of Corroded Steel Beam Bridges and Effects on Load Rating	225	Qualitative	
20	4537	Speed Management on Freeways in Transition Zones between Rural and Urban Conditions	157	Qualitative	
21	4541	Roadside Barrier End Treatments: Safety Evaluation of INDOT Inventory and Practices	157.127	Qualitative	
22	4600	Impacts to Traffic Behavior from Queue Warning Truck – Current Pilot Project	150	Qualitative	
23	4610	Crawfordsville Technical Services Asset Management Workflow Improvement Project	46.052	Qualitative	

24	4616	GIS based Geotechnical Database for Collaborative GIS	75.705	Qualitative	
25	4632	Steel Bridge Coating Evaluation and Rating Criteria	29.868	Qualitative	
26	4637	Speed Enforcement in Work Zones and Synthesis on Cost-Benefit Assessment of Installing Speed Enforcement Cameras on INDOT Road Network	146.017	Quantitative	3,924.365 RUC Savings
27	4638	Integration of the Lane-specific Traffic Data Generated from Real-time CCTV Videos into INDOT's Traffic Management System	117.640	Qualitative	
28	4651	Synthesis Study on Employing Snowplow Driving Simulators in Training	147.537	Qualitative	
29	4652	Synthesis Study on Best Practices of Cleaning Tools & Paving Equipment	52.644	Quantitative	166.667 Agency Savings

Total FY 2023 Research spending is $3,996,160

Total FY 2023 Expected Agency Savings is $7,952,143

Total FY 2023 Expected RUC Savings is $6,345,317

Appendix B - Individual Project Analysis

SPR-4320: Implementing Epoxy Injection in Concrete Overlaid Bridge Decks

Introduction

Indiana has approximately 6,000 state-owned and maintained bridges. These are designed and constructed for a life of approximately 75 years with the most vulnerable and replaceable component is the deck. A bridge deck life typically consists of the following maintenance activities:

- Deck cleaning and crack sealing
- Thin deck overlays, typically 2 during a bridge deck life
- Latex modified concrete (LMC) overlay, typically 2
- Deck patching, typically 2

INDOT has observed that after an LMC overlay installation due to bridge vibrations, traffic loads and deck flexibility; a weak bond can develop between the overlay and the original concrete deck. This de-bonding creates voids providing space for moisture and de-icing chemicals to reside after it penetrates through cracks in the overlay which can cause freeze-thaw and corrosion damage thereby reducing the deck life. INDOT maintenance has responded with deck patching to eliminate or minimize this damage. This project proposed, developed, tested, and implemented a new maintenance option, epoxy injection of these voids. Figure 1 is an image of epoxy injecting a bridge deck and a visual representation of what occurs.

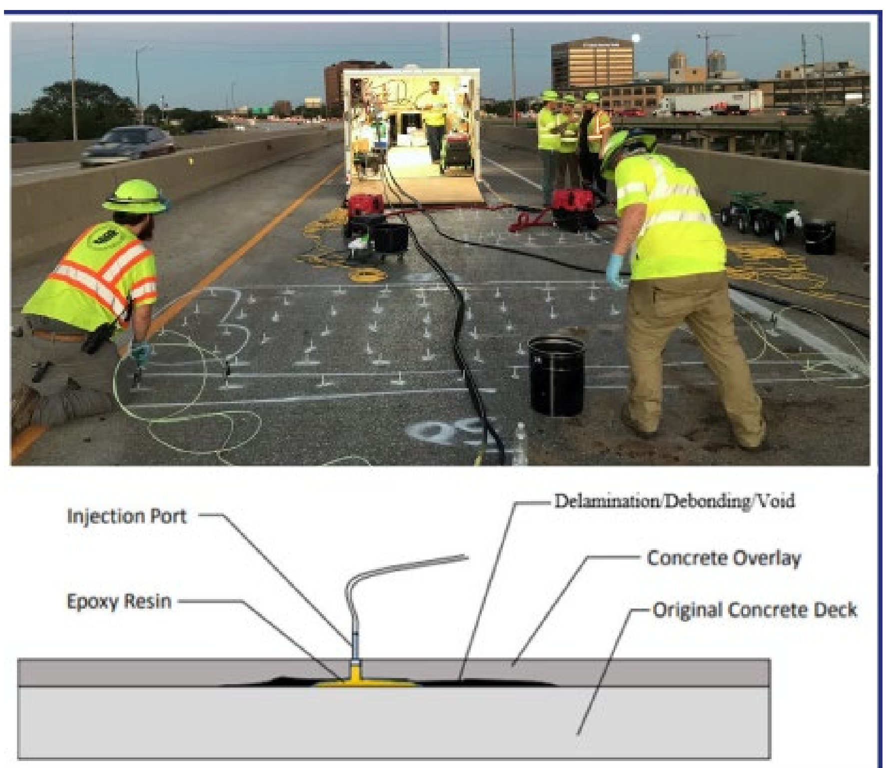

Figure 1. Epoxy injection of a bridge deck overlay.

Epoxy injection can extend the deck life 7–8 years based on experience by the Iowa DOT and minimizes the need for emergency deck repairs.

Other project outcomes were the development of an epoxy injection trailer for use at bridge sites (Figure 2); the development of step-by-step procedures for epoxy injection, field training sessions, and the addition of epoxy injection to the INDOT Maintenance Work Performance Standards.

Figure 2. Epoxy injection trailer.

Analysis

Since both maintenance activities, deck patching and epoxy injection extend deck life, the return on investment (ROI) analysis is based on the cost differential between these methods. In other words, the cost savings of using epoxy injection versus deck patching. The below cost comparison was developed by Prince Baah and Christopher Wheeler[1].

Assumptions in the cost analysis are both epoxy injection and deck patching extend the deck life the same number of years.

Cost figures were captured from a Vincennes District bridge deck injected with epoxy by an INDOT maintenance crew and compared to the cost of the same bridge deck area being patched by the same crew. Maintenance of traffic cost would be the same for both methods, so it was eliminated in the cost comparison. A before and after analysis of the epoxy injection revealed that bridge deck delamination and debonding percentage reduced from 27% to 4%.

<u>Epoxy Injected Deck Cost</u>

Total area of bridge deck: 2925 ft^2

Total percentage of deck area injected: 23%

Injected area: 672.75 ft^2

Amount of epoxy material injected: 108 gallons

Total epoxy material cost: $6,800

Cost of equipment and epoxy injection accessories: $4,000

Maintenance crew size used for injection: 4 technicians

Number of days used for injection: 1.5 days

Total man hours used: 45 hours

Total labor cost: $900

Overall Cost: $6,800 + $4,000 + $900 = $11,700

Deck Patching Cost

Total patching volume: 280 ft^3

Patching material: Quick Set Concrete (USG Duracal Cement): One 50 lb. Bag is $21 and fills 0.45 ft^3

Number of required bags of patching material with added waste: 685 bags

Total cost of patching material: $14,385

Equipment cost: $3,500

Maintenance crew size required for patching: 8 technicians

Number of days required for patching: 4 days

Total man hours used: 240 hours

Total labor cost: $4,800

Overall Cost: $14,385 + $3,500 + $4,800 = $22,685

Cost difference between methods: $22,865(patching cost) - $11,700 (injection cost) = $11,165 (savings) for this bridge.

This cost comparison uses INDOT maintenance costs while patching of this size is typically performed by a contractor, so the cost differential and actual savings would likely be much higher making this ROI analysis conservative.

Potential Savings

Of the 6,000 state-owned bridges, 1,575 bridges have LMC overlays, and 770 of these have overlay condition ratings of 5 or 6 making them candidates for epoxy injection. The project recommended each district (6 INDOT districts) inject 5 bridge decks annually to introduce epoxy injection into INDOT operations. INDOT works off a 5-year work plan, so the ROI analysis is based on this time period.

Annual state-wide cost savings = 6 (districts) x 5 (bridges per district) x $11,165 (savings per bridge) = $334,950.

Projected annual agency savings for a 5-year period and a corresponding benefit cost analysis is shown in Table 1. Estimated annual savings are increased by a 5% inflation factor.

Table 1. 4320 Cash Flow Analysis

Years	2024	2025	2026	2027	2028	2029
Research Cost	($149,650)					
Analysis savings		$334,950	$351,698	$369,282	$387,746	$407,134
NPV Benefit	$1,595,000					
B/C	10.7					

NPV – net present value

Summary

The BC ratio is **11 (10.7)** due to calculated agency savings is more than the research cost. The savings come from epoxy injection of bridge deck overlays replacing deck patching.

These numbers are based on the following:

- Research cost for 4320 is $149,650.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2024$.

This analysis is <u>only for this project</u>'s cost to conduct the research and implementation. In the summary report an overall 2023 benefit cost analysis is based on total program costs.

References

[1] Prince Baah PhD, PE, INDOT Division of Research Bridge Research Engineer; Christopher Wheeler.

Baah, P. (2023). *Implementing epoxy injection in concrete overlaid bridge decks* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2023/03). West Lafayette, IN: Purdue University. https://doi. org/10.5703/1288284317588

SPR-4439: Guidelines for Evaluating Safety Using Traffic Encounters: Proactive Crash Estimation on Roadways with Conventional and Autonomous Vehicle Scenarios

Introduction

With the entrance of semi-autonomous and autonomous vehicles into the vehicle pool, road safety is changing and will continue. The need for improved and efficient methods to evaluate intersection safety and develop corresponding countermeasures are needed and was the objective of this project. This project developed a method for observing traffic encounters using LiDAR-based traffic monitoring units named TScan (Figure 1), which were developed through previous JTRP projects.

Figure 1. TScan unit.

The use of the TScan and the analysis methodology developed has reduced the period needed to collect sufficient data for safety analysis from years to weeks. This time reduction for data collection and analysis reduces the period motorists are exposed to the heightened crash risks is the main safety benefit; with another benefit the improvement in observing traffic conflicts that reveals the source of the risk, which produces adequate countermeasures. Reduction in crashes correlates to lower road user costs (RUC) and generates the corresponding cost benefit analysis.

Analysis

The cost benefit analysis was produced by the Center for Road Safety at Purdue University[1] and is incorporated into this report.

Each conflicts-based evaluation of an intersection may take up to three weeks and excluding winter a maximum of (52-13 (winter))/3 = 13 conflict studies per TScan set (two TScan units) are feasible annually. The actual number of studies is lower and the need for safety improvements is confirmed at two intersections annually. In other words, a single TScan set helps identify/confirm a need for modernization at two intersections a year on average.

Since the traditional justification of safety projects is based on crash data collected for 3 years, implementation of a traffic conflict technique reduces this period by more than 2 years. Past research[1] indicates that implemented safety countermeasure reduces the frequency of crashes at a treated intersection by 14% on average (CRF – crash reduction factor). This reduction is converted to the TScan lifetime monetary benefit road users are willing to pay to avoid crashes:

> Total monetary saving in lifetime of one TScan set = Intersection annual crash cost × CRF of 0.14 × 2 improved intersections a year × 2 years of treatment speed-up × 10 years of TScan lifetime

Conflict-based studies are applied to intersections with serious safety concerns. Consistently, the monetary saving in lifetime of one TScan set was estimated for three alternatives that correspond to the top intersections with the 15%, 10% and 5% highest crash costs among the INDOT-administered intersections.[2] These crash costs are summarized in Table 1.

Table 1 Crash Costs Saved During the Equipment Lifetime of Ten Years

Percent of intersections with crash costs higher than others	Intersection annual crash cost	Annual savings per intersection (CRF=0.14)
15%	$840,000	$117,000
10%	$966,000	$135,000
5%	$1,732,000	$242,000

The following analysis estimates the present-worth benefit-cost ratio generated with one set of two TScan units required to sufficiently cover an intersection area studied.

Due to the uncertainty regarding the nature of safety improvements and required simplifying assumptions, the analysis is limited to a single benefit-cost period of 10 years (TScan life expectancy) with the assumption of no traffic change and assumed zero residual value of the equipment.

Table 1 summarizes expected RUC savings. There are associated costs that occur during the 10-year time period.

Equipment cost

Advancements in technology have significantly reduced equipment costs in recent years. Currently, a single mobile TScan unit costs approximately $60,000. The expected service life of a TScan unit is 10 years. The cost of TScan set (two units): 2 units x $60,000 = $120,000.

Operating cost

Operating the TScan unit requires a team of two people for setup and shutdown, each process taking about two hours. Additionally, an engineer is needed to analyze the data collected, a task that typically takes two full days. Overall, each intersection studied requires approximately 24 hours of labor.

A conservative number of two intersections per year was previously stated and used to calculate operating costs.

Total labor hours = 24 hours per operation × 2 studies per year × 1 two-unit set (2) = 96 hours.

Average hourly labor rate is $50.

Annual Operational Cost = 96 hours/year × $50/hour = $4,800.

Potential Savings

The cost benefit analysis is based on making safety improvements to two (2) INDOT intersections per year for 10 years (service life of a TScan unit) and the corresponding improvements in safety costs and their associated equipment and operating costs. Table 2 summarizes this analysis.

The annual RUC savings is based on the lowest intersection category of 15% which is $117,000 per intersection, with 2 intersections the annual savings is $117,000 x 2 = $234,000. These savings would be higher if the other intersection categories were selected.

The TScan costs of $120,000 occurs in year 0, year 2024, with an expected life of 10 years which sets the cash flow analysis period.

Annual expenses are operating costs which is $4,800.

Table 2. 4439 Cash Flow Analysis

Years	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Research Cost/Operating Costs	$(335,000)	$4,800	$5,040	$5,292	$5,557	$5,834	$6,126	$6,432	$6,754	$7,092	$7,446
Analysis savings		$234,000	$245,700	$257,985	$270,884	$284,428	$298,650	$313,582	$329,261	$345,725	$363,011
Net Annual Savings		$229,200	$240,660	$252,693	$265,328	$278,594	$292,524	$307,150	$322,507	$338,633	$355,564
NPV Benefits	$2,182,857										
B/C	6.5										

NPV – net present value

Cost in 2024 (Year 0) = research cost + TScan cost = $215,000 + $120,000 = $335,000

Benefit/Cost (B/C) ratio = NPV Benefits/2024 Cost = $2,182,857/$335,000 = 6.5

Summary

The BC ratio is **7 (6.5)** due to calculated RUC savings is more than the research cost. The savings come from reduced intersection crash costs.

These numbers are based on the following:

- Research cost for 4439 is $215,000.
- TScan equipment cost is $120,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2024$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2023 benefit cost analysis is based on total program costs.

References

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SPR-4442: Highway Lighting Test Bed on INDOT Facility (Off-Roadway)

Introduction

INDOT's evaluation of new highway lighting products (luminaires) performance has occurred at INDOT rest areas and other locations. When a test occurs the rest area is closed for 6 hours for setup and testing causing a cost for road users for its closure. When a test is performed at other INDOT locations, i.e. interchanges and intersections, traffic control measures are used which increases the safety risk for road users.

To eliminate these situations occurring in the future, this project developed two off-roadway lighting test bed sites in Indianapolis (Figure 1) and at the West Lafayette Research Division. These two sites give INDOT the ability to effectively evaluate lighting products under controlled and safe conditions.

Another project outcome was developing an automation method that improves the efficiency and flexibility of illuminance measurement. This consisted of a remote-controlled cart and drone (Figure 2). Measurement values obtained by the automation method were very similar to those obtained by the manual "point to point" method.

Figure 1. INDOT Indianapolis highway lighting test bed.

(a) Illuminance meter (b) Remote control cart (c) Drone

Figure 2. Remote control cart and drone.

Analysis

Switching to off road test sites will eliminate safety issues for road users that traveled through INDOT test locations at night. Since this benefit is difficult to quantify, it is not included as a quantifiable benefit in the return on investment (ROI) analysis.

The expected life of test bed facilities is 25 years, so the ROI analysis is for this time period. Below are the analysis assumptions[1] for road user cost (RUC) savings by eliminating rest areas as a testing site.

- 25-year service life for system
- 2 new roadway luminaire models per year (average use since Indy Subdistrict test site opened)
- 2 field tests per model
- 496 vehicles per 6 hours of closure (3 pm–9 pm)
- 1.5 persons per vehicle (National Household Travel Survey)
- Additional 10 minutes of travel to use services at an adjacent interchange
- Value of time: $20 per hour (US DOT median value from the INDOT Design Manual)

Annual road user cost savings from not closing a rest area as a testing site based on the above assumptions:

Annual RUC savings = 2 (luminaire models) x 2 (tests per year) x 496 (vehicles per 6-hour time period)) x 1.5 (persons per vehicle) x 10/60 (additional travel time (hour) for closure) x $20 (time value) = $9,920. Use $10,000 as the current annual savings.

Potential Savings

Projected annual savings for a 25-year period and a corresponding benefit/cost analysis is shown in Table 1. The 25-year period is the expected life of the test bed facilities. Estimated annual savings are increased by a 5% inflation factor. Table 1 is truncated because of page space limitations. The complete cash flow table is kept with the report documents.

Table 1. 4442 Cash Flow Analysis

Years	2024	2025	2026	2027	2028	……..2049
Research Cost	$ (171,375)					
Analysis savings		$10,000	$10,500	$11,025	$11,576	$32,251
NPV Benefits (25 years)	$238,095					
B/C	1.4					

NPV – net present value

Summary

The BC ratio is **1.40** due to calculated RUC savings is more than the research cost. The savings come from eliminating closing INDOT rest areas to test and evaluate new luminaire products.

These numbers are based on the following:

- Research cost for 4442 is $171,375.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2024$.

This analysis is **only for this project's** cost to conduct the research and implementation. In the summary report an overall 2023 benefit cost analysis is based on total program costs.

References

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SPR-4504: Development of INDOT Slab Jacking Program

Introduction

Slab jacking is a pavement rehabilitation technique that raises concrete pavement slabs to restore the ride quality (eliminate uneven sections) and to preserve the underneath pavement structure. Over the life of concrete pavements pumping occurs which causes voids and loss of slab support in concrete pavement sections. These voids cause pavement slabs to rock creating faulting and slab corner breaking that affects ride quality and safety hazards for vehicles.

There are alternatives for slab jacking materials. Materials include cementitious base (grout), liquid asphalt, and polyurethane materials (foam). INDOT stopped the slab jacking practices in the late 1980s and resorted to pavement patching; however, traffic control is a time consuming and expensive component. Slab jacking has returned to INDOT as a pavement maintenance activity, primarily because of potential cost savings.

This project developed a field manual for maintenance operations and investigated differences in material usage. Figure 1 is slab jacking using foam. Figure 2 shows a deep patching operation.

Figure 1. Foam jacking of concrete pavement.

Figure 2. Concrete pavement deep patching.

Analysis

The return on investment (ROI) analysis compares the cost differences between using foam jacking and deep patching of concrete pavements. Foam is the only material option for jacking that restores vertical alignment and improves in-place stability riding surface. The cost analysis is based on foam jacking replacing deep pavement patching.

Table 1 summarizes deep patching costs for 2023 and 2024.[1]

Table 1. Deep Patching Costs

Year	Deep Patching quantity (SYS)	Average Bid price ($) per SYS	Total Estimated Patching Cost ($)
2023	59,135	422	24,954,970
2024	51,401	366	18,812,766
Two Year Average	55,268	394	21,883,868

Concrete deep patches vary in size, typically the lane width (12 ft.) and a variable length between 8 – 10 ft. Using a 9 ft. as an average, a typical patch size is 12' (4 yards) x 9' (3 yards) = 12 SYS.

Foam jacking cost consists of material, equipment and labor which includes drilling holes, placing the foam, and monitoring. Foam material is made from mixing 2 different chemicals at the job site and based on state bid prices and average quantities used, the per slab cost is $800.[1] Equipment consists of air compressors, air hammers and drills, pumps, tank truck, hose and injection nozzles, and monitoring equipment. Labor costs is based on time required per slab and number of personnel.

Estimated equipment cost based on 2023 -2024 expansion foam work order cost[1] is a highly variable cost. Comparing foam material cost within the proximity of $800, average equipment cost ranges between $200 to $500. For conservative calculations, equipment cost used is the upper end value of $500.

Labor cost is calculated by using 3 workers at $40/hr. for 3 hours = 3(workers) x $40 x 3 hours = $360.

Total slab cost = material + equipment + labor = $800 + $500 + $360 = $1660. For cost calculations $1700/slab will be used.

A foam jacking SYS cost then is $1700/12 SY = $142 /SYS, compared to the average concrete patching cost in table 1 of $394 per SYS. The cost differential is $394 - $142 = $252 per SYS. Maintenance of traffic will be higher for patching, however that cost is not included in the financial analysis adding to a more conservative comparison.

Potential Savings

Table 1 shows an average patching quantity of 55,268 SYS. Foam jacking will not replace patching but can be an option for a portion of this work; how much of a portion is difficult to predict so in this analysis an assumption is made to replace 10% of the annual patching quantity.

Annual cost savings = $252/SYS x 55,268 SYS x 0.1(10%) = $1,392,753. For calculation purposes the annual cost savings is estimated at $1,300,000.

Projected annual agency savings for a 5-year period (INDOT work plan) and a corresponding benefit cost analysis is shown in Table 2. Estimated annual savings are increased by a 5% inflation factor.

Table 2. 4504 Cash Flow Analysis

Years	2024	2025	2026	2027	2028	2029
Research Cost	$ (85,000)					
Analysis savings		$1,300,000	$1,365,000	$1,433,250	$1,504,913	$1,580,158
NPV Benefits	$190,476					
B/C	72.8					

NPV – net present value

Benefit/Cost (B/C) ratio = NPV Benefits/ Research Cost

Summary

The BC ratio is **73 (72.8)** due to calculated agency savings is more than the research cost. The savings come from using foam jacking to repair concrete pavements in lieu of concrete deep patching.

These numbers are based on the following:

- Research cost for 4439 is $85,000.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2024$.

This analysis is **only for this project's** cost to conduct the research and implementation. In the summary report an overall 2023 benefit cost analysis is based on total program costs.

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SPR-4637: Speed Enforcement in Work Zones and Synthesis on Cost-Benefit Assessment of Installing Speed Enforcement Cameras on INDOT Road Network

Introduction

Traffic speed in INDOT work zones consistently exceed posted speed limits which is a main cause of accidents at these locations. To determine the frequency and magnitude of work zone traffic speed behavior, this project used connected vehicle (CV) trajectory data (probe data) that is collected by a private vendor in contract with INDOT. Three different work zone speed compliance methods were evaluated: posted speed limit signs (Figure 1), radar-based speed feedback signs (Figure 2), and automated speed enforcement (Figure 3).

Figure 1. Workzone speed limit sign.

Figure 2. Radar-based speed feedback sign.

(a) Field unit with radar equipment and roof mounted cameras (b) Warning signs

Figure 3. Automated speed enforcement setup.

The automated speed enforcement method uses an advance sign (Figure 3b) that alerts motorist work zone speeders will have their license plate photo captured by a field unit (Figure 3a). This method impact is based on data collected by Pennsylvania DOT in 2020.

CV data produced the following results for the three methods.

1. Posted speed limit sign – 90% of vehicles traveled over the posted speed and 50% traveled more than 11 mph (legal threshold) over the posted speed.

2. Radar-based speed feedback sign – median speeds were 14 mph above posted speed.

3. Automated speed enforcement – median speeds were within 1-2 mph of the speed limit and 9-10 mph below the 11-mph threshold above the posted speed.

Based on the CV data, the automated speed enforcement method is the most effective for reducing vehicle speed in work zones. Reduced speeds reduce the number and severity of crashes which correlates to lower road user safety costs (RUC).

Analysis

To calculate the impact of speed reduction on crashes the INDOT Safety team produced the following relationship[1]: crashes after = crashes before* (speed after/speed before)^^{X} The equation exponent or X value is based on accident severity and shown in table 1. Table 2 shows costs by crash type. Tables 1 and 2 are used by the INDOT Safety team.

Table 1. Accident Severity Coefficient

Accident or injury severity	exponent	interval
Fatalities	4.5	(4.1 – 4.9)
Seriously injured road user	3.0	(2.2 – 3.8)
Slightly injured road user	1.5	(1.0 – 2.0)
All injured road users (severity not stated)	2.7	(0.9 – 4.5)
Fatal accidents	3.6	(2.4 – 4.8)
Serious injury accidents	2.4	(1.1 – 3.7)
Slight injury accidents	1.2	(0.1 – 2.3)
All injury accidents (severity not stated)	2.0	(1.3 – 2.7)
Property-damage-only accidents	1.0	(0.2 – 1.8)

Source: TØI report 740/2004

Table 2. Crash Costs

Crash Type	Cost (Estimated)
Fatal/Incapacitating Crash	$857,956
Non-Incapacitating Crash	$212,262
Property Damage Only	$15,587

Using Tables 1 and 2 and based on severity for the State of Indiana, Table 3 can be generated that calculates the financial safety impact of automated speed enforcement. The first four columns represent data inputs and the exponent from Table 1. The crashes after number then comes from the equation noted above. The avoided crash cost impact, or reduction in crash cost is then based on crashes reduced, provided by INDOT Safety team, and the crash cost numbers (Table 2).

Table 3. Road User Annual Savings

Crash Severity	Crashes Before from Data	Speed Before from Data	Speed After from Data	Table 1 Exponent	Crashes After from equation	Crashes Reduced	Avoided Crash Cost ($)
Fatality & Incapacitating Injury	5	70	55	4.5	1.69	3.31	2,840,588
Non-Incapacitating Injury	10	70	55	1.5	6.96	3.04	644,298
Property Damage	20	70	55	1	15.71	4.29	66,801
Totals	35				24.37	10.63	3,551,687

Potential Savings

Table 3 describes how the annual RUC is calculated, with annual savings of $3,551,687 from lower crashes by reducing speeds in work zones through automated speed enforcement.

INDOT has contracted with a vendor to provide annual enforcement services.[2] The annual cost is $3,00000 through 2028 with the option to extend additional years. This cost is included in the cost analysis shown in Table 4.

Projected annual RUC savings for a 5-year period and a corresponding benefit/cost analysis is shown in Table 4. A 5-year period coincides with INDOT's 5-year work program project estimates. Estimated annual savings are increased by a 5% inflation factor.

Table 4. 4637 Cash Flow Analysis

Years	2024	2025	2026	2027	2028	2029
Research Cost/Vendor Cost	$ (146,017)	$3,000,000	$3,000,000	$3,000,000	$3,000,000	$3,000,000
Analysis savings		$3,551,687	$3,729,271	$3,915,735	$4,111,522	$4,317,098
Net Annual Savings		$551,687	$729,271	$915,735	$1,111,522	$1,317,098
NPV Benefits	$3,924,365					
B/C	26.9					

NPV – net present value

Summary

The BC ratio is **27** (26.9) due to calculated RUC savings is more than the research and enforcement costs. The savings come from reducing crashes in INDOT work zones through the use of automated speed enforcement.

These numbers are based on the following:

- Research cost for 4637 is $146,017.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2024$.

This analysis is **only for this project's** cost to conduct the research and implementation. In the summary report an overall 2023 benefit cost analysis is based on total program costs.

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[1] Daniel McCoy, PE, Director of Traffic Engineering Indiana Department of Transportation.

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SPR-4652: Synthesis Study on Best Practices of Cleaning Tools and Paving Equipment

Introduction

Tools and equipment used in asphalt paving operations, previously were cleaned using diesel fuel which has several inherent risks. Diesel fuel on freshly placed asphalt surfaces weakens asphalt strength through bond loss in the pavement. Other risks are environmental impacts, worker health, and fire hazards. This project evaluated alternative cleaning methods and products that reduce these risks and hazards.

Two product types were evaluated: asphalt release agents (ARAs) and asphalt cleaners (AC). ARA products are non-hazardous, environmentally friendly, that produces an adhesive free interface between asphalt and truck beds, paving equipment, and tools. AC products are used to clean and dissolve asphalt products from equipment and tools.

Product evaluations used a comprehensive scoring system developed by the research team that includes environmental, economic, and safety criteria, resulting in a decision support dashboard to guide the selection of ARA and AC products.

Switching to these products will prevent asphalt damage, improve environmental and worker health benefits, which are difficult to quantify. One benefit is the elimination of worker fire hazard from flash fire events which can be quantified. The below analysis is based on the elimination of this hazard through the use of ARA and Ac products.

Figure 1. Asphalt paving operations.

Analysis

Since 2020 INDOT had 4 flash fire events while cleaning asphalt residue from equipment and tools[1]. Three of these resulted in injuries, the other resulted in superficial damage to the equipment with no injury.

The three injury cases incurred direct medical and temporary disability costs with each claim as provided by the State claims management contractor; and indirect costs that are calculated using the Federal OSHA online indirect cost calculator tool. These costs are combined to provide the estimated total costs for injury cases.

In one of these cases, an employee chose to leave INDOT as a direct result of the injury, which triggers costs for hiring a replacement, onboarding and training a new employee. This cost was calculated by INDOT HR staff and shown below but due to uncertainty of employee replacement this cost is not included in the return on investment (ROI) analysis.

Employee turnover cost - $10,976

Case 1 – Minor injury, one incident

- $430 direct costs
- $1,935 indirect costs
- $2,365 total costs

Case 2 – Serious injury

- $25,406 direct costs
- $27,947 indirect costs
- $53,353 total costs

Case 2 – Serious injury

- $23,477 direct costs
- $25,824 indirect costs
- $49,301 total costs

Total for all three cases over a 3-year time period (2020–2023) is $105,019.

Potential Savings

Potential future annual cost savings are based on the above project data experienced over a 3-year period which is $105,019/3 = $35,000 (rounded). Projected annual savings for a 5-year period and a corresponding benefit/cost analysis is shown in Table 1. A 5-year period coincides with INDOT's 5-year work program project estimates. Estimated annual savings are increased by a 5% inflation factor.

Table 1. 4625 Cash Flow Analysis

Years	2024	2025	2026	2027	2028	2029
Research Cost	$ (52,644)					
Analysis savings		$ 35,000	$ 36,750	$38,588	$40,517	$42,543
NPV Benefits	$ 166,667					
B/C	3.2					

NPV – net present value

Summary

The BC ratio is **3.2** due to calculated savings is more than the research cost. The savings come from eliminating flash fire incidents during asphalt paving operations.

These numbers are based on the following:

- Research cost for 4652 is $52,644.
- Annual costs and savings are inflated by 5%.
- 5% cost of capital.
- NPV of future costs and benefits based on 2024$.

This analysis is only for this project's cost to conduct the research and implementation. In the summary report an overall 2023 benefit cost analysis is based on total program costs.

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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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